Title
TECHNICAL PERFORMANCE AND COST-EFFECTIVENESS OF CONSERVATION RETROFITS IN EXISTING U.S. RESIDENTIAL BUILDINGS: ANALYSIS OF THE EECA-B DATA BASE

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TECHNICAL PERFORMANCE AND COST-EFFECTIVENESS OF CONSERVATION RETROFITS IN EXISTING U.S. RESIDENTIAL BUILDINGS: ANALYSIS OF THE BECA-B DATA BASE

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ABSTRACT

This study assesses the technical performance and economics of energy conservation retrofit measures in existing residential buildings. Most retrofit projects included in this study attempted to reduce space heating consumption. Energy savings, retrofit costs and measures installed, and project and building characteristics are compiled for approximately 115 data sources in four general categories: utility-sponsored conservation programs, weatherization programs directed at single-family low-income homes, research studies, and multi-family buildings. Annual average resource energy savings range from 23 to 38 MBtu in the four categories. Savings achieved are typically 20 to 35 percent of pre-retrofit space heating energy use. The sample size for each project varies greatly, ranging from individual buildings to 33,000 homes. Large variations are observed both in energy savings (absolute and percent) and in costs per unit of energy saved. Savings between groups of retrofitted houses varied by a factor of five at any particular investment level. Approximately 75-80 percent of the retrofit projects are cost-effective - i.e. have costs of conserved energy below their respective space heating fuel or electricity price. Homes retrofitted in nineteen utility-sponsored conservation programs have a median net present value (NPV) of $1015; the NPV is positive in sixteen of the nineteen programs. Predicted versus actual savings are also compared for groups of homes in 25 retrofit projects. Actual energy savings, averaged over a large sample of homes, are greater than or equal to predicted estimates in three of eight utility-sponsored conservation programs.

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PREFACE

This study summarizes my work over the last two years in the Building Energy Data Group at the Lawrence Berkeley Laboratory.* The Group compiles data on the energy savings and cost-effectiveness of conservation and solar measures in buildings. My efforts have focused on collection and analysis of data on the technical performance and cost-effectiveness of conservation retrofits in existing residential buildings. The study represents a careful attempt to aggregate the data from many different projects and express the results in comparable terms; in the process, current retrofit experience is summarized and major gaps are identified.

* This study is part of a continuing project that collects and reviews measured data on the energy performance of low-energy new homes (BECA-A), existing "retrofitted" homes (BECA-B), existing commercial buildings (BECA-CR), new commercial buildings, (BECA-CN), appliances and new equipment (BECA-D), water heating (BECA-W), and model validation studies (BECA-V).

NOTE ON UNITS

Energy consumption data in this report are presented in the English system of units.

MBtu = 10^6 Btu = 1.055 GJ = 10^9 joules.

Gallon of fuel oil = .139 MBtu.

1 cubic foot of Natural gas (residential) = 1020 Btu

Quad = 10^{15} Btu = 1.055 EJ (exajoules) [1 EJ = 10^{18} joules].

Unless indicated, electricity consumption data are in resource energy units. The conversion factor used is 11500 Btu = 1 kWh (in SI units, 12.1 MJ = 1 kWh), which assumes a typical power plant efficiency of 33 percent and transmission losses of approximately 10%.

Area is given in square feet (ft^2); 1 ft^2 = 0.0929 m^2.

30-year normal heating degree-day values are given in Fahrenheit (base 65^o).

1. INTRODUCTION

"If the United States were to make a serious commitment to conservation, it might well consume 30 to 40 percent less than it now does, and still enjoy the same or an even higher standard of living. That saving would not hinge on a major technological breakthrough, and it would require only modest adjustments in the way people live. The possible energy savings would be the equivalent of the elimination of all imported oil-and then some." - Daniel Yergin and Robert Stobaugh, Energy Future (1979)

"Despite considerable theoretical analysis and thousands of audits, there is still very little documented information on the results of actual retrofits on different types of buildings." - Office of Technology Assessment (OTA), Energy Efficiency of Buildings in Cities, (March, 1982)

The juxtaposition of Daniel Yergin's assessment of conservation potential in contrast to the recent survey report issued by the Office of Technology Assessment reflects the current situation in the United States. Several major studies have concluded that, in the near term, conservation could do more to alleviate U.S. energy problems, with less disruption to the natural environment and American lifestyle, than any of the conventional energy sources. Yet, many building owners are concerned about the unpredictable nature of building retrofits to a sufficient degree that it represents a barrier to investment. The Office of Technology Assessment (OTA) concluded that improved data on the results of individual retrofits, on the results of retrofit packages, and on actual savings compared to predicted could greatly improve the situation.[1] This study compiles data from different conservation programs and retrofit projects directed at the existing residential housing sector. Changes in energy consumption attributable to conservation retrofits are analyzed. The study represents an initial effort to answer the questions raised by the Office of Technology Assessment report.

A brief overview of the economic and resource impact of U.S. residential energy use provides a useful context for understanding recent efforts to improve the efficiency of existing homes. The U.S. residential sector, comprised of over 83 million households, consumed approximately 15.4 resource Quads of energy in 1981.[2] Space heating accounts for roughly 50 percent of total usage while water heating uses 15 percent. Most conservation programs have focused on reducing consumption in these end-uses. In the last four years, aggregate residential energy consumption has leveled off, a marked departure from the 1960's when it increased at a 4.7 percent annual rate.[3] During this period, average consumption per household has actually declined from 138 to 114 MBtu, a 17 percent decrease. [2] These results should be interpreted with caution because aggregate data from the Residential Energy Consumption Survey (RECS) do not account for changes in annual weather patterns or shifts in heating fuels (i.e. increasing penetration of electric heating). Demographic changes, including reduced population growth, smaller average household size and a high household formation rate (2.4% annually), partially explain this phenomenon. The resource mix has gradually changed over the last two decades with electricity usage increasing as a fraction of total consumption, due mostly to its increased use in home heating, cooling, and appliances.

Annual expenditures for home energy have risen dramatically, driven by spiraling price increases (Table 1).

TABLE 1. U.S. expenditures for home energy

YEAR	TOTAL EXPENDITURES (BILLION $)	AVE. EXPENDITURE PER HOUSEHOLD (NOM $)	(1978 $)[a]
1978	55.5	724	724
1979	63.2	815	750
1980	74.8	917	770
1981	85.0	1022	790

[a] Converted to Constant $ using GNP Implicit Price Deflator

Source: Energy Information Administration, Residential Energy Consumption Survey, EIA-0321/1(81), Sept. 1983.

The burden of rising energy costs is not shared equally among all classes. Data from the 1981 Residential Energy Consumption Survey indicates that low-income households (less than $5,000) spend about 20 percent of their income on home energy while high-income households (greater than $20,000) spend only 3 to 4 percent of their income on energy.

At the aggregate level, patterns of residential energy consumption change slowly, shaped in large part by the long useful life of homes and the long lifetime of major heating equipment. The Energy Information Administration estimates that there will be 95 million occupied structures in 1990, of which 78 percent will have been constructed before 1980.[4] Retrofitting existing homes is one means to cope with escalating fuel costs. Millions of homeowners engage in conservation activities each year. In 1981 alone, it is estimated that 2.7 million households installed attic insulation, 2.5 million installed storm windows, while 8.8 million households did some caulking or weatherstripping.[5] Conservation actions were only one possible response to increasing residential energy expenditures. From 1979-1981, it is estimated that 6 million homes switched their primary space heating fuel. This compilation is not a representative survey of the portion of the housing stock that has been retrofitted during the last several years. Yet, the results obtained from analyzing over 100 retrofit projects and conservation programs (representing over 70,000 households) provide a fairly broad picture of retrofit performance under varying conditions.

This report is divided into two parts. In the main body, we briefly discuss the methodology of the study. Each retrofit project is categorized into one of four broad groups and the distinguishing characteristics of each group are discussed. We then examine the level of energy savings in retrofitted homes and the range of savings among households installing similar conservation measures. The cost-effectiveness of retrofit projects is assessed using various economic indicators and the sensitivity of the economic results to changes in key assumptions is tested. Finally, we assess the accuracy of computer simulation models and auditor skill by comparing pre-retrofit predictions with actual measured energy savings. Several technical appendices comprise the second part of the study. These include:

- o a brief summary of each case study
- o a detailed description of the methods used to analyze the data
- o discussion of the key assumptions underlying the economic analysis.

2. METHODOLOGY AND DATA SOURCES

2.1. Methodology

Existing data on the technical performance of individual conservation measures in occupied buildings are drawn mainly from various research studies. In order to develop a more comprehensive database, results from evaluations of residential energy conservation programs were included. These case studies are "indirect" sources in the sense that analysis of retrofit performance must be extracted from data collected for the purpose of program evaluation. This approach has some important limitations. Often, only aggregate results (e.g., average energy savings and retrofit costs for a sample of homes) are presented for a conservation program. The findings represent the cumulative impact of several retrofit measures, installed in varying combinations in individual homes. It is difficult to obtain information on a group of houses in which the same package of measures were installed. It is also impossible, with the data available, to determine the relative contribution of individual measures. An alternative approach, limiting the database to research-oriented projects that report the performance of individual retrofits, has even more serious flaws. The sample would be extremely small and not representative of actual retrofit activity in existing residential buildings. It would also lead to a less meaningful economic analysis because retrofit cost is not often a key consideration or constraint in research studies.

In addition to evaluation studies of conservation programs and demonstration projects, data were gathered from public housing authorities, state energy offices, and firms providing building energy services. Information entered in the database included: building type and physical characteristics, project sponsor, sample size, retrofit description and cost, annual energy consumption by fuel type before and after retrofit, local weather, and energy prices. The data were entered in a uniform format to permit standardized analysis.

In some cases, this required adjustment of several key variables (e.g., energy consumption, retrofit cost).*

Typically, energy consumption data were analyzed by a linear regression of fuel use per time interval against average outdoor temperature or heating degree days for the same interval for each house. The two major adjustments to the consumption data were:

- o isolation of the space heating portion of the fuel bill by subtracting an estimated baseload usage
- o correction of actual consumption data for the varying severity of winter in different years by normalizing pre-and-post retrofit energy use to a "standard" heating season.

The implicit assumption was made that observed pre-/post retrofit changes in (weather-normalized) energy use were caused by the retrofit though it is recognized that other factors (i.e., life-style of residents, change in the number and age distribution of occupants) are also significant variables. In almost all cases, there was not sufficient information to adjust for possible changes in the amount of 'free' heat (e.g., solar gains, appliance usage or replacement), changes in occupants' comfort levels, or management of heating systems. Retrofit projects with a substantial number of homes that used secondary heating equipment (i.e. wood stoves, kerosene room heater) are noted in Appendix B. In some cases these homes were excluded from the analysis. Homes were eliminated from the data set when there was a known change in occupants.

The retrofit cost data cited in various studies used different accounting definitions and in some cases were incomplete. The cost data were adjusted to provide a comparable basis for evaluating the relative cost-effectiveness of various retrofit projects. We attempted to impute the direct costs to the homeowner of contractor-installed measures. Most utility administrative overhead costs were excluded. For consistency, an equivalent contractor cost was estimated in cases where

* A detailed explanation of the procedures used to analyze and adjust the energy consumption and cost data is provided in Appendix A.

only materials costs were known (i.e., the DOE Low-income Weatherization Program). In most studies, costs were expressed in nominal rather than constant dollars. Original retrofit costs were converted to constant dollars using the Gross National Product Implicit Price Deflators.

Information on operations and maintenance costs for retrofits installed in multi-family buildings was considered essential for several reasons. In large multi-unit buildings, maintenance costs are usually "explicit." Often, a hired staff performs regular maintenance actions, in contrast to the do-it-yourself approach adopted by many single-family homeowners. Many retrofits installed in multi-family buildings require significant expenditures on operations and maintenance. For example, the annual cost of a service contract for a computerized energy management system represents a significant fraction of the original investment. In other cases, reduction in maintenance expenses are an important by-product of retrofits installed in multi-family buildings. In both instances, maintenance costs have a far greater impact on the economics of retrofitting multi-family buildings compared to single-family dwellings. Hence, for multi-family buildings, the initial investment plus the net present value of projected annual operations and maintenance costs are included in the retrofit cost.*

Every project included in this study has actual metered pre-and-post retrofit energy consumption data. Each project was assigned a confidence-level ranking because of the uneven data quality. The ranking, indicated by the letter grades A through F, assesses the overall reliability of results obtained from specific retrofit projects (see Tables 3 through 6). It is based on a critical review of the following factors:

- o experimental design and analytical model (e.g., sample selection, use of a control group, use of fixed or variable reference temperature for each house)
- o quality of consumption data (e.g., the accuracy, duration, and

* This discussion relates primarily to the cost of the investment used in calculating "cost of conserved energy" as well as the meaning of contractor cost in the various figures.

frequency of fuel bills)

- o method used to separate the space heating component from total energy use (e.g., sub-metered end-uses or estimation of baseload)
- o weather-correction method
- o accuracy of retrofit cost data

2.2. Data Sources

The compilation is a diverse collection of retrofit efforts including:

- o monitored individual homes and randomly selected groups of many hundred homes
- o elaborate research projects and large-scale utility audit/loan programs
- o single-family residences and thousand-unit public housing complexes
- o middle-income families and poverty households.

Each retrofit project was placed in one of four broad, fairly homogenous categories based on structural, demographic, and usage characteristics to permit a more consistent and useful treatment of results.* These included:

- o weatherization programs aimed at low-income single-family homes
- o utility-sponsored conservation programs, targeted mainly at middle-income, owner-occupied, single-family households
- o research studies and demonstration programs
- o retrofit efforts in large multi-family apartment buildings.

A brief description of each retrofit project included in this study is presented in Appendix B with summary data shown in Tables 3 through 6.

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* These categories are not mutually exclusive and the choice of appropriate category was not always clearcut. For example, some utility programs (e.g., Northern States Power and the TVA pilot program) were directed at low-income residents; but a decision was made to group all large-scale utility-sponsored programs together.

Low-income weatherization programs. Retrofit results for low-income single-family homes came principally from several sources: the Department of Energy (DOE) Low-income Weatherization Assistance Program, the CSA/NBS Weatherization Demonstration Research Project, and several retrofit pilot projects for oil-fired heating systems funded by the Low-income Energy Assistance Program.

Nearly one million low-income homes have been weatherized under the auspices of the Department of Energy program. 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. Reliability of the data from the Weatherization Program varies considerably.[6,7] The studies typically lack a control group. There are often inconsistencies in either energy or cost data and varying space heating fuels among a sample of homes. Despite these problems, the Low-income Weatherization Program represents a significant fraction of the U.S. government's investment in residential conservation and focuses on a housing sector where the potential for increased energy efficiency is large.*

The Community Services Administration, 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.[8] The demonstration project entailed extensive retrofitting of homes with close monitoring of energy consumption and cost data. Although the sample houses were fairly typical of low-income housing in terms of size and occupants' income level, their pre-retrofit physical condition and maintenance level were better than normally found in low-income residences. Energy savings and retrofit costs were carefully compiled on 142 houses in 12 different locations.[9]

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* The Program was authorized in 1976 under Title IV of the Energy Conservation and Production Act (ECPA) and approximately one billion dollars has been spent from 1977 through fiscal year 1983.

Utility-sponsored conservation programs. These programs typically represent large-scale efforts involving the retrofit of thousands of homes. The sample has a distinct regional bias. Thirteen of the 19 conservation programs (approximately 68%) were sponsored by utilities located in the Pacific Northwest or California while three studies were conducted by the Tennessee Valley Authority, serving the Southeastern portion of the U.S.

Early utility-sponsored programs often targeted high-energy consumers or low-income households. Recent initiatives have been directed at all residential customers, although they typically reach single-family, middle-income homeowners who live in structurally sound homes. Most of the initial programs financed either the installation of attic insulation or various low-cost measures (e.g., the insulation of water heaters) whereas later programs offered a large set of measures to eligible households. The strength of these programs is their ability to reflect energy savings for a significant fraction of the general population.

Research projects. Experiments conducted by universities and National Laboratories account for most of the research studies in the data base. Research projects often test innovative retrofit measures or strategies. For example, Princeton University analyzed measured energy savings from "house-doctoring," a strategy that involves instrumented diagnosis of homes combined with on-the-spot retrofits.[10] The Solar Energy Research Institute evaluated savings from the DOE's 50-50 program as it was adapted to Colorado. This program involved a selection of retrofits from a collection of 50 measures that individually save only a small amount of energy but in combination are estimated to produce substantial savings.[11]

Cost is usually not a dominant consideration in research studies. Sample size tends to be small (fewer than 20 homes) and a comparison group is employed as part of the experimental design. Often, the effect of occupant behavior on a building's energy performance is accounted for explicitly. Research projects generally undertake extensive analysis of the consumption data, sometimes including sub-metering of specific end-uses.

Multi-family retrofits. A recent study conducted by the Office of Technology Assessment found that, despite significant conservation opportunities, actual retrofit activity in multi-family buildings lags far behind that occurring in single-family homes due to a variety of institutional and technical factors. [1] The multi-family housing sector has some unique characteristics that hinder investments in energy conservation. Roughly 85 percent of the units in multi-family buildings are rented. The problem of 'split incentives' between tenants and landlords is not easily resolved. In addition, many landlords have limited access to capital (on attractive terms). In the last several years there has been increased governmental and utility support for conservation programs directed towards multi-family buildings and energy savings data are now becoming available.

All of our large U.S. multi-unit buildings are located in the Northeast or Midwest.* The inhabitants are almost all renters and are often low-income. For example, 50% of the buildings are in public housing projects. There are several cases of retrofits performed by energy service companies who contract with building owners to manage building energy systems.[12] They provide an agreed-upon level of service (i.e., thermal comfort) at a price no greater than existing energy bills, and invest in conservation measures (or initiate better management practices) as they see fit, to reduce the cost of providing the agreed-upon level of service.

2.3. Economic Analyses

The economic effectiveness of conservation investments can be evaluated using a variety of indicators.[13,14] In this study, four investment statistics are calculated; simple payback time (SPT), cost of conserved energy (CCE), net present value (NPV), and internal rate of

* We also have consumption but not cost data for approximately 120 Swedish multi-family buildings that were retrofitted.

return (IRR).** The four indicators are briefly described below:

1) Simple Payback Time - the period required for the undiscounted value of the future energy savings, at today's energy prices, to equal the original investment

2) Cost of Conserved Energy - equals the ratio of annualized investment over annual energy savings, where annualized investment equals total investment multiplied by a capital recovery factor. The cost of conserved energy is independent of energy prices, but current and/or projected fuel and electricity prices are the benchmark against which CCE is judged.

3) Net Present Value - is the difference between the present- value of (a discounted stream of benefits from) lifetime energy savings and the present value of lifetime costs of a conservation measure. A worthwhile investment has a net present value greater than zero.

4) Internal Rate of Return - is the compound rate of interest which, when used to discount the life-cycle costs and savings of a retrofit project, will cause the two to be equal. It is typically compared to an investor's minimum acceptable rate of return in evaluating the desirability of an investment.

The concept of payback time on an investment is easily understood and widely used, yet, it contains several inherent drawbacks that sharply limit its usefulness as an economic analysis tool. The cost of conserved energy provides an effective means of rank-ordering conservation investments and of comparing conservation investments to alternative energy supply options but has the disadvantage of not explicitly accounting for variations in fuel escalation rates or local variations in energy prices.[15,16] Net present value analysis and internal rate of return evaluate the worthiness of conservation investments taking into account future benefits and costs. Benefits and costs are discounted to

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** A more detailed explanation of each indicator, including its advantages and disadvantages, mathematical expression, and underlying assumptions, is presented in Appendix C.

reflect the "time value of money." These indicators incorporate the initial investment cost, annual operation and maintenance costs, future replacement cost, salvage value, and the stream of benefits (the dollar value of energy savings over a measures's useful lifetime) adjusted over a consistent time basis. In calculating net present value or internal rate of return, many of the practical conventions and decision rules developed for the Federal Energy Management Program were adopted.[17]

All analyses were performed using real (or constant dollar) discount rates and energy price escalation rates. Both the discount rate and energy price escalation rate were varied in order to assess the sensitivity of the results to such changes. Real escalation rates for energy prices ranged from 4 to 8 percent while the real discount rate varied between 3 and 10 percent. A real discount rate of 7 percent was used in the base economic case and is the value used in those figures that show the cost of conserved energy.

Useful lifetimes were estimated for each individual conservation measure and package of retrofits. Retrofit lifetimes were derived partly from a literature survey in addition to consultation with various LBL researchers working in the area of residential energy conservation.

3. 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. There are easily several hundred different retrofit measures that have been installed in residential buildings. Individual conservation measures were grouped into broader categories. For example, the installation of a high-efficiency retention-head burner, a vent damper, and a flue-gas heat exchanger were all included in the general category of heating system (HS) retrofits. Table 2 describes the various retrofit categories along with the two-character code used in the summary data tables.

Fig. 1 indicates the relative frequency with which various retrofit measures were installed in each of three data sub-groups: 28 multi-unit buildings, 418 homes that participated in research studies, and 142 low-income homes from the CSA/NBS optimal weatherization program. The eleven most frequent retrofit measures (averaged over the three groups) are shown on the x-axis.

"Shell retrofits" were extremely popular in the CSA/NBS low-income homes. Insulation of the attic and walls and caulking and weatherstripping were installed in 94, 66, and 95 percent of the homes, respectively. In contrast, no caulking and weatherstripping actions or wall insulation retrofits were reported in our multi-family buildings while attic insulation was installed in only 15 percent of the buildings. Several factors partially account for the low installation rate for these measures. Existing insulation levels were already adequate as a result of previous retrofits in some multi-unit buildings in our sample (e.g., the New York City Housing Authority buildings). In other cases, the structural characteristics of the building (e.g., flat roof, either clad-wall or masonry bearing-walls) precluded installation of these measures, particularly wall insulation, without exorbitant expense. Possibly, multi-family building owners also prefer retrofits that allow for a 'single-fix' approach with no need to deal with many individual apartments (i.e., weatherstripping).

TABLE 2
Description of retrofit categories

Operations and Maintenance (OM)	Actions which affect the manner in which the HVAC equipment is operated; but do not involve any new equipment or significant physical modifications (e.g. tuning, manual temp. set-backs, cleaning)
Heating System (HS)	Modification or replacement of heating system equipment, de-rating, distribution system improvements. Includes measures such as installation of high-efficiency burner, thermostatic radiator valve and automatic flue damper.
HVAC Controls (HC)	Installation of centralized computer control systems or heating system local controls (e.g., high-limit outdoor stat); utilized in multi-unit buildings
Automatic or clock thermostats (T)	Timer that can be set to turn the heating system off and on at certain preset times of day or installation of additional thermostat for improved zoning; used in single-family buildings
Heating System Replacement (HR)	Replacement of entire system (i.e. boiler or furnace)
Duct Insulation (ID)	Additional insulation around the heating ducts
Solar Space Heat (SH)	Active or passive systems (i.e. direct gain, addition of thermal mass)
Insulation, General (IX)	Insulation of other miscellaneous areas (e.g., crawl space or basement wall, band joist); or used if location, i.e. attic or wall, is not specified
Attic/Ceiling Insulation (IA)	
Wall Insulation (IW)	
Underfloor Insulation (IF)	Insulation between bottom floor and the unheated basement or crawl space
Caulking and Weatherstripping (CW)	Includes sealing of exterior doors and windows
Infiltration Reduction (PI)	Use of diagnostic equipment (e.g., blower door pressurization an infrared camera) to locate heat loss paths; sealing of infiltration and bypass losses
Lighting System (LS)	Includes installation of new, higher-efficiency lamps, ballasts, or fixtures (switching to different generic type, i.e. incandescents to fluorescents); use of task lighting
Lighting Controls (LC)	Includes automatic timers and occupancy sensors (e.g., controlling the lighting schedule in public areas of a building)
Windows (WM)	Installation of storm windows, double or triple glazing, insulated covering, and thermal patio door glass
Doors (DR)	Installation of storm doors and vestibules
Windows, Replace (WR)	Repair or replacement of broken window glass
Water Heating (WH)	Includes replacement of or modifications to hot water equipment, pipe/tank insulation, flow reduction, lowering of the hot water temperature

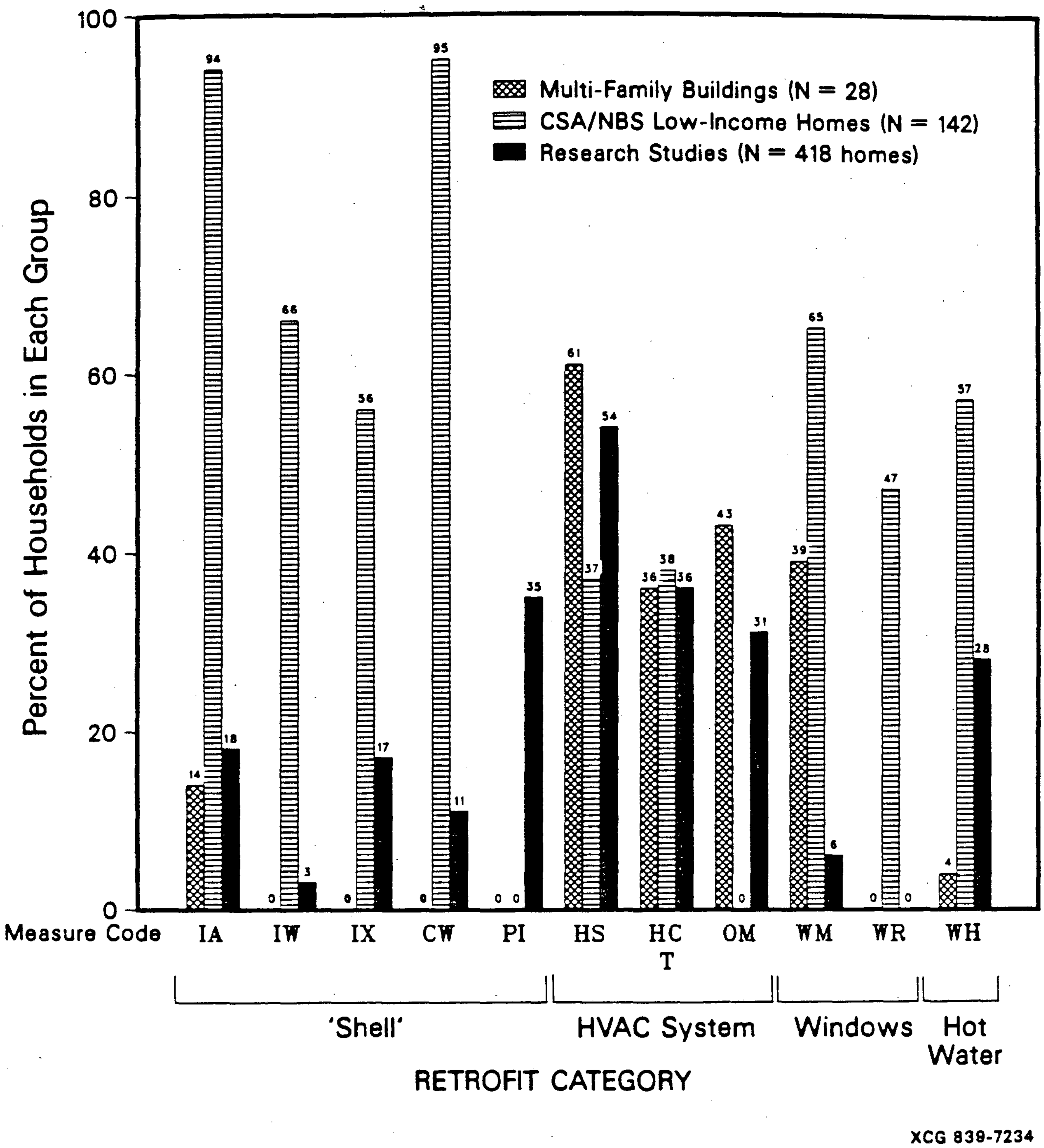

Fig. 1. Relative frequency with which retrofit measures were installed in each of three groups (research studies, multi-family buildings, low-income homes participating in the CSA/NBS Demonstration Project). The eleven most popular retrofits averaged over the three groups are shown. A description of the retrofit measures associated with each code is contained in Table 2 (i.e., IA = attic insulation).

Measures designed to improve the efficiency of the heating system (HS) through modification and replacement of various components were installed in 61% of the multi-family buildings. Improved operations and maintenance (OM) practices or installation of control systems (HC) were also popular retrofits. These measures were implemented in roughly 40 percent of the multi-unit buildings. The control systems range from centralized computer energy management systems that control the firing rate of central boilers based on monitoring of actual indoor apartment temperatures to heating system local controls (e.g. burner controls with programmable setbacks). Heating system (HS) retrofits occurred in 54% of the research homes and 37% of the CSA/NBS low-income homes.* The installation of an automatic setback thermostat (T) in single-family homes was viewed as relatively analogous to the heating control (HC) systems implemented in multi-family buildings. These retrofit categories were represented in roughly the same relative frequency (i.e., 36-38 percent of the homes or buildings).

Infiltration-reduction measures (PI) in which diagnostic equipment and specialized techniques (e.g.,"house-doctoring") are employed were implemented very frequently in research studies (35 percent of homes). In this treatment, a house is pressurized using a 'blower door'; major leakage paths and "bypasses" are identified, typically with the aid of a smoke stick and an infrared camera; and leakage sites are then sealed. "House-doctoring" is an example of an innovative retrofit strategy which was initially demonstrated in research projects and is now being marketed commercially by a number of private firms specializing in energy services. Conventional measures such as storm windows, insulation of the attic, floor, and walls, and caulking and weatherstripping were rarely installed in research studies.

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* In the CSA/NBS experiment, the furnace or boiler were cleaned in all homes prior to testing of steady state efficiency; thus, in a sense, operations and maintenance activities were undertaken, though not explicitly indicated.

Retrofits designed to reduce the heat loss through windows (WM) were installed in 65% of the CSA/NBS low-income homes and in 39% of the multi-family buildings. In the CSA/NBS project, storm windows were chosen in most locations while triple glazing and insulating shutters were installed in the most severe climates. Storm windows were also installed in multi-unit buildings in Chicago while double-hung, double-glazed thermal break aluminum windows were favored in large 1000-unit complexes operated by the New York City Housing Authority. Forty-seven percent of the low-income homes required window glass replacement or repair (WR), reflective of the poor structural condition found in much of the low-income housing stock.

Several conservation measures and practices are grouped in the retrofit category, domestic water heating (WH). Insulation of hot water tanks and pipes, flow reduction in showers, and lowered thermostat settings in hot water heaters are inexpensive measures and practices that reduce the energy used to heat domestic hot water; an end use that accounts for approximately 15% of the total residential energy consumption.[18] Water heating retrofits were installed in 57% of the CSA/NBS low-income homes and in 28% of the research homes, yet were implemented in only 4% of our multi-unit buildings. This low rate is probably misleading because, in some cases, these measures were previously installed. For example, many Public Housing Authorities implemented these water heating retrofits in the mid-1970's as an initial response to the first OPEC oil embargo.

It is difficult to construct a frequency distribution of installed retrofit measures for two major groups (participants in utility-sponsored programs and the DOE Low-income Weatherization program) because of data limitations. Evaluations of these programs often list conservation measures that are eligible for installation but not the frequency of occurrence in the sample of homes included in the study. Hence, it is not possible to develop a meaningful frequency distribution of installed measures at the individual house level. However, some tentative conclusions can be drawn regarding the frequency of implementation for particular measures in these two groups by examining Table 3 and 4. In both groups, conventional retrofits dominate; particularly "shell" measures, window, and hot water retrofits. For example, attic insulation was installed in each program and 6 of 19 utility-sponsored projects financed only attic insulation. Approximately, 50 percent of the utility conservation programs financed floor insulation, storm windows and doors, and caulking and weatherstripping. There were few utility-sponsored programs that installed retrofit measures designed to improve the efficiency of the heating system. Duct insulation and an automatic setback thermostat were installed in at least 20 percent of the homes in three utility-sponsored programs.

It is also useful to consider the lack of data for various retrofit categories. For example, only two studies analyzed the performance of lighting retrofits (LS and LC) in multi-unit buildings. Lighting accounts for approximately 6% of total residential consumption and is an end use identified by several studies as having significant conservation potential.[19] Only one passive solar space heat retrofit (SH) is included in the data base. To summarize, most conventional retrofits are well-represented, yet, except for the 'house-doctor' experiments, there are relatively few 'innovative' retrofits in the data base. More examples are needed at both extremes of the conservation retrofit spectrum; studies on the performance and economics of "super-retrofits" that approach the identified conservation potential and additional data on low- cost measures.

4. RESULTS

In this section, the technical performance and economics of energy conservation retrofit measures are analyzed. We examine the level of energy savings in retrofitted homes, the range of savings among households installing similar conservation measures, the economic worthiness of these investments from the homeowners' perspective, and the sensitivity of the economic results to changes in key variables.

4.1. Energy Savings

Data on project and building characteristics and average energy consumption for homes in each retrofit project, grouped in one of four major categories, are presented in Table 3 through 6.* Each of the major indices derived or listed are explained in the notes following Table 6. The tables also contain information on average building performance levels achieved in addition to energy savings data. The mean heat loss rate for homes in each project is characterized by a heating factor, expressed in Btu fuel per ft^2 per degree day (65°F). The heating factor is an index of the level of space heating consumption normalized by house size and weather. [10] Lowered interior temperature, better insulation, higher free heat, and increased efficiency will all lead to a lower heating factor.** It is interesting to compare the pre-and post-retrofit average heating factor values calculated for homes in various retrofit projects with values estimated for the entire U.S. residential sector. Studies by Meyers at LBL and Latta at the Energy Information Administration found that the average heating factor in existing gas or oil-heated single-family homes ranges between 12.4-15.6 Btu/ft^2-DD.[20,21]

* Results for control groups are also included in these tables, identified by the suffix -A (active control) or -B (blind control) in the label for each entry.

** The heating factor gives only approximate relative values of a building shell and heating system. Note that the heating factor is affected by the accuracy of our baseload subtraction because it is derived from space heat consumption. Lack of knowledge about interior thermostat settings, other occupant management variables and other sources of "free heat" contribute to the uncertainty to the heating factor.

Notes to Table 3 through 6

Label : This is a project's identification number. First letter indicates the principal fuel used for space heating ("G" = natural gas "M" = mixed fuel; heating fuel differed from house to house within a study sample "O" = fuel oil "E" = electricity). The number after the initial letter is a counting index that identifies each retrofit project. The number after the decimal point indicates that groups of homes received different retrofit treatments at a particular site. The letter "A" or "B" at the end of the label signifies an "active" or a blind" control group. Example: "G7.3A" signifies gas-heated homes which are part of an active control group at the 7th site.

Number of Homes : The number of homes in a retrofit project included in the database. The number of apartment units is indicated for each multi-family building.

Heating Degree-Days : The 30-year average of heating degree-days for the retrofit site(s).

Year of Retrofit : The actual year of retrofit or the median year in cases where a large sample of homes was retrofitted over several years.

Floor Area : Average floor area (in ft^2) for homes in the sample. In multi-family dwellings, floor area per apartment unit is indicated. A missing value indicates that floor area was not available for a particular retrofit project.

Retrofit Measures : Two character code, described in Table 2, used to identify measures installed in homes in a particular retrofit project. The measure must have been implemented in at least 20 percent of the homes in a group to be listed.

NAC (Normalized Annual Consumption) : Annual consumption of the heating fuel before and after retrofit. Yearly savings in absolute terms and as a percentage of pre-retrofit consumption are shown. Energy usage includes all end uses of the space heating fuel. In multi-family buildings, consumption refers in almost all cases to space heating and hot water usage. The space heating portion of consumption is normalized to the long-term average weather at that site. Percent savings are calculated by taking the mean consumption before and after retrofit for homes in a retrofit project and calculating percent savings for the group as a whole.

Space Heating Consumption : The space heating portion of total consumption before and after retrofit is calculated by subtracting the baseload usage. Space heating consumption is normalized to long-term average weather at that site. Yearly savings in absolute terms and as a percentage of pre-retrofit consumption are shown. Percent savings are calculated using the method described in NAC. See Appendix A for details regarding baseload and weather correction methods.

Heating Fuel Intensity : Average heating fuel intensity before and after retrofit. Value is derived by dividing space heat consumption by average floor area (units are MBtu/1000 ft^2). For electric heating, we convert to resource energy using 11,500 Btu per kWh [$MJ/m^2 \times 0.088 =$

MBtu/1000 ft^2].

Heating Factor : The average heating factor before and after retrofit. Value is derived by dividing space heat consumption by average floor area and the long-term value for heating degree-days at that site (units are Btu/ft^2-DD_F). For electric heating, we multiply by 1.5 to normalize for 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. [KJ/m^2-DD_C x 0.049 = Btu/ft^2-DD_F]

Note that the heating factor values give only approximate relative values of the performances of a building shell and heating system. Our lack of knowledge about interior thermostat settings, other occupant management variables and other sources of "free heat" (appliances, solar gains etc.) contribute uncertainty to the heating factor. 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.

Confidence Level : Assessment of overall reliability of results from a particular retrofit project. Criteria for each ranking level are explained below:

"A" = high confidence in the data. There is sub-metered data for the principal end-uses affected by the retrofit or the consumption data for each house has been analyzed using a three-parameter (baseload, heating slope, and reference temperature) linear regression model. The analytical method utilizes detailed, site-specific weather information (daily or monthly HDD's) and adjusts annual consumption to a year with 'typical' weather using the long-term value of heating degree-days to the reference temperature base. Retrofit costs are also well-documented, i.e. often total costs are itemized by measure or divided into material and labor costs. The experimental design includes a control group.

"B" = medium high confidence. Consumption data has been analyzed using a two-parameter regression model in which the reference temperature is fixed at 65°F. Baseload usage is determined from the summer months fuel bills. Space heating consumption is then estimated by subtracting the baseload usage from fuel bills during the heating season. Actual space heating consumption is normalized to a year with 'typical' weather by using the monthly long-term heating degree-day value (base 65°F) at that site. Retrofit costs are fairly-well documented. In some cases, a control group is employed.

"C" = average confidence. Often, only annual consumption data are available for each house and no weather or baseload correction has been made by the original authors. A simplified baseload subtraction is made using summer months fuel bills (when monthly fuel bills are available) or regional estimates for similar households (in cases where we do not have summer months usage). The weather correction consists of scaling by annual HDD's (base 65°F). Retrofit cost data are barely adequate, in some cases consisting of only materials cost.

"D" = low confidence. Consumption or cost data used in the project evaluation are poor. In some cases, data have been collected for only a small fraction of the pre-and-post retrofit heating season. It is not possible to make a baseload correction or weather adjustment because of inadequate data. Often, retrofit measures installed are not indicated or cost data are unavailable.

"F" = no confidence. Very crude data with much missing information. Major flaws exist in the data, i.e., metered consumption data were not collected.

(No "F"-level data are included in this study. "D"-level projects are shown in Table 4 but not in the figures.)

Comments : Descriptive comments for a particular retrofit project.

TABLE 3.
UTILITY-SPONSORED PROGRAMS - SUMMARY DATA ON ENERGY CONSUMPTION

LABEL	NUMBER OF HOMES	LOCATION	SPONSOR	HDD (F)	YR OF RETRO FIT	FLOOR AREA (SQFT)	RETROFIT MEASURES	NAC BEFORE (MBTU)	NAC SAVINGS (MBTU)	NAC SAVINGS (PER CENT)
G 11	84	RAMSEY COUNTY,MINN	NORTHERN STATES PWR.	8159	79	1900	IA,CW	195.8	11.8	6
G 12.1	33	BAKERSFIELD,CA	PACIFIC GAS & ELEC.	2185	79		IA			
G 12.2	16	FRESNO,CA	PACIFIC GAS & ELEC.	2650	79		IA			
G 13	33000	COLORADO	PUBLIC SERVICE CO.	6016	77		IA	157.2	19.7	13
G 30	71	DETROIT,MICH.	MICH. CONSOL. GAS CO	6258	74		IA			
								(KWH)	(KWH)	
E 1.1	69	TENNESSEE	TVA	4436	76	1013	IA,IF,CW			
E 1.2	105	TENNESSEE	TVA	4421	76		IA			
E 2	546	TENNESSEE	TVA	4010	78		IA			
E 4.1	973	OREGON	PACIFIC PWR & LIGHT	4905	79	1488	IA,IF,WM,DR,CW,WH	25421.0	4461.0	18
E 4.4B	69337	SIX NORTHWEST STATES	PACIFIC PWR & LIGHT	4905				24386.0	869.0	4
E 5.1	133	SEATTLE,WA.	SEATTLE CITY LIGHT	5185	79		IA,IF			
E 5.2B	551	SEATTLE,WA.	SEATTLE CITY LIGHT	5185						
E 6.1	6289	WASHINGTON	PUGET POWER	5500	80	1672	IA,IW,IF,WM,DR,T,WH	32800.0	8575.0	26
E 7.1	300	PORTLAND,ORE	PORTLAND GEN ELEC	4792	78		IA,IF,WM,DR,WH,CW	23638.0	3937.0	17
E 7.2B	200	PORTLAND,ORE	PORTLAND GEN ELEC	4792				20177.0	8.0	0
E 9.2	810	E. WASH./IDAHO	WASH. WATER POWER	6835	79	1250	IA,IF,DR,WM	30137.0	4349.0	14
E 9.3B	251	E. WASH./IDAHO	WASH. WATER POWER	6835		1390		24794.0	1248.0	5
E 11.1	195	ORE,WASH,MONTANA	BPA/ORNL	5324	81	1760	IA,IF,IW,DR,WM,CW	27200.0	4400.0	16
E 11.2A	54	ORE,WASH,MONTANA	BPA/ORNL	5324	81	1320		22500.0	2200.0	10
E 11.3B	200	ORE,WASH,MONTANA	BPA/ORNL	5324				23000.0	1100.0	5
E 13.1	183	SEATTLE,WA.	SEATTLE CITY LIGHT	5185	81	1644	IA,WM,IF,WH,IW,ID,CW	26320.0	2880.0	11
E 13.2A	270	SEATTLE,WA.	SEATTLE CITY LIGHT	5185	81	1530		25320.0	-80.0	0
E 13.3B	112	SEATTLE,WA.	SEATTLE CITY LIGHT	5185	81	1664		25690.0	-490.0	- 2
E 14.1	293	SEATTLE,WA.	SEATTLE CITY LIGHT	5185	81	1274	IA,IF,IW,WH,ID,CW	21055.0	3039.0	14
E 14.2B	208	SEATTLE,WA.	SEATTLE CITY LIGHT	5185		1312		21840.0	-299.0	- 1
E 15.1	321	SEATTLE,WA.	SEATTLE CITY LIGHT		79		WH	11249.0	465.0	
E 15.2A	124	SEATTLE,WA.	SEATTLE CITY LIGHT					11894.0	-83.0	
E 16.1	208	PORTLAND,ORE	PORTLAND GEN ELEC	4792	79	1577	IA,IF,WM,DR,WH,CW	24491.0	4243.0	17
E 16.2A	105	PORTLAND,ORE	PORTLAND GEN ELEC	4792		1565		23464.0	2899.0	12
E 16.3B	91	PORTLAND,ORE	PORTLAND GEN ELEC	4792		1445		21045.0	1763.0	8
E 17.1	101	BOISE,IDAHO	IDAHO POWER CO.	5833	81	1322	IA,IF,IW,WM,ID,CW	23080.0	2180.0	9
E 17.2B	48	BOISE,IDAHO	IDAHO POWER CO.	5833				20880.0	550.0	3

TABLE 3.
UTILITY-SPONSORED PROGRAMS - SUMMARY DATA ON ENERGY CONSUMPTION (CONT)

LABEL	ANNUAL SPACE HTG CONSUMP BEFORE (MBTU)	SPACE HEAT SAVINGS (MBTU)	SPACE HEAT SAVINGS (PER CENT)	HEATING FUEL INTENS. BEFORE (MBTU/ KSQFT)	HEATING FUEL INTENS. AFTER (MBTU/ KSQFT)	HEATING FACTOR BEFORE (BTU/ SQFTDD)	HEATING FACTOR AFTER (BTU/ SQFTDD)	CONFI- DENCE LEVEL	COMMENTS
G 11	156.7	11.8	8	82.5	76.3	10.1	9.3	B	UTILITY LOW-INCOME WEATH.PROGRAM
G 12.1	83.0	14.9	18					B	ATTIC INSUL PROG IN SAN JOAQUIN VALLEY
G 12.2	61.5	19.6	32					B	ATTIC INSUL PROG IN SAN JOAQUIN VALLEY
G 13	119.2	19.6	16					B	LOW INT LOANS FOR ATTIC INSUL
G 30	255.2	33.9	13					C	ATTIC INSULATION PROG.
	(KWH)	(KWH)							
E 1.1	11270.0	6122.0	54	127.9	58.4	12.8	5.9	C	DEMO PROGRAM BY PRIVATE CONTRAC.
E 1.2	12383.0	4112.0	33					C	DEMO PROGRAM BY TVA PERSONNEL
E 2	10148.0	2211.0	22					A	EARLY STAGE OF HOME INSUL. PROGRAM
E 4.1	12060.0	3980.0	33	93.2	62.4	8.5	5.7	C	GROUP 1 - WEATH. + HTR.WRAP + AUDIT
E 4.4B								C	CONTROL GROUP - ALL SF NON-PARTICIPANTS
E 5.1	17110.0	4180.0	24					C	EARLY PART OF WEATH. PROGRAM
E 5.2B	16843.0	2209.0	13					C	BLIND CONTROL GROUP
E 6.1	19336.0	7903.0	41	133.0	78.6	10.8	6.4	C	ZERO-INTEREST WEATHERIZATION PROGRAM
E 7.1	11900.0	3500.0	29					B	EARLY PART OF WEATHERIZATION PROG.
E 7.2B								B	CONTROL GROUP OF ELIGIBLE NON-PART.
E 9.2	18137.0	4349.0	24	166.9	126.8	10.9	8.3	B	ZERO-INTEREST WEATHERIZATON PROGRAM
E 9.3B								B	CONTROL GROUP
E 11.1	15740.0	4130.0	26	102.8	75.9	8.6	6.3	A	WEATH. PILOT PROGRAM - AUDIT+LOAN GROUP
E 11.2A	14400.0	1410.0	10	125.5	113.2	10.5	9.5	A	WEATH. PILOT PROGRAM - AUDIT ONLY
E 11.3B	12750.0	850.0	7					A	WEATH. PILOT PROGRAM - NON-PARTICIPANTS
E 13.1	14320.0	2380.0	17	100.2	83.5	8.6	7.2	B	HOME ENERGY LOAN PGM- WEATHERIZED HOMES
E 13.2A	13720.0	-80.0	- 1	103.1	103.7	8.9	8.9	B	HOME ENERGY LOAN PGM.- AUDIT ONLY
E 13.3B	14090.0	-490.0	- 3	97.4	100.8	8.4	8.7	B	HOME ENERGY LOAN PGM.- NON-PART.
E 14.1	10555.0	2555.0	24	95.3	72.2	8.2	6.2	C	LOW-INCOME ELEC.PGM- WEATHERIZED HOMES
E 14.2B								C	LOW-INCOME ELEC.PGM.- CONTROL GROUP
E 15.1								C	AUDIT PGM.-HOT WATER CONS.ACTIONS TAKEN
E 15.2A								C	AUDIT PGM.-NO HOT WATER ACTIONS TAKEN
E 16.1	11880.0	3800.0	32	86.6	58.9	8.1	5.5	A	ZIP WEATH. PGM - AUDIT + FINANCE GROUP
E 16.2A	11240.0	2500.0	22	82.6	64.2	7.7	6.0	A	ZIP WEATH. PGM.- AUDIT ONLY GROUP
E 16.3B	9340.0	1340.0	14	74.3	63.7	6.9	5.9	A	ZIP WEATH. PGM.- NON-PARTICIPANTS
E 17.1	12080.0	2180.0	18	105.1	86.1	8.0	6.6	C	ZERO-INTEREST LOAN PROGRAM
E 17.2B	9880.0	550.0	6					C	BLIND CONTROL GROUP

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TABLE 4.
LOW-INCOME WEATHERIZATION PROJECTS - SUMMARY DATA ON ENERGY CONSUMPTION

LABEL	NUMBER OF HOMES	LOCATION	SPONSOR	HDD (F)	YR OF RETRO FIT	FLOOR AREA (SQFT)	RETROFIT MEASURES	NAC BEFORE (MBTU)	NAC SAVINGS (MBTU)	NAC SAVINGS (PER CENT)
O 6	13	VERMONT	DOE/LOW-INC. WEATH.	7876	80		IA,WM,DR			
O 7.1	47	PHILADELPHIA,PA.	IHD/ASE/DOE	4865	80		HS,OM,T	146.5	27.4	19
O 7.2A	45	PHILADELPHIA,PA.	IHD/ASE/DOE	4865						
O 11.1	42	MINNESOTA	IHD/LIEAP	8983	83		HS			
O 11.2	29	MINNESOTA	IHD/LIEAP	8983	83		IA,IW,CW,WM			
O 11.3	15	MINNESOTA	IHD/LIEAP	8983	83		HS,IA,IW,CW,WM			
O 11.4A	32	MINNESOTA	IHD/LIEAP	8983	83					
M 1.1	13	CHARLESTON,SC	CSA/NBS	2146	79	1111	IA,IX,CW,WR,WH			
M 1.2A	5	CHARLESTON,SC	CSA/NBS	2146						
M 2	8	ATLANTA,GA	CSA/NBS	3095	79	1055	IA,WM,IX,CW,IW,WR			
M 3	4	WASH,DC	CSA/NBS	4211	79	915	IA,IW,IX,CW,WM,HS,WH,T			
M 4.1	9	TACOMA,WA	CSA/NBS	5185	79	978	IA,IW,IX,WM,CW,WH			
M 4.2A	5	TACOMA,WA	CSA/NBS	5185						
M 5.1	13	EASTON,PA	CSA/NBS	5827	79	1334	IA,IW,CW,WR,WH,T,HS			
M 5.2A	3	EASTON,PA	CSA/NBS	5827						
M 6.1	14	PORTLAND,ME	CSA/NBS	7498	79	1008	IA,IW,IX,CW,WM,HS,T,WH,WR			
M 6.2A	4	PORTLAND,ME	CSA/NBS	7498						
M 7.1	12	FARGO,ND	CSA/NBS	9271	79	786	IA,IW,IX,CW,WM,WH,HS,T			
M 7.2A	5	FARGO,ND	CSA/NBS	9271						
M 9	65	NW WISCONSIN	CSA	8388	76	1292	IA,WM,DR,CW			
M 10.1	59	MINNESOTA	DOE/LOW-INC. WEATH.	8310	78	806	IA,CW,DR,WR,WM,IW			
M 10.2B	37	MINNESOTA	DOE/LOW-INC. WEATH.	8310		1325				
M 10.3	19	MINNESOTA	DOE/LOW-INC. WEATH.	8310	78	774	IA,CW,DR,WR,WM,IW			
M 11	13	WISCONSIN	DOE/LOW-INC. WEATH.	8820	79					
M 12	86	ALLEGAN CTY.,MICH.	DOE/LOW-INC. WEATH.	6801	80					
G 1	11	WISCONSIN	DOE/LOW-INC. WEATH.	7597	81	900	IA,IF,CW,WM,WR,WH	143.7	20.5	14
G 14.1	8	OAKLAND,CA	CSA/NBS	2909	79	1300	IA,CW,WR			
G 14.2A	4	OAKLAND,CA	CSA/NBS	2909						
G 15	18	ST LOUIS,MO	CSA/NBS	4750	79	1355	IA,CW,WM,IW,IX			
G 16	10	CHICAGO,ILL	CSA/NBS	6127	79	1464	IA,IW,WM,CW,WR,HS,WH,ID,T			
G 17.1	16	COLORADO SPRINGS	CSA/NBS	6473	79	998	IA,IW,IX,CW,WM,WR,HS,WH,T			
G 17.2A	4	COLORADO SPRINGS	CSA/NBS	6473						
G 18.1	17	ST PAUL,MINN	CSA/NBS	8159	79	1421	IA,IW,CW,WR,WM,IX			
G 18.2A	5	ST PAUL,MINN	CSA/NBS	8159						
G 19	30	LUZERNE CTY,PA	DOE/LOW-INC. WEATH.	6277	79		IA,CW,WM			
G 20	89	LOUISIANA	DOE/LOW-INC. WEATH.	1800	80					
G 21.1	21	KANSAS CITY,MO	DOE/LOW-INC. WEATH.	5161	77		IX,CW			
G 21.2	45	KANSAS CITY,MO	DOE/LOW-INC. WEATH.	5161	77		IX,CW			
G 21.3	44	KANSAS CITY,MO	DOE/LOW-INC. WEATH.	5233	78		IX,CW			
G 22	138	KENTUCKY	DOE/LOW-INC. WEATH.	4729	79		IX,WM,DR,CW			
G 23	30	INDIANA	DOE/LOW-INC. WEATH.	5577	78	1102	IA,IF,CW,HS,WH			

TABLE 4.
LOW-INCOME WEATHERIZATION PROJECTS - SUMMARY DATA ON ENERGY CONSUMPTION (CONT)

LABEL	ANNUAL SPACE HTG CONSUMP BEFORE (MBTU)	SPACE HEAT SAVINGS (MBTU)	SPACE HEAT SAVINGS (PER CENT)	HEATING FUEL INTENS. BEFORE (MBTU/ KSQFT)	HEATING FUEL INTENS. AFTER (MBTU/ KSQFT)	HEATING FACTOR BEFORE (BTU/ SQFTDD)	HEATING FACTOR AFTER (BTU/ SQFTDD)	CONFI-DENCE LEVEL	COMMENTS
O 6	143.5	43.5	30					C	LOW INCOME WEATHERIZATION
O 7.1	146.5	27.4	19					C	OIL FURNACE PILOT RETR. PROGRAM
O 7.2A	149.4	3.9	3					C	ACTIVE CONTROL-OIL FURN.RETR.PGM.
O 11.1			22					C	GROUP I - OIL FURNACE RETROFIT
O 11.2			12					C	GROUP II - WEATHERIZATION ONLY
O 11.3			29					C	GROUP III - OIL FURN. RETR.+ WEATH.
O 11.4A			0					C	GROUP IV - ACTIVE CONTROL
M 1.1	62.5	21.1	34	56.3	37.3	26.2	17.4	A	DEMO PGM. LOW-INCOME WEATHERIZATION
M 1.2A	36.3	5.6	15					A	ACTIVE CONTROL GROUP
M 2	108.1	14.0	13	102.5	89.2	33.1	28.8	A	DEMO PGM. LOW-INCOME WEATHERIZATION
M 3	130.5	61.4	47	142.6	75.5	33.9	17.9	A	DEMO PGM. LOW-INCOME WEATHERIZATION
M 4.1	168.8	69.0	41	172.6	102.0	33.3	19.7	A	DEMO PGM. LOW-INCOME WEATHERIZATION
M 4.2A	59.5	9.4	16					A	ACTIVE CONTROL GROUP
M 5.1	121.7	28.6	24	91.2	69.8	15.7	12.0	A	DEMO PGM. LOW-INCOME WEATHERIZATION
M 5.2A	44.0	4.2	9					A	ACTIVE CONTROL GROUP
M 6.1	187.3	81.9	44	185.8	104.6	24.8	13.9	A	DEMO PGM. LOW-INCOME WEATHERIZATION
M 6.2A	232.5	28.7	12					A	ACTIVE CONTROL GROUP
M 7.1	109.5	43.7	40	139.3	83.7	15.0	9.0	A	DEMO PGM. LOW-INCOME WEATHERIZATION
M 7.2A	145.1	13.8	10					A	ACTIVE CONTROL GROUP
M 9	143.0	27.1	19	110.7	89.7	13.2	10.7	C	LOW-INCOME WEATHERIZATION
M 10.1	110.9	11.3	10	137.6	123.6	16.6	14.9	B	LOW-INCOME WEATHERIZATION
M 10.2B	128.5	-3.2	- 2	97.0	99.4	11.7	12.0	B	BLIND CONTROL GROUP
M 10.3	103.6	6.9	7	133.9	124.9	16.1	15.0	B	19 HOME SUB-GROUP WITH 2 POST-RETR.YRS
M 11	139.3	23.0	17					D	LOW-INCOME WEATHERIZATION
M 12	156.0	44.0	28					D	LOW-INCOME WEATHERIZATION
G 1	120.3	20.8	17	133.7	110.6	17.6	14.6	C	LOW-INCOME WEATHERIZATION
G 14.1	76.1	2.2	3	58.5	56.9	20.1	19.6	A	DEMO PGM. LOW-INCOME WEATHERIZATION
G 14.2A	116.9	-11.5	-10					A	ACTIVE CONTROL GRP.
G 15	174.7	17.4	10	128.9	116.1	27.1	24.4	A	DEMO PGM. LOW-INCOME WEATHERIZATION
G 16	264.8	109.7	41	180.9	105.9	29.5	17.3	A	DEMO PGM. LOW-INCOME WEATHERIZATION
G 17.1	132.0	60.4	46	132.3	71.7	20.4	11.1	A	DEMO PGM. LOW-INCOME WEATHERIZATION
G 17.2A	164.8	0.2	0					A	ACTIVE CONTROL GROUP
G 18.1	180.9	39.3	22	127.3	99.6	15.6	12.2	A	DEMO PGM. LOW-INCOME WEATHERIZATION
G 18.2A	286.1	23.4	8					A	ACTIVE CONTROL GROUP
G 19	157.9	23.7	15					C	LOW-INCOME WEATHERIZATION
G 20	48.3	14.2	29					D	LOW-INCOME WEATHERIZATION
G 21.1	135.0	20.0	15					C	LOW-INCOME WEATHERIZATION
G 21.2	196.0	44.0	22					C	LOW-INCOME WEATHERIZATION
G 21.3	191.0	52.0	27					C	LOW-INCOME WEATHERIZATION
G 22	118.5	15.7	13					C	LOW-INCOME WEATHERIZATION
G 23	182.1	46.4	25	165.2	123.1	29.6	22.1	B	LOW-INCOME WEATHERIZATION

TABLE 5.
RESEARCH STUDIES - SUMMARY DATA ON ENERGY CONSUMPTION

LABEL	NUMBER OF HOMES	LOCATION	SPONSOR	HDD (F)	YR OF RETRO FIT	FLOOR AREA (SQFT)	RETROFIT MEASURES	NAC BEFORE (MBTU)	NAC SAVINGS (MBTU)	NAC SAVINGS (PER CENT)
O 1	1	NEW JERSEY	PRINCETON/ HS 21	4911	79	1990	IA,WM,OM,PI			
O 10	169	LONG ISLAND,NY	BNL/DOE	5500	80	2045	HS,OM,T			16
O 10 B	30	LONG ISLAND,NY	BNL/DOE	5500		1559		148.3	17.5	12
O 10.0	45	LONG ISLAND,NY	BNL/DOE	5500	80	2045	HS,OM			
O 10.1	24	LONG ISLAND,NY	BNL/DOE	5500	80		HS			11
O 10.2	28	LONG ISLAND,NY	BNL/DOE	5500	80		HS,OM			19
O 10.3	21	LONG ISLAND,NY	BNL/DOE	5500	80		HS,OM,T			20
O 10.4	20	LONG ISLAND,NY	BNL/DOE	5500	80		HS,OM			21
O 10.5	19	LONG ISLAND,NY	BNL/DOE	5500	80		HS			14
O 10.6	22	LONG ISLAND,NY	BNL/DOE	5500	80		HS			10
O 10.7	18	LONG ISLAND,NY	BNL/DOE	5500	80		HS,T			9
O 10.8	17	LONG ISLAND,NY	BNL/DOE	5500	80		HS,T			21
M 13.1	130	SWEDEN	ROYAL INST. OF TECH	7220	77	1485	IW	142.4	18.5	13
M 13.2	106	SWEDEN	ROYAL INST. OF TECH.	7220	77	1808	IA	157.7	16.2	10
M 13.3	105	SWEDEN	ROYAL INST. OF TECH.	7220	77	1528	IW,IA	151.1	17.2	11
M 13.4	140	SWEDEN	ROYAL INST. OF TECH.	7220	77	1636	IA,HS	164.9	24.2	15
M 13.5	111	SWEDEN	ROYAL INST. OF TECH.	7220	77	1829	WM	155.0	11.5	7
M 13.6	17	SWEDEN	ROYAL INST. OF TECH.	7220	77	1549	WM,IA	142.1	14.1	10
M 13.7	32	SWEDEN	ROYAL INST. OF TECH.	7220	77	1937	HS	173.3	21.1	12
M 14.1	30	SWEDEN	ROYAL INST. OF TECH	7220	77	689	IW	64.5	9.0	14
M 14.2	25	SWEDEN	ROYAL INST. OF TECH.	7220	77	764	IA	78.7	6.6	8
M 14.7	63	SWEDEN	ROYAL INST. OF TECH.	7220	77	807	HS	76.7	5.9	8
G 2	1	TWIN RIVERS,NJ	PRINCETON	4911	77	1500	IX,WM,CW,PI			
G 3	1	NEW JERSEY	PRINCETON/ HS 11	4911	79	1200	IA,WM,OM,PI			
G 4	1	NEW JERSEY	PRINCETON/ HS 22	4911	79	1560	IA,DR,OM,PI			
G 5.1	6	MRE/FREEHOLD,NJ	PRINCETON/NJNG	4872	80	2500	IX,IA,PI,WH,T	179.0	44.0	25
G 5.2	12	MRE/FREEHOLD,NJ	PRINCETON/NJNG	4872	80	2500	PI,WH,T	172.0	29.0	17
G 5.3B	6	MRE/FREEHOLD,NJ	PRINCETON/NJNG	4872		2500		185.0	11.0	6
G 5.4B	140000	MRE/NJNG	PRINCETON/NJNG	4872						
G 6.1	6	MRE/TOMS RIVER,NJ	PRINCETON/NJNG	4872	80	870	IX,IA,PI,WH,T	87.0	17.0	20
G 6.2	12	MRE/TOMS RIVER,NJ	PRINCETON/NJNG	4872	80	860	PI,WH,T	99.0	7.0	7
G 6.3B	6	MRE/TOMS RIVER,NJ	PRINCETON/NJNG	4872		900		98.0	0.0	0
G 6.4B	140000	MRE/NJNG	PRINCETON/NJNG	4872						
G 7.1	6	MRE/OAK VALLEY,NJ	PRINCETON/SJG	4872	80	1400	IX,T,PI,WM	116.0	27.0	23
G 7.2	9	MRE/OAK VALLEY,NJ	PRINCETON/SJG	4872	80	1400	PI,WH,T	121.0	27.0	22
G 7.3A	6	MRE/OAK VALLEY,NJ	PRINCETON/SJG	4872		1400		128.0	13.0	10
G 7.4B	75000	MRE/SJG	PRINCETON/SJG	4872						
G 8.1	5	MRE/WHITMAN SQ,NJ	PRINCETON/SJG	4872	80	2120	IX,IA,PI,WH,T	147.0	35.0	24
G 8.2	9	MRE/WHITMAN SQ,NJ	PRINCETON/SJG	4872	80	1880	PI,WH,T	135.0	26.0	19
G 8.3A	4	MRE/WHITMAN SQ,NJ	PRINCETON/SJG	4872		2000		134.0	22.0	16
G 8.4B	75000	MRE/SJG	PRINCETON/SJG	4872						
G 9.1	5	SASKATCHEWAN,CANADA	EN.CONS INFO C./NRC	10939	80	2157	IA,IF,CW,PI			
G 9.2	5	SASKATCHEWAN,CANADA	EN.CONS INFO C./NRC	10939	80	1752	CW,PI			
G 9.3	10	SASKATCHEWAN,CANADA	EN.CONS INFO C./NRC	10939	80		IA,IW,WM,DR			
G 10	1	BUTTE,MT	NCAT	9669	80	2300	IA,IW,CW,SH			
G 24.1	6	MRE/EDISON,NJ	PRINCETON/ELIZ.GAS	4872	80	1780	IX,T,PI	163.0	38.0	23
G 24.2	5	MRE/EDISON,NJ	PRINCETON/ELIZ.GAS	4872	80	1810	PI,T	164.0	24.0	15
G 24.3A	6	MRE/EDISON,NJ	PRINCETON/ELIZ.GAS	4872		1800		166.0	11.0	7
G 24.4B	75000	MRE/ELIZ. GAS	PRINCETON/ELIZ.GAS	4872						
G 25.1	6	MRE/WOOD RIDGE,NJ	PRINCETON/PSEG	4872	80	1345	IX,PI	177.0	26.0	15
G 25.2	6	MRE/WOOD RIDGE,NJ	PRINCETON/PSEG	4872	80	1370	PI,WH	159.0	21.0	13
G 25.3A	6	MRE/WOOD RIDGE,NJ	PRINCETON/PSEG	4872		1400		148.0	17.0	11
G 25.4B	550000	MRE/PSEG,NJ	PRINCETON/PSEG	4872						
G 26.1	5	MRE/NEW ROCHELLE,NY	PRINCETON/CONED	4872	80	1300	IX,T,PI,OM	155.0	31.0	20
G 26.2	5	MRE/NEW ROCHELLE,NY	PRINCETON/CONED	4872	80	1460	PI,WH,OM,T	160.0	24.0	15
G 26.3A	6	MRE/NEW ROCHELLE,NY	PRINCETON/CONED	4872		1400		159.0	19.0	12
G 27.1	13	WALNUT CREEK,CA	PG&E/LBL	2900	80	2240	PI,HS,WH,OM	128.2	16.4	13
G 27.2A	6	WALNUT CREEK,CA	PG&E/LBL	2900		2500		134.6	14.2	11
G 27.3B	1800	WALNUT CREEK,CA	PG&E/LBL	2900				87.8	6.2	7
G 28	12	CHAMPAIGN, ILL.	UNIV. OF ILLINOIS	5773	78	1596	IA,IW	175.1	41.6	24
G 29.1	25	DENVER,COL.	SERI/DOE	6016	81		CW,OM,WH,IA,IX,ID,T	153.6	29.4	19
G 29.2A	25	DENVER,COL.	SERI/DOE	6016				135.5	19.8	15
								(KWH)	(KWH)	
E 3.1	29	DENVER,COL	JOHNS MANVILLE	6016	78	1600	PI			
E 3.2A	30	DENVER,COL	JOHNS MANVILLE	6016						
E 3.3B	30	DENVER,COL	JOHNS MANVILLE	6016						
E 8.1	5	MIDWAY,WA	BPA/LBL	4760	80	1260	PI			
E 8.2	5	MIDWAY,WA	BPA/LBL	4760	79	1253	IA,IX,CW			
E 8.3	4	MIDWAY,WA	BPA/LBL	4760	79	1239	IA,IX,WM,DR,CW			
E 10	1	BOWMAN HOUSE,MD	NBS	4610	75	2054	IA,IF,IW,WM,CW			

TABLE 5.

RESEARCH STUDIES - SUMMARY DATA ON ENERGY CONSUMPTION (CONT)

LABEL	ANNUAL SPACE HTG CONSUMP BEFORE (MBTU)	SPACE HEAT SAVINGS (MBTU)	SPACE HEAT SAVINGS (PER CENT)	HEATING FUEL INTENS. BEFORE (MBTU/ KSQFT)	HEATING FUEL INTENS. AFTER (MBTU/ KSQFT)	HEATING FACTOR BEFORE (BTU/ SQFTDD)	HEATING FACTOR AFTER (BTU/ SQFTDD)	CONFI- DENCE LEVEL	COMMENTS
O 1	132.0	69.5	53	66.3	31.4	13.5	6.4	A	RESEARCH STUDY - REDUCING BYPASS LOSSES
O 10								B	COMPOSITE RESULTS- OIL-FIRED BOILER RETR
O 10 B								B	CONTROL GR.- EFFECT OF PRICE INCREASE
O 10.0			11					B	COMPOSITE RESULTS-OIL FIRED FURNACE RETR
O 10.1								B	GROUP #1-RETENTION HEAD BURNER (RHB)
O 10.2								B	GROUP #2 - RHB WITH OPT. INSTALLATION
O 10.3								B	GROUP #3-RHB (OPT) W/ TEMP. PROGRAMMER
O 10.4								B	GROUP #4-RHB (OPT) WITH VENT DAMPER
O 10.5								B	GROUP #5-VENT DAMPER WITH CONV. BURNER
O 10.6								B	GROUP #6-FLUE HT.EXCHANGER W/ CONV.BURN.
O 10.7								B	GROUP #7-SETBACK THERMO. W/ CONV. BURN.
O 10.8								B	GROUP #8-SETBACK + TEMP PGM W/ CONV BURN
M 13.1								C	WALL INSULATION - SF AGGREGATE RESULTS
M 13.2								C	ATTIC INSULATION - SF AGGREGATE RESULTS
M 13.3								C	WALL + ATTIC INS.- SF AGGREGATE RESULTS
M 13.4								C	WALL + ATTIC INS.+TRV -AGG.RESULTS
M 13.5								C	TRIPLE GLAZING - AGGREGATE RESULTS
M 13.6								C	TRIPLE GLAZING + WALL INS.-AGG.RESULTS
M 13.7								C	TRV VALVE
M 14.1								C	WALL INSULATION - MF AGGREGATE RESULTS
M 14.2								C	ATTIC INSULATION - MF AGGREGATE RESULTS
M 14.7								C	TRV VALVE + VARIATOR EQUIP.
G 2	81.0	61.8	76	54.0	12.8	11.0	2.6	A	EXTENSIVE RETROFIT AT TWIN RIVERS
G 3	59.6	23.9	40	49.7	29.8	10.1	6.1	A	RESEARCH PROJ.-REDUCING BYPASS LOSSES
G 4	114.4	30.3	26	73.3	53.9	14.9	11.0	A	RESEARCH PROJ.-REDUCING BYPASS LOSSES
G 5.1	112.0	35.3	32	44.8	30.7	9.2	6.3	A	HOUSE DOCTOR + CONTRACTOR RETR.
G 5.2	113.3	14.6	13	45.3	39.5	9.3	8.1	A	HOUSE DOCTOR RETR. ONLY
G 5.3B	132.8	1.3	1	53.1	52.6	10.9	10.8	A	BLIND CONTROL GROUP
G 5.4B								A	UTILITY AGGREGATE
G 6.1	60.1	14.5	24	69.0	52.4	14.2	10.7	A	HOUSE DOCTOR + CONTRACTOR RETR.
G 6.2	65.8	4.0	6	76.5	71.8	15.7	14.7	A	HOUSE DOCTOR RETR. ONLY
G 6.3B	69.3	0.0	0	77.0	77.0	15.8	15.8	A	BLIND CONTROL GROUP
G 6.4B								A	UTILITY AGGREGATE
G 7.1	68.2	21.1	31	48.7	33.6	10.0	6.9	A	HOUSE DOCTOR + CONTRACTOR RETR.
G 7.2	66.2	16.4	25	47.3	35.6	9.7	7.3	A	HOUSE DOCTOR RETR. ONLY
G 7.3A	72.3	13.0	18	51.6	42.3	10.6	8.7	A	ACTIVE CONTROL GROUP
G 7.4B								A	UTILITY AGGREGATE
G 8.1	124.7	33.1	27	58.8	43.2	12.1	8.9	A	HOUSE DOCTOR + CONTRACTOR RETR.
G 8.2	101.3	20.4	20	53.9	43.0	11.1	8.8	A	HOUSE DOCTOR RETR. ONLY
G 8.3A	103.3	23.4	23	51.6	40.0	10.6	8.2	A	ACTIVE CONTROL GROUP
G 8.4B								A	UTILITY AGGREGATE
G 9.1	177.1	53.3	30	82.1	57.4	7.5	5.2	B	INFILTRATION STUDY - INSUL.+ SEALED
G 9.2	163.5	14.9	9	93.3	84.8	8.5	7.8	B	INFILTRATION STUDY - SEALED ONLY
G 9.3	127.2	15.9	12					C	INFILTRATION STUDY - INSUL. MAINLY
G 10	262.9	58.5	22	114.3	88.9	11.8	9.2	B	PASSIVE SOLAR WALL RETR. IN 2ND YR
G 24.1	108.7	35.0	32	61.0	41.4	12.5	8.5	A	HOUSE DOCTOR + CONTRACTOR RETR.
G 24.2	105.2	21.9	21	58.1	46.0	11.9	9.4	A	HOUSE DOCTOR RETR. ONLY
G 24.3A	114.9	23.7	21	63.8	50.7	13.1	10.4	A	ACTIVE CONTROL GROUP
G 24.4B								A	UTILITY AGGREGATE
G 25.1	128.9	35.5	28	95.8	69.4	19.7	14.2	A	HOUSE DOCTOR + CONTRACTOR RETR.
G 25.2	114.6	25.9	23	83.6	64.7	17.2	13.3	A	HOUSE DOCTOR RETR. ONLY
G 25.3A	109.8	23.2	21	78.4	61.8	16.1	12.7	A	ACTIVE CONTROL GROUP
G 25.4B								A	UTILITY AGGREGATE
G 26.1	99.6	21.8	22	76.6	59.8	15.7	12.3	A	HOUSE DOCTOR + CONTRACTOR RETR.
G 26.2	88.0	13.0	15	60.3	51.3	12.4	10.5	A	HOUSE DOCTOR RETR. ONLY
G 26.3A	111.9	16.4	15	79.9	68.2	16.4	14.0	A	ACTIVE CONTROL GROUP
G 27.1								A	HOUSE DOCTOR ONLY
G 27.2A								A	AUDIT ONLY-ACTIVE CONTROL
G 27.3B								A	BLIND CONTROL-UTILITY AGGREGATE
G 28	133.7	40.2	30	83.8	58.6	14.5	10.1	B	ATTIC & WALL INSUL DONE BY PRIV.FIRMS
G 29.1								B	50/50 PROGRAM
G 29.2A								B	NON-PARTICIPANT CONTROL GROUP
	(KWH)	(KWH)							
E 3.1	17615.0	2836.0	16	126.6	106.2	9.4	7.9	A	RESEARCH STUDY OF AIR LEAKAGE ON USAGE
E 3.2A	20606.0	2891.0	14					A	ACTIVE CONTROL GROUP
E 3.3B	23886.0	2852.0	12					A	BLIND CONTROL GROUP
E 8.1	19984.0	1846.0	9	182.4	165.5	17.1	15.5	A	EXTENDED INFILTRATION REDN.
E 8.2	19803.0	3235.0	16	181.8	152.1	17.0	14.2	A	ATTIC AND CRAWLSPACE INS.
E 8.3	19649.0	8204.0	42	182.4	106.2	17.1	9.9	A	INS. PLUS STORM DOOR,WINDOW
E 10	20330.0	11906.0	59	113.8	47.2	11.0	4.6	A	FIRST EXTENSIVE RETR. RESEARCH STUDY

TABLE 6
MULTI-FAMILY BUILDINGS - SUMMARY DATA ON ENERGY CONSUMPTION

LABEL	NUMBER OF HOMES	LOCATION	SPONSOR	HDD (F)	YR OF RETRO FIT	FLOOR AREA (SQFT)	RETROFIT MEASURES	NAC BEFORE (MBTU)	NAC SAVINGS (MBTU)	NAC SAVINGS (PER CENT)
O 2.1	159	TRENTON,NJ	BUMBLEBEE/THA/HUD	4908	81	830	HC,HS,WH	129.0	57.2	44
O 2.2B	1500	TRENTON,NJ	HUD/TRENTON	4911				116.7	18.4	16
O 3	521	WASHINGTON,D.C.	SCALLOP THERMAL MAN.	4211	78		HS,HC,OM	116.3	7.9	7
O 4	752	MARYLAND	SCALLOP THERMAL MAN.	4211	78		HS,HC,OM	84.9	1.8	2
O 5	60	NEW YORK CITY,NY	SCALLOP THERMAL MAN.	4848	78		HS,HC,OM	167.3	15.2	9
O 8	277	NEW YORK CITY,NY	NYC HOUSING AUTH	4800	77	870	HS			
O 8 A	277	NEW YORK CITY,NY	NYC HOUSING AUTH.	4800						
O 8.1	42	NEW YORK CITY,NY	NYC HOUSING AUTH	4800	77	890	HS			
O 8.1A	42	NEW YORK CITY,NY	NYC HOUSING AUTH	4800						
O 8.2	98	NEW YORK CITY,NY	NYC HOUSING AUTH	4800	77	850	HS			
O 8.2A	98	NEW YORK CITY,NY	NYC HOUSING AUTH	4800						
O 8.3	56	NEW YORK CITY,NY	NYC HOUSING AUTH	4800	77	830	HS			
O 8.3A	56	NEW YORK CITY,NY	NYC HOUSING AUTH	4800						
O 8.4	81	NEW YORK CITY,NY	NYC HOUSING AUTH	4800	77	920	HS			
O 8.4A	81	NEW YORK CITY,NY	NYC HOUSING AUTH	4800						
O 9	10959	NEW YORK CITY,NY	NYC HOUSING AUTH.	4800	80	820	WM			
O 9.1	1444	NEW YORK CITY,NY	NYC HOUSING AUTH.	4800	80	850	WM			
O 9.2	1338	NEW YORK CITY,NY	NYC HOUSING AUTH.	4800	80	775	WM			
O 9.3	1791	NEW YORK CITY,NY	NYC HOUSING AUTH.	4800	80	810	WM			
O 9.4	1310	NEW YORK CITY,NY	NYC HOUSING AUTH.	4800	80	810	WM			
O 9.5	1229	NEW YORK CITY,NY	NYC HOUSING AUTH.	4800	81	840	WM			
O 9.6	1084	NEW YORK CITY,NY	NYC HOUSING AUTH.	4800	80	760	WM			
O 9.7	1246	NEW YORK CITY,NY	NYC HOUSING AUTH.	4800	80	825	WM			
O 9.8	786	NEW YORK CITY,NY	NYC HOUSING AUTH.	4800	81	845	WM			
O 9.9	733	NEW YORK CITY,NY	NYC HOUSING AUTH.	4800	81	850	WM			
M 15	503	ST. PAUL,MINN.	ST.PAUL HOUSING AUTH	8159	81		HC,LC	64.8	11.6	18
G 31.1	19	CHICAGO,ILL.	CT. NEIGHBOR. TECH.	6500	81	950	IA,HC,HS,OM			
G 31.2	22	CHICAGO,ILL.	CT. NEIGHBOR. TECH.	6500	81	1030	IA,HS,OM			
G 31.3	25	CHICAGO,ILL.	CT. NEIGHBOR. TECH.	6500	81	1040	IA,HC,HS,WM,OM			
G 31.4	7	CHICAGO,ILL.	CT. NEIGHBOR. TECH.	6500	81	960	HC,HS,OM,ID			
G 31.5	6	CHICAGO,ILL.	CT. NEIGHBOR. TECH.	6500	81	1200	IA,WM,HS,OM			
G 31.6	6	CHICAGO,ILL.	CT. NEIGHBOR. TECH.	6500	81	1165	HS,OM			
G 31.7	4	CHICAGO,ILL.	CT. NEIGHBOR. TECH.	6500	81	1280	HS,OM			
G 31.8	13	CHICAGO,ILL.	CT. NEIGHBOR. TECH.	6500	81	765	HS,HC,OM			
G 32	530	NEWARK,NJ	BUMBLEBEE/NHA/HUD	4857	82	738	HC,OM,HS			
								(KWH)	(KWH)	
E 12	159	NEW YORK CITY,NY	NYCHA		79	865	LS	1285.0	793.0	

TABLE 6.
MULTI-FAMILY BUILDINGS - SUMMARY DATA ON ENERGY CONSUMPTION (CONT)

LABEL	ANNUAL SPACE HTG CONSUMP BEFORE (MBTU)	SPACE HEAT SAVINGS (MBTU)	SPACE HEAT SAVINGS (PER CENT)	HEATING FUEL INTENS. BEFORE (MBTU/ KSQFT)	HEATING FUEL INTENS. AFTER (MBTU/ KSQFT)	HEATING FACTOR BEFORE (BTU/ SQFTDD)	HEATING FACTOR AFTER (BTU/ SQFTDD)	CONFI- DENCE LEVEL	COMMENTS
O 2.1								B	PAGE HOMES RETROFIT
O 2.2B	116.7	18.4	16					B	BLIND CONTROL GROUP
O 3								C	THERMAL SERVICES CONTRACT FOR MF APT
O 4								C	THERMAL SERVICES CONTRACT FOR MF APT
O 5								C	THERMAL SERVICES CONTRACT
O 8	63.1	13.9	22	72.5	56.6	15.1	11.8	B	THERMO. RAD. VALVE DEMO. -COMPOSITE
O 8 A	61.7	9.8	16					B	CONTROL BLDGS - TRV DEMO PROJECT
O 8.1	109.8	28.4	26	123.3	91.4	25.7	19.0		BREUKELEN - TRV DEMO PROJECT
O 8.1A	110.3	17.0	15					B	BREUKELEN CONTROL BLDG - TRV DEMO
O 8.2	38.8	9.6	25	45.7	34.4	9.5	7.2		CYPRESS HILLS - TRV DEMO PROJECT
O 8.2A	36.4	8.5	23					B	CYPRESS HILLS CONTROL BLDG - TRV DEMO
O 8.3	48.5	3.3	7	58.4	54.4	12.2	11.3		MARLBORO - TRV DEMO PROJECT
O 8.3A	45.5	-2.2	- 5					B	MARLBORO CONTROL BLDG - TRV DEMO
O 8.4	55.4	14.4	26	60.2	44.6	12.5	9.3		OCEAN HILLS - TRV DEMO PROJECT
O 8.4A	54.6	16.0	29					B	OCEAN HILLS CONTROL BLDG - TRV DEMO
O 9	67.4	11.9	18	82.2	67.7	17.1	14.1	C	NYCHA WINDOW RETR. PROJECT - COMPOSITE
O 9.1	67.7	11.0	16	79.6	66.7	16.6	13.9	C	CYPRESS HILLS WINDOW RETR. PROJECT
O 9.2	63.8	9.7	15	82.3	69.8	17.2	14.5	C	BROWNSVILLE WINDOW RETR. PROJECT
O 9.3	73.1	16.2	22	90.2	70.2	18.8	14.6	C	PATTERSON WINDOW RETR. PROJECT
O 9.4	67.2	11.2	17	83.0	69.1	17.3	14.4	C	JOHNSON HOUSE WINDOW RETR. PROJECT
O 9.5	74.8	10.8	14	89.0	76.2	18.6	15.9	C	ALBANY I&II WINDOW RETR. PROJECT
O 9.6	68.8	14.2	21	90.5	71.8	18.9	15.0	C	AMSTERDAM WINDOW RETR. PROJECT
O 9.7	60.1	10.2	17	72.8	60.5	15.2	12.6	C	CARVER WINDOW RETR. PROJECT
O 9.8	62.7	11.2	18	74.2	60.9	15.5	12.7	C	SEDGWICK WINDOW RETR. PROJECT
O 9.9	62.4	5.9	9	73.4	66.5	15.3	13.8	C	GUN HILL HOUSES WINDOW RETR. PROJECT
M 15								C	MGMT CONTROL SYS IN PUBLIC HOUSING
G 31.1	111.8	57.8	52	117.7	56.8	18.1	8.7	C	MULTI-FAMILY APT. RETROFIT - MONROE 19
G 31.2	139.7	57.5	41	135.6	79.8	20.9	12.3	C	MULTI-FAMILY APT. RETROFIT - MADISON 22
G 31.3	97.1	29.2	30	93.4	65.3	14.4	10.0	C	MULTI-FAMILY APT. RETROFIT - REBA 25
G 31.4	85.8	9.6	11	89.4	79.4	13.8	12.2	C	MULTI-FAMILY APT. RETROFIT - ALBANY 7
G 31.5	227.4	119.7	53	189.5	89.8	29.2	13.8	C	MULTI-FAMILY APT. RETROFIT - REBA 6
G 31.6	89.7	24.5	27	77.0	56.0	11.8	8.6	C	MULTI-FAMILY APT. RETROFIT - MONROE 6
G 31.7	108.8	39.7	36	85.0	54.0	13.1	8.3	C	MULTI-FAMILY APT. RETROFIT - ELMWOOD 4
G 31.8	84.9	26.0	31	111.0	77.0	17.1	11.8	C	MULTI-FAMILY APT. RETROFIT - MONROE 13
G 32	116.8	16.3	14	158.3	136.2	32.6	28.0	C	ENERGY MGMT.CONTROL SYST - PUBLIC HOUS.
	(KWH)	(KWH)							
E 12								C	FLUORESCENT LIGHT RETR. - 830 AMSTERDAM

Pre-and-post retrofit heating factor values are far higher in low-income homes compared to homes that participated in research studies or utiity-sponsored programs. After retrofit, low-income homes have a heating factor approaching the national average. Post-retrofit heating factor values for homes that were retrofitted in research studies or utility-sponsored conservation programs are, on the average, substantially lower than the national average for existing residences.

Fig. 2 shows annual weather-normalized space heat energy savings, by type of project, as a function of the contractor cost of the retrofit (Table 3 and 4). At any given investment level, there is substantial variation in savings (e.g., savings differ by a factor of 4 for an investment of $2400). The sloping reference lines show the minimum energy savings that must be achieved, for each level of investment, if the retrofit is to be cost-effective compared to national average residential prices for fuel and electricity. The future stream of energy purchases for 15 years, assuming constant energy prices (in 1983$), are converted to a single present value, assuming a 7% real discount rate, in order to compare energy savings over time with the "one-time" conservation investment. Seventy-four percent of the points lie above their respective price lines and hence are cost-effective compared to these fuel prices. Note, however, that there are regional variations in the price of gas and electricity, so that cost-effectiveness of individual retrofit projects may be different from that indicated here. Participants in the nineteen utility-sponsored conservation programs achieved average annual space heat savings of 38.4 million Btu (MBtu), while low-income residents reduced their annual consumption by 35.9 MBtu.

Conservation programs initiated by Puget Power and TVA (data points E6.1 and E1.1) achieved high energy savings (91 and 70 MBtu) relative to cost ($1450 and $700). The TVA pilot program specifically targeted low-income high-energy consumers; hence significant improvements in building thermal performance were obtained at low cost. Savings from the Puget Power program are impressive, especially given the large

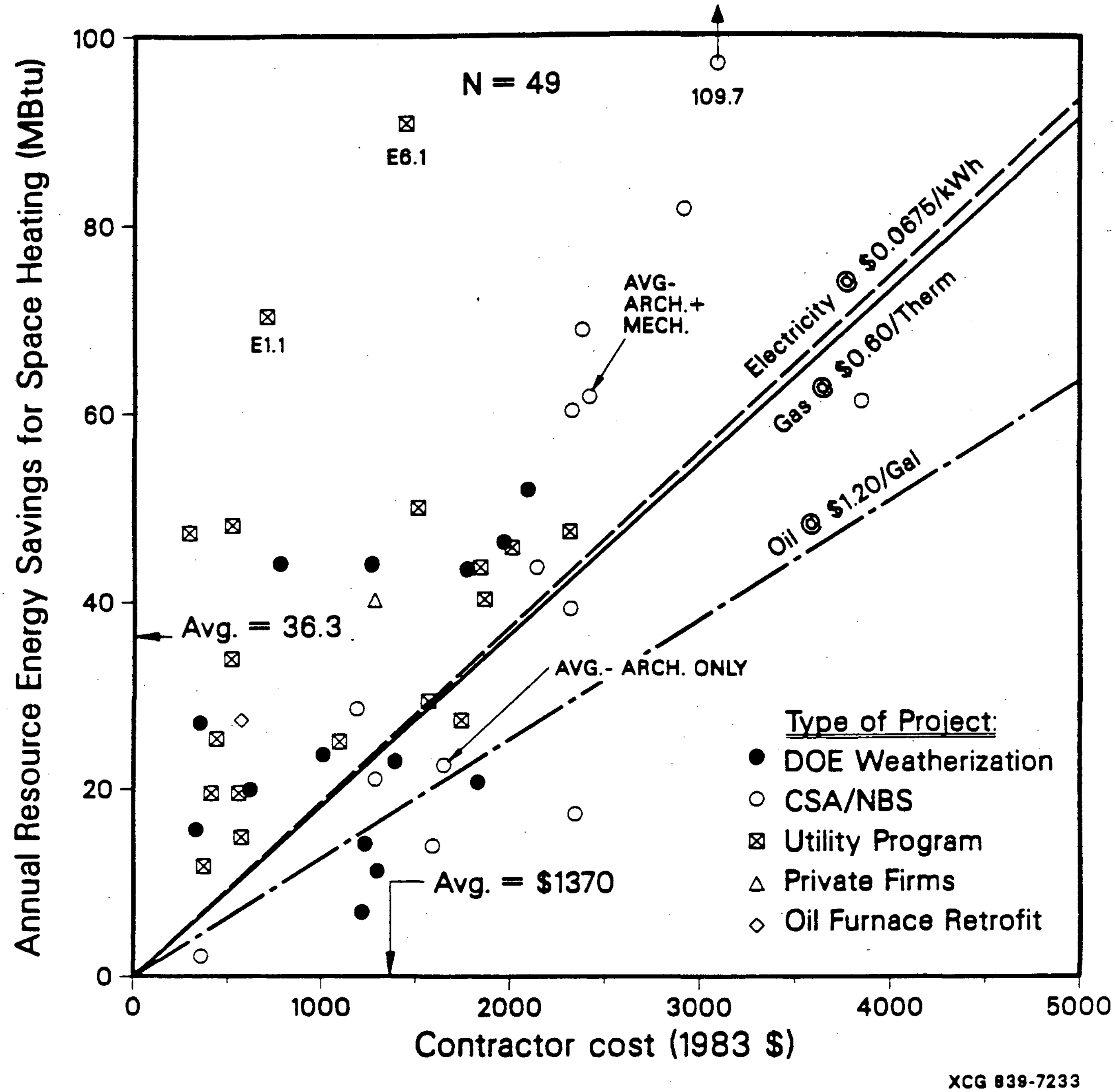

Fig. 2. Annual space heat energy savings are plotted against the first-cost of the retrofit investment for utility-sponsored or low-income weatherization programs. Average space heat savings are 36.3 million Btu (MBtu). The 49 data points represent results from over 50,000 homes. The sloping reference lines show the minimum energy savings that must be achieved, for each level of investment, if the retrofit is to be cost-effective compared to national average residential prices for fuel and electricity. The future stream of energy purchases for 15 years, assuming constant energy prices (in 1983 $), is converted to a single present-value, using a 7% real discount rate, in order to compare it with the "one-time" conservation investment. Roughly 75% of the data points lie above their respective reference line. Electricity is measured in resource units of 11,500 Btu per kWh.

sample (6289 homes). Prior to the mid-1970's, energy-efficient design of homes was a low priority in the Pacific Northwest as the region relied on cheap hydroelectric power. Most homes were uninsulated and "leaky"; thus, structural retrofitting (in addition to changes in occupant behavior spurred by dramatic increases in the price of electricity) contributed to substantial reductions in electricity consumption.

The CSA/NBS Optimal Weatherization Demonstration Program (shown as open circles in Fig. 2) achieved average space heating energy savings of 31% in the 12 cities. Analysis of individual house data reveals that the 69 homes that received only architectural options (retrofits designed to reduce building shell conduction and infiltration heat loss) saved an average of 23 MBtu per year for an average cost of $1650. Seventy-three homes that installed architectural plus mechanical options (retrofits applied to the heating system or hot water system) reduced their annual consumption by an average of 62 MBtu at an average cost of $2400. Hence, for these homes, heating system retrofits installed in conjunction with "shell" retrofits were roughly 2-3 times more cost-effective than shell measures alone.

Fig. 3 illustrates annual resource energy savings for space heating compared with the contractor cost of the retrofit for 30 data points from research studies (representing results from 430 homes in Table 5). The average first-cost ranges from $400 spent in homes that participated in "house-doctor" experiments to $16,400 invested in a south-facing passive wall retrofit in a Butte, Montana building. Average space heat savings are 35 MBtu for research studies but the data are widely scattered. Seventy-two percent of the gas-heat data points lie on or above the $0.60/Therm ($6.00/MBtu) reference line. There are only three electric space heat retrofits.

Fig. 4 shows annual resource energy savings as a function of total cost for multi-family apartment buildings. Energy savings and retrofit costs for each building are divided by the number of apartment units in that building. In contrast to the previous two Figures, retrofit costs include the first-cost plus the present value of the estimated annual maintenance cost. With two exceptions, each data point represents one

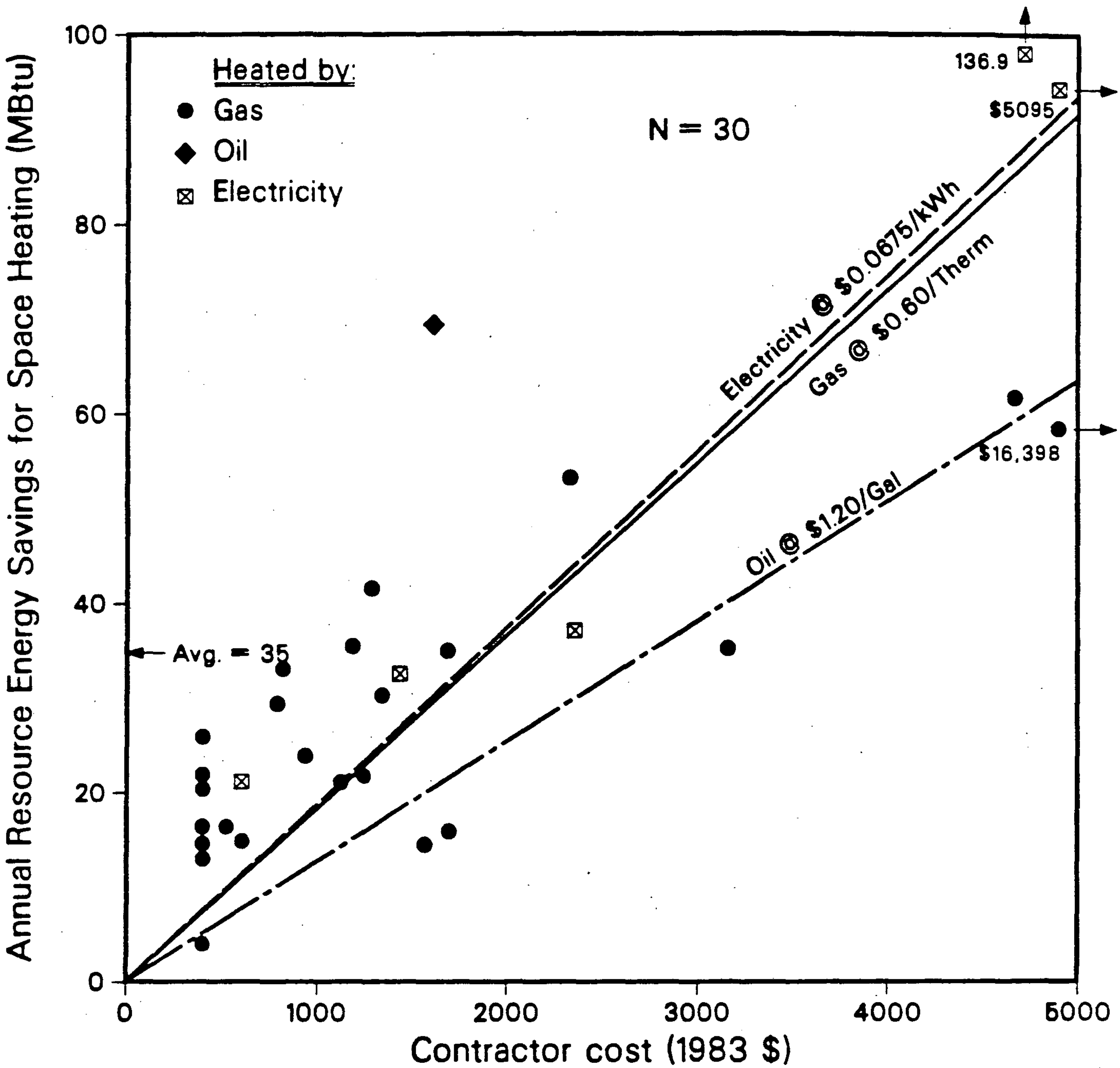

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Fig. 3. Annual space heat savings as a function of the contractor cost of the retrofit are shown for 30 research studies, representing data from 430 homes. Mean annual space heat savings are 35 MBtu but there is wide variation in savings at any given investment level. Reference lines for conservation cost-effectiveness are defined as in Fig. 2. Electricity is measured in resource units of 11,500 Btu per kWh.

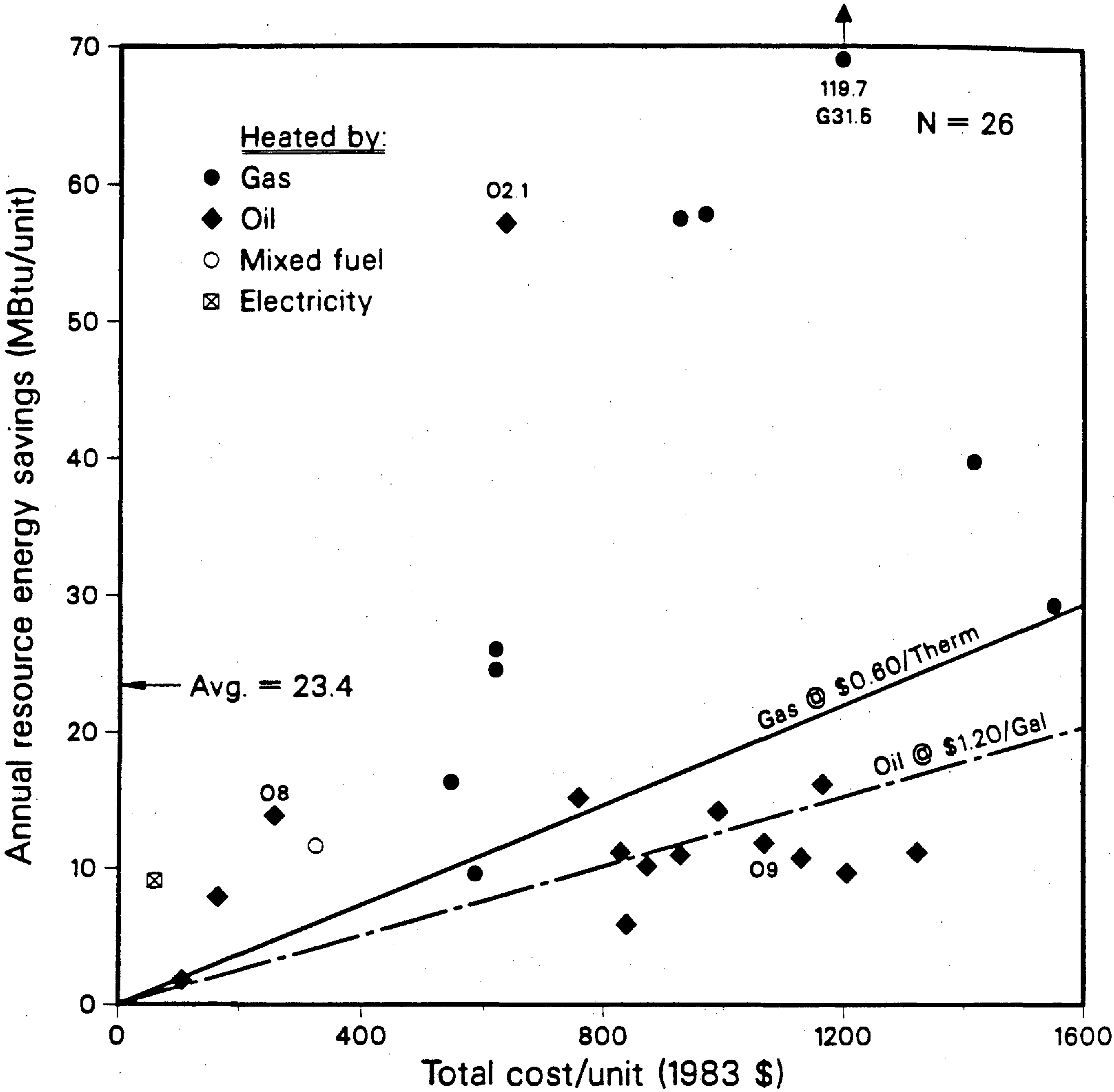

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Fig. 4. Annual resource energy savings are compared to the total cost of the retrofit investment in 26 multi-unit buildings. The buildings range in size from 5 to 1790 units with 68% of the buildings larger than 50 units. Mean annual savings are 23.4 MBtu per apartment unit. In most cases, the savings apply to space heat only, except for 5 buildings where the retrofit addressed both space heat and domestic hot water usage. In those 5 cases, we plot the combined savings. Total cost includes the first-cost for the retrofit plus the present value of annual estimated additional operations and maintenance cost (assuming a 7% real discount rate over the estimated lifetime of each measure). Reference lines for conservation cost-effectiveness are defined as in Fig. 2. Electricity is measured in resource units of 11,500 Btu per kWh.

apartment building. Annual space heat energy consumption in four buildings (site label 08) operated by the New York City Public Housing Authority (NYCHA) was reduced by 13.9 MBtu after the installation of thermostatic radiator valves, at an average total cost of $260 per apartment unit. Overall results from a window retrofit project at nine New York City locations are shown in data point 09. Using Department of Housing and Urban Development (HUD) Modernization funds, NYCHA spent approximately $13 million to install double-glazed thermal-break aluminum windows in nine buildings constructed prior to the mid-1950's (roughly $1070 per apartment unit). Annual space heat energy consumption declined by 12 MBtu per apartment in the post-retrofit period. Pre-retrofit consumption levels were already quite low in these buildings as a result of NYCHA's on-going energy conservation efforts. The relative energy-efficiency of these buildings compared to other multi-family retrofit projects in the data base partially explains the low ratio of energy savings to total cost.

Several retrofit strategies employed in multi-family buildings were very successful in reducing energy consumption. For example, the installation of a micro-computer-based boiler control system in Page Homes (data point 02.1), a 159-unit public housing complex in Trenton, New Jersey, was particularly effective. The system consists of remote temperature sensors located in selected apartments on each floor of each building and at one outdoor location. The sensors transmit perodic readings to the computer. Using this information, the computer controls heating system pumps and boilers to maintain comfortable temperatures in each apartment. The apartment temperatures were lowered from a pre-retrofit average of 82 ^{o}F to 75 ^{o}F during the day and 73 ^{o}F at night. Annual energy consumption was 129 MBtu per apartment (approximately 930 gallons of fuel oil per unit) prior to the retrofit. Consumption declined by 44 percent during the post-retrofit heating season, yielding annual savings of approximately $75,000. The installation cost was $65,000, giving a simple payback time of approximately one year. One factor contributing to the substantial energy savings at Page Homes is its relative energy-inefficiency compared to the U.S. multi-family housing stock. Page Homes had a pre-retrofit heating factor of 23.6 Btu/ft^2-DD_F, far higher than the U.S. average of 15.6-17.3 Btu/ft^2-DD_F

for gas-heated multi-family buildings with similar heated floor area. Because of the absence of actual fuel bills, RECS data on consumption in oil-heated multi-family buildings is almost entirely imputed; and hence is not considered reliable.[22,23] This successful retrofit suggests that substantial savings may be possible in some large multi-family buildings by installing improved heating control systems to reduce over-heating, even without changes to the building shell.

Substantial savings were also obtained in eight cooperatively- owned multi-family buildings in Chicago (all gas-heated data points). Building shell measures (attic and wall insulation and storm windows) were installed in cases where it was structurally feasible but most of the energy savings were attributed to various heating system retrofits. De-rating burners in heating systems that were oversized following weatherization, installing temperature-sensing burner controls, and balancing radiators and steam lines were among the heating system retrofits. In one building (Site Label G31.5), annual savings for space heating were 119.7 MBtu per unit, a 53 percent reduction from pre-retrofit levels, for an investment of $1200 per apartment. Prior to retrofit, the building was extremely energy-inefficient, as indicated by its heating factor of 29 Btu/ft^2-DD. Results from these eight apartment buildings suggest that heating system improvements in multi-family buildings may produce substantial energy savings at reasonable investment levels. Yet, there is a definite need for more data from different climatic regions, additional building and/or heating types, and varying combinations of who pays the heating bill and who controls the heating system energy use to determine if these results can be widely replicated.

4.2. Range of Savings among Households

In the previous section, we found substantial variation in average energy savings between different retrofit projects at similar investment levels in each major category. Does this trend continue if the data are disaggregated and the range of savings among households that installed similar measures is examined?

Range of Fuel and Electricity Savings Among Households

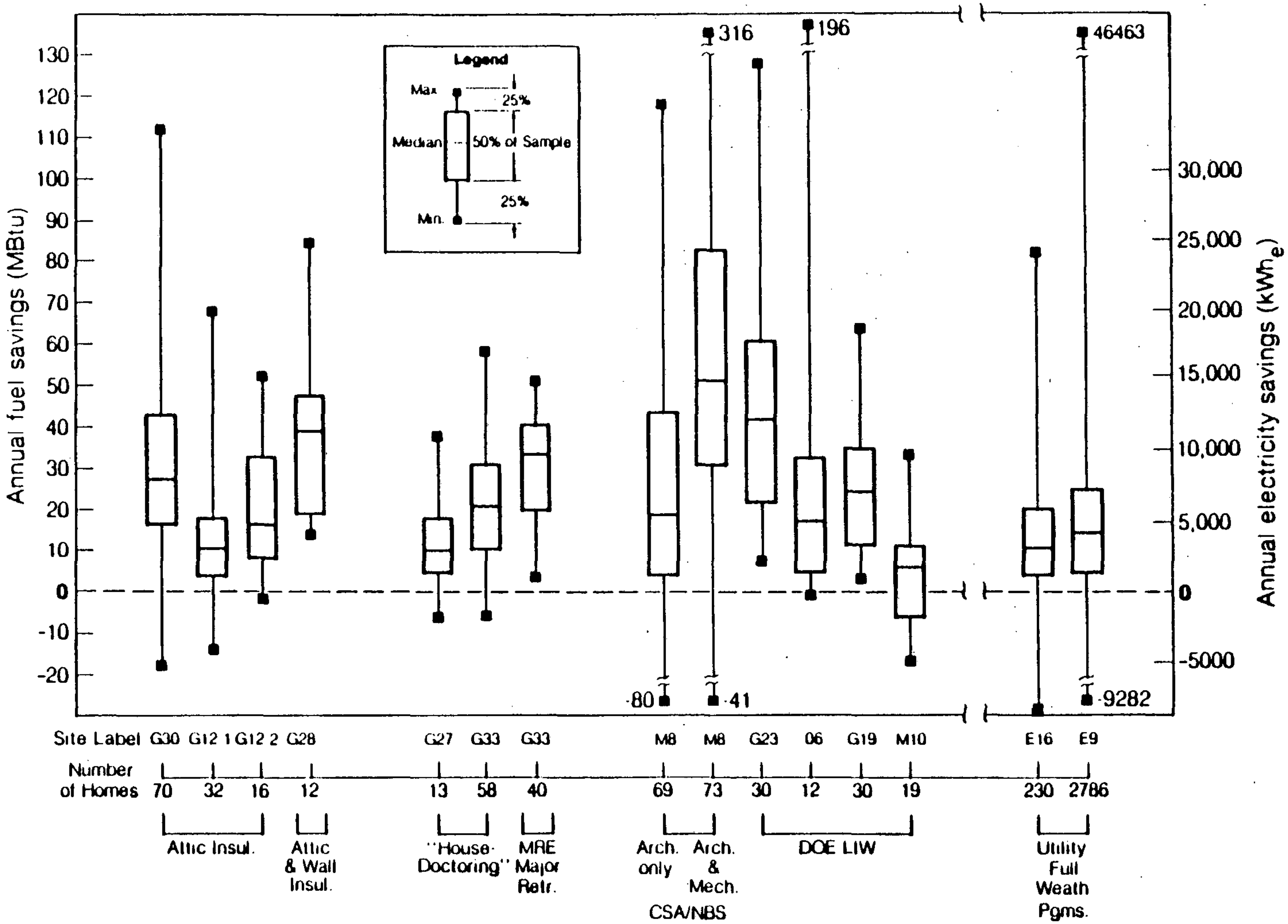

Fig. 5. Range in annual fuel and electricity savings among households. Note the large variance in energy savings even for households that installed similar measures. For example, maximum energy savings are 3.2 to 6.7 times greater than the median value among homes in the same location that installed attic insulation. The wide variation in savings among participants in utility or low-income weatherization programs is less surprising. In these programs, residents have the option of installing one or more measures; hence, there is wide variation in investment levels as well as varying results for those installing similar measures. In most cases, the savings apply to space heat only, except for the electric utility programs and the "house-doctor" experiments where consumption includes all end uses of the space heating fuel. Electricity savings are expressed in terms of site energy (3413 Btu per kWh).

The range in fuel and electricity savings among households that either installed the same conservation measure or participated in the same retrofit program is shown in Fig. 5. The site label, number of homes in the project, and description of the installed measures or type of program are included below each distribution.

Note the large variance in energy savings even for households that installed similar measures. For houses where only attic insulation was installed, maximum energy savings are 3.2 to 6.7 times greater than the median value among homes in the same location. Maximum savings are 3 to 4 times greater than the median in homes that received the "house-doctor" infiltration-reduction treatment. For a set of measures installed in either utility-sponsored conservation programs (E9 or E16) or in retrofit projects aimed at low-income households (M8), maximum savings are 6 to 11 times greater than the median. The wider variation in savings among participants in utility or low-income weatherization programs is not unexpected. In these programs, residents have the option of installing one or more measures; hence, there is substantial variation in investment levels as well as varying results for those installing similar measures.

It is instructive to consider results from one project (Site Label G12.1) in some detail, as it is indicative of the variation in savings that occurs even among households that install the same measure. Pacific Gas & Electric analyzed annual space heat savings for 32 single-family homes in Bakersfield, Ca., where contractors installed R-19 attic insulation in previously uninsulated attics. Median savings were 10.2 MBtu, but 50 percent of the homes saved less 4 MBtu or more than 17.8 MBtu. One house achieved savings of 68 MBtu (the maximum) while four households experienced increases in space heating usage in the heating season following the retrofit. Maximum savings are 6.7 times greater than median savings. How do we explain the wide variation in savings? Possibly, the variation is attributable to the area's mild climate (i.e., the long-term normal heating degree-day value is 2185); the relative effects of occupant behavior, particularly indoor temperature preferences, become more pronounced in milder climates.[24] Though our sample is quite limited, similar variation between maximum and median savings are found in more severe climates (e.g., Site Label G30). The large range in savings indicates the need for more detailed and accurate information on key variables that affect energy consumption.

It would be useful to know conditioned floor area, temperature settings, changes in occupant behavior, and use of secondary heating sources. This is expensive information to obtain, yet it would allow conservation researchers to better assess the effectiveness of retrofit measures and programs.

In 6 percent of the households (30 of 474 homes), weather-adjusted energy consumption actually increased after retrofit.* Results were most variable in low-income homes. For example, 13 of 69 homes in the CSA/NBS Demonstration Project (Site Label M8) that installed only architectural retrofits failed to save energy. A greater percentage of these homes were also located in mild climates compared to homes in that project that installed both architectural and mechanical options. In that group, post-retrofit consumption increased in only 3 of 73 homes.

Comparison of the ratio of maximum to median savings tends to focus attention on extreme cases. The coefficient of variation is another indicator that measures the 'spread' in a series of values, yet is more sensitive to dispersion around the mean. The coefficient of variation (CV), a nondimensional value, is the ratio of the standard deviation to the sample mean. A high CV means energy savings are more uncertain; a low CV means that there was less variability in savings in the sample. A CV of one indicates that the standard deviation is equal to the mean.

Table 7 lists the coefficient of variation and the ratio of maximum to median savings for those retrofit projects that either calculated the standard deviation of energy savings or for which we have individual house data. Homes that received conventional retrofits (attic and wall insulation plus storm windows) in addition to "house-doctoring" in Princeton's Modular Retrofit Experiment had the lowest CV (0.39). The

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* Individual house data for two utility programs (Site Label E16 and E9) was not available; hence this number represents results from all fuel-heated homes (gas, oil, mixed).

TABLE 7

Range of Energy Savings - Coefficient of Variation

SITE LABEL	NUMBER OF HOMES	SPONSOR	END USE	ANNUAL ENERGY SAVINGS (MBTU)	COEFF. OF VAR.	RATIO OF MAX. TO MEDIAN SAVINGS[c]
		INDIVIDUAL MEASURE OR SET OF MEASURES[a]				
G 12.1	33	PACIFIC GAS & ELEC.	H	14.9 ± 16	1.07	6.7
G 12.2	16	PACIFIC GAS & ELEC.	H	19.6 ± 17	0.87	3.2
G 27.1	13	PG&E/LBL-HOUSE DR.	F	16.4 ± 13	0.79	3.8
G 28	12	UNIV. OF ILLINOIS	F	41.6 ± 23	0.55	2.2
G 30	71	MICH. CONSOL. GAS CO	H	33.9 ± 22	0.65	4.0
G 33.1	40	MRE/MAJOR RETR.	F	31.0 ± 12	0.39	1.5
G 33.2	58	MRE/HOUSE-DOCTOR	F	22.0 ± 15	0.66	2.9
M 13.1	130	SWEDEN - WALL INS.	W	18.5 ± 20	1.07	
M 13.2	106	SWEDEN - ATTIC INS.	W	16.2 ± 20	1.25	
M 13.3	105	SWEDEN - WALL + ATTIC	W	17.2 ± 24	1.40	
M 13.4	140	SWEDEN - INS. + TRV	W	24.2 ± 25	1.01	
M 13.5	111	SWEDEN - WINDOWS	W	11.5 ± 17	1.50	
M 13.6	17	SWEDEN - WINDOWS + INS	W	14.1 ± 17	1.22	
M 13.7	32	SWEDEN - HEATING SYS.	W	21.1 ± 22	1.04	
M 14.1	30	SWEDEN - MULTI-UNIT	W	9.0 ± 11	1.25	
M 14.2	25	SWEDEN - MULTI-UNIT	W	6.6 ± 4	0.60	
M 14.7	63	SWEDEN - MULTI-UNIT	W	5.9 ± 8	1.32	
		PROGRAM RESULTS FOR MEASURES INSTALLED WITH VARYING FREQUENCY[b]				
M 8.1	142	CSA/NBS-12 CITY AVG	H	44.8 ± 49	1.10	
M 8.1	69	CSA/NBS ARCH. ONLY	H	22.6 ± 36	1.59	6.5
M 8.1	73	CSA/NBS MECH.+ ARCH	H	61.9 ± 53	0.85	6.2
G 1	11	DOE/LOW-INC. WEATH.	H	20.8 ± 13	0.60	
G 23	30	DOE/LOW-INC. WEATH.	H	46.4 ± 29	0.63	3.1
M 10.1	59	DOE/LOW-INC. WEATH.	H	11.3 ± 12	1.08	
M 10.2B	37	DOE/LOW-INC. WEATH.	H	-3.2 ± 11	3.34	
M 10.3	19	DOE/LOW-INC. WEATH.	H	6.9 ± 12	1.70	5.6
O 6	13	DOE/LOW-INC. WEATH.	H	43.5 ± 52	1.20	11.4
				(kWh)		
E 2	546	TVA	H	2211.0 ± 3870	1.75	
E 11.1	195	BPA/ORNL	F	4400.0 ± 4135	0.94	
E 11.2A	54	BPA/ORNL	F	2200.0 ± 3845	1.75	
E 11.3B	200	BPA/ORNL	F	1100.0 ± 3900	3.55	
E 16.1	208	PORTLAND GEN ELEC	F	4243.0 ± 4188	0.99	7.2
E 16.2A	105	PORTLAND GEN ELEC	F	2899.0 ± 5599	1.93	
E 16.3B	91	PORTLAND GEN ELEC	F	1763.0 ± 3275	1.86	
E 17.1	101	IDAHO POWER CO.	F	2180.0 ± 5090	2.33	

Notes to Table 7

[a] Indicates that an individual measure or set of measures was installed in the homes.

[b] Indicates that a set of measures was installed with varying frequency among a sample of participating homes.

[c] This ratio was calculated from the distributions presented in Fig. 5.

Energy Savings : The annual energy savings come from several residential end uses as indicated in the column End Use. Space heating consumption only is indicated by an 'H'; space heating plus hot water is given by 'W'; and 'F' indicates that all end uses of the space heating fuel are included (i.e., electric appliances in addition to electric space heating).

Coefficient of Variation : This dimensionless value is obtained by dividing the standard deviation of all houses in a particular retrofit project by the sample mean.

difference in CV (0.39 compared to 0.66) between the two treatment groups in that experiment reflects the greater variability in energy savings associated with the "house-doctor" treatment. The coefficient of variation ranges from 0.39 to 1.07 for U.S. retrofit projects in which similar measures were installed. One should be cautious in comparing results from the Swedish retrofit program directly with U.S. retrofit efforts. These results are included primarily for informational purposes. The Swedish project is particularly interesting because participating homes agreed not to install additional conservation measures during the time of the experiment. It is tempting to use CV values as an indicator of variability in energy savings associated with a particular retrofit measure or set of measures. Unfortunately, factors such as conditioned living area, different investment levels, and indoor temperature preferences also contribute to variation in retrofit outcome. For example, the installation of R-19 attic insulation in two previously uninsulated homes should produce variable energy savings if one house has twice the conditioned floor area as the second. Limitations in the data (information on living area or indoor thermostat settings were unavailable) lead us to treat the results with caution.

As expected, values for CV are far higher for projects in which a homeowner has the option of installing one or more retrofit measures. The CV ranges from 0.60 to 2.33. Note that homes that received an energy audit (but retrofit activity is unknown) or control groups had the highest values for the coefficient of variation (indicated by the suffix -A or -B at the end of the site label). This result suggests that homeowner response to an utility audit program is extremely variable. Some residents may initiate several conservation retrofits and change their energy usage patterns while other homeowners either do not alter their behavior, do not invest in structural retrofits, or their actions may not be particularly effective in reducing consumption.

4.3. Cost-Effectiveness of Retrofit Measures

We have observed significant declines in energy consumption in retrofitted homes. Annual average resource energy savings range from 23 to 38 MBtu in the four major categories (research studies, utility-sponsored programs, low-income homes, multi-family dwellings). In almost all instances, declines in consumption can not definitely be attributed to conservation retrofits. The effect of other factors (changes in thermostat setting, number of occupants, zoning, additional efficiency measures/practices) which influence energy use, and mask the impact of retrofits, have not been accounted for explicitly. Wide variation in energy savings are also common.

The prospects for significant retrofit investment in existing residential buildings hinges ultimately on the economic attractiveness of these investments to various actors. In this section, the cost-effectiveness of conservation measures is analyzed. Mean values for energy savings and retrofit cost are used in the economic calculations; hence, economic indicators reflect the experience of the 'typical' homeowner in each retrofit project.

Simple Payback time. Homes in the nineteen conservation programs sponsored by utilities (Fig. 6) had a median simple payback time (SPT) of 5.7 years with a mean of 10.3 years. Every project is weighted equally in the calculation of mean and median values. Note that within each project sample size varies. Four programs had average payback periods greater than 15 years. At the time of retrofit (1978-1979), residential customers of these utilities faced very low electricity prices ($0.01 to 0.02/kWh). This phenomenon partially accounts for the high average simple payback times in these programs. In recent years, their residential customers have experienced dramatic rate increases. Calculation of SPT at today's electricity prices would produce significantly lower payback times. The distribution of SPT for low-income weatherization projects is relatively flat in contrast to the bi-modal distribution found for utility-sponsored programs. The median value for homes in 27 low-income projects is 9.2 years with a mean of 11.4 years (Fig. 7). The 69 low-income homes that had only architectural retrofits

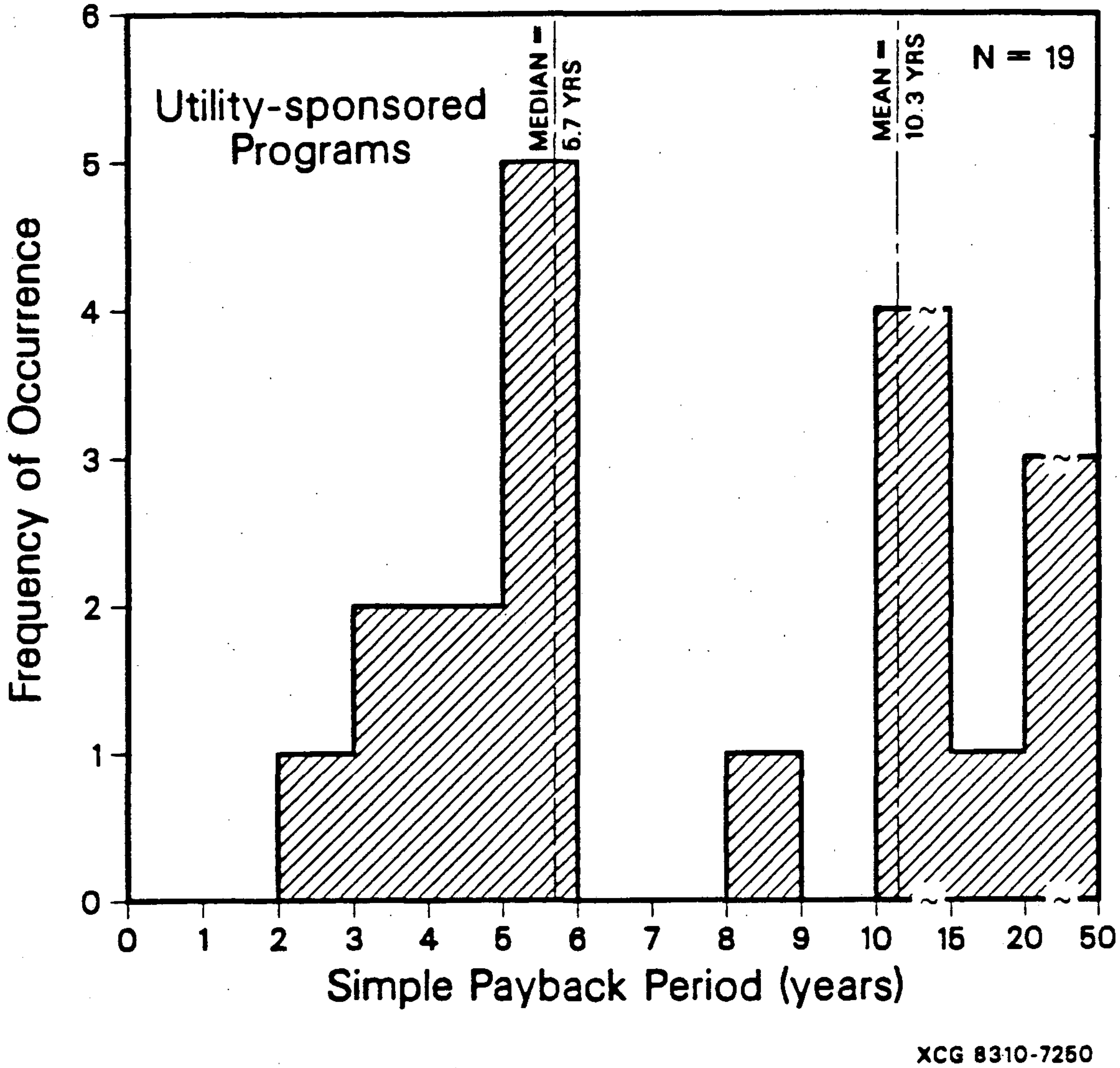

Fig. 6. The simple payback period for 19 utility-sponsored conservation programs is shown. The median payback time is 5.7 years with a mean value of 10.3 years. Note that 13 of the 19 programs were sponsored by utilities located in the Pacific Northwest or California, giving a rather distinct regional bias to the results.

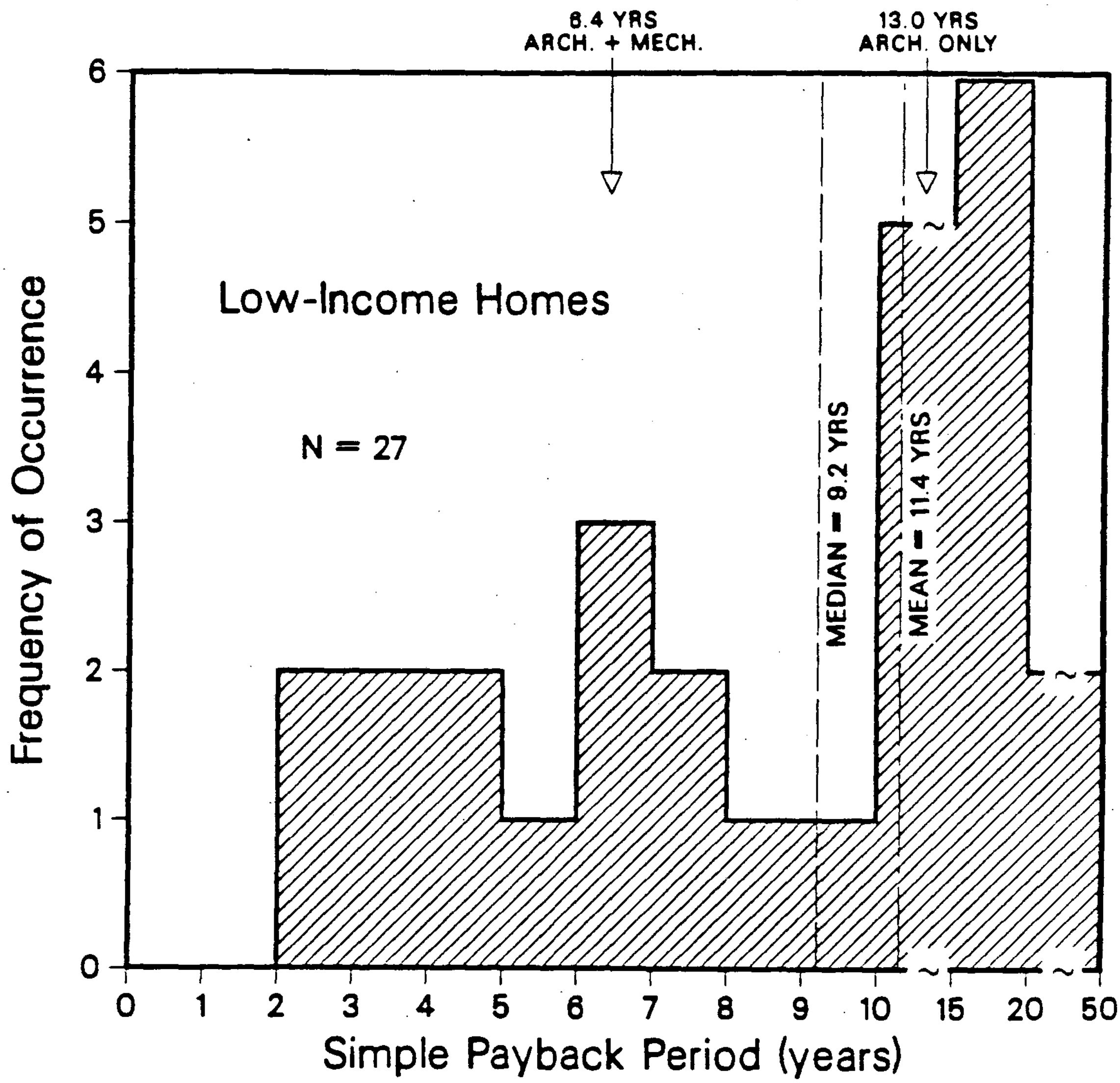

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Fig. 7. Histogram of the distribution of simple payback periods for 27 low-income weatherization projects, representing aggregate results from approximately 850 homes. The median payback time is 9.2 years with a mean of 11.4 years. Note that 73 homes that received architectural and mechanical system retrofits in the CSA/NBS Demonstration Project had a median payback time of only 6.4 years.

in the CSA/NBS Demonstration Project had a median payback time of 13 years; far longer than the median of 6.4 years for 73 homes that installed both architectural and mechanical system retrofits.

Simple payback times for 28 multi-family buildings are shown in Table 8. In many cases, the inclusion of maintenance cost dramatically alters the economic attractiveness of the retrofit compared to the conventional usage of SPT which only utilizes the initial investment. For example, three buildings retrofitted by Scallop Thermal Management (Site label 03, 04, and 05) have payback periods of between 1 to 2 years. Yet, when Scallop's estimate of operations and maintenance expenditures are included, the payback time increases dramatically, ranging from 6.7 to 19 years. Conversely, the installation of double-glazed aluminum windows in the NYC Housing Authority buildings (Site label 09.1 to 09.9) resulted in a <u>reduction</u> in maintenance costs which, if considered, lowers the payback time by roughly four years. In cases where the initial investment accounts for almost the entire cost of the retrofit, SPT can give a first-order approximation of cost-effectiveness, but it is a distorted and often misleading indicator for retrofits in which operations and maintenance costs are a significant factor. Simple payback time is biased towards investments with low first-cost, irrespective of other recurring expenses, and against retrofits that reduce annual operating costs.

<u>Cost of conserved energy</u>. The relationship between the contractor cost of the retrofit and the cost of conserved energy (CCE) for utility-sponsored and low-income weatherization programs is examined in Fig. 8. The horizontal lines represent average U.S. residential prices for various fuels against which conservation retrofits are compared. All fourteen conservation programs directed at single-family electric space heat customers save energy at a price lower than $0.0675/kWh, the national average price for electricity. Seventy-four percent (14 of 19) of the gas-heat projects have a cost of conserved energy below the gas price of $0.60/Therm ($6.00/MBtu).

TABLE 8

Effect of maintenance costs on simple payback time in multi-family buildings

LABEL	NUMBER OF UNITS	SPONSOR	FIRST COST ($)	MAINT. COST ($)	SIMPLE PAYBACK TIME (YRS)	SPT[a] (WITH MAINT. COSTS) (YRS)
O 3	521	SCALLOP THERMAL MAN.	17	20	0.7	6.7
O 2.1	159	BUMBLEBEE/THA/HUD	410	25	0.9	1.2
O 5	60	SCALLOP THERMAL MAN.	40	100	0.9	16.5
E 12	159	NYCHA	75	-5	1.4	0.7
G 31.5	6	CT. NEIGHBOR. TECH.	784	35	1.4	1.9
O 4	752	SCALLOP THERMAL MAN.	10	13	1.9	19.0
G 31.2	22	CT. NEIGHBOR. TECH.	541	35	2.0	3.0
O 8.1	42	NYC HOUSING AUTH	141	10	2.0	3.0
G 31.1	19	CT. NEIGHBOR. TECH.	580	35	2.1	3.1
G 31.8	13	CT. NEIGHBOR. TECH.	269	35	2.1	4.4
G 31.6	6	CT. NEIGHBOR. TECH.	269	35	2.3	4.7
G 32	530	BUMBLEBEE/NHA/HUD	260	40	2.8	5.7
O 8.4	81	NYC HOUSING AUTH	128	10	3.5	5.5
M 15	503	ST.PAUL HOUSING AUTH	290	0	4.5	4.5
O 8.2	98	NYC HOUSING AUTH	119	10	4.9	7.9
G 31.7	4	CT. NEIGHBOR. TECH.	980	35	5.1	6.6
G 31.4	7	CT. NEIGHBOR. TECH.	239	35	5.2	11.3
G 31.3	25	CT. NEIGHBOR. TECH.	1100	35	7.8	9.8
O 8.3	56	NYC HOUSING AUTH	93	10	11.2	19.6
O 9.3	1791	NYC HOUSING AUTH.	1230	-30	11.9	8.8
O 9.6	1084	NYC HOUSING AUTH.	1110	-30	12.3	8.8
O 9.8	786	NYC HOUSING AUTH.	1040	-30	14.6	10.1
O 9.1	1444	NYC HOUSING AUTH.	1056	-30	15.1	10.5
O 9.7	1246	NYC HOUSING AUTH.	1010	-30	15.5	10.7
O 9.4	1310	NYC HOUSING AUTH.	1360	-30	19.1	14.6
O 9.5	1229	NYC HOUSING AUTH.	1370	-30	19.9	15.3
O 9.2	1338	NYC HOUSING AUTH.	1325	-30	21.4	16.3
O 9.9	733	NYC HOUSING AUTH.	1095	-30	29.1	20.7

[a] In this column, total investment, the first-cost plus the present value of annual maintenance costs is included in the calculation of payback time.

Notes to Table 8

Label : This is a project's identification number; each label represents one multi- family building. A decimal point after the first number (which is a counting index) indicates that more than one building was retrofitted at a particular site.

Number of Units : Indicates the number of apartment units in the building.

First Cost : Indicates the initial capital investment per apartment unit.

Maintenance Cost : Represents the present value of estimated annual operations and maintenance costs per apartment unit. In some instances, the retrofit results in a reduction in maintenance expenses.

The average CCE for the 47 data points is $5.00/MBtu but the nineteen utility-sponsored programs have a mean value of only $2.69/MBtu. In contrast, the 27 low-income weatherization projects have a mean CCE of $6.71/MBtu with a median value of $4.65/MBtu. There are several important differences between these two data groups that may account for the varying levels of cost-effectiveness. As noted earlier, in our sample, most conservation programs sponsored by utilities reached middle-income, electric space heat customers who lived in the Pacific Northwest.* In contrast, low-income homes in the database are geographically dispersed throughout the U.S. and residents use either natural gas or fuel oil as the primary space heating fuels. In low-income homes, a portion of the total investment (i.e. ranging from 0 to 25% of the total) was often spent for energy-related structural repairs (e.g. broken window glass). This additional expense raises the cost of conserved energy relative to middle-income homes. Several General Accounting Office reports found that poor workmanship and lack of quality control were important problems that adversely affected the DOE Weatherization Program during the first several years.[25] Most homes retrofitted in the DOE Low-Income Weatherization Program used "free" CETA labor. Only the cost of materials were reported and it is possible that the formula used to estimate equivalent contractor cost is biased. Systematic variations in the choice of retrofit options are another factor that account for the higher CCE values found in low-income projects. For example, caulking and weatherstripping were installed in almost all low-income homes; these are measures whose energy savings are likely to be small and whose effectiveness is greatly impacted by the quality of workmanship.

The average cost of conserved energy for 30 research studies is $5.32/MBtu with a median value of $4.26/MBtu (Fig. 9). Eighteen of 24 gas-heat data points have a CCE lower than $6.00/MBtu, the average price for gas. The cluster of gas-heat data points (from Princeton's Modular Retrofit Experiment) with cost of conserved energy values around $1-2/MBtu and a retrofit cost of $400 illustrate the cost-effectiveness of

* Four of nineteen programs were targeted specifically at low-income customers.

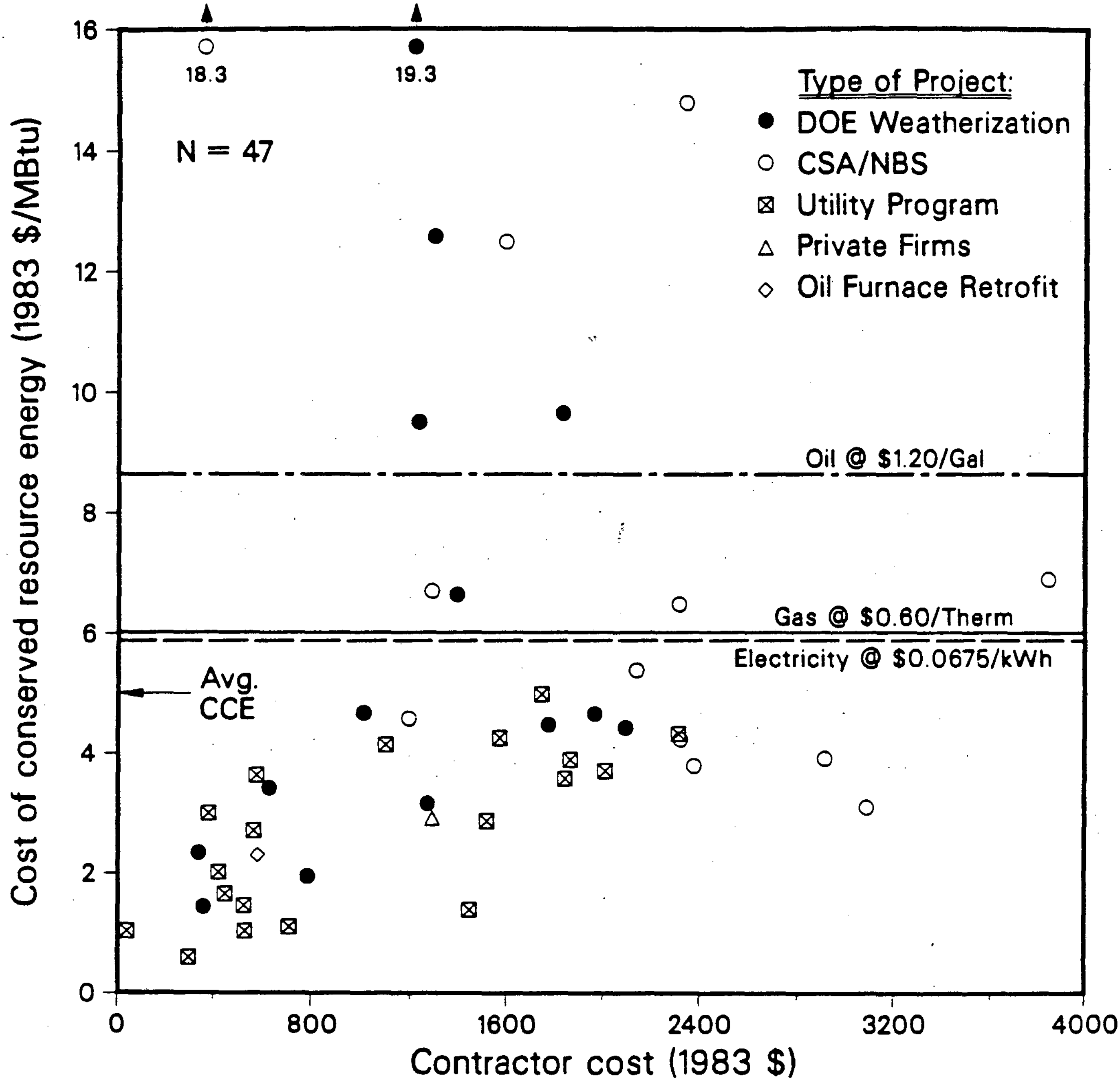

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Fig. 8. The scatter plot shows the relationship between the cost of conserved energy (CCE) and the contractor cost for the measures for 47 utility-sponsored or low-income weatherization programs. The cost of conserved energy equals the ratio, total investment over annual savings, multiplied by the capital recovery factor (assuming a 7% real discount rate and an estimated useful lifetime for each measure or set of measures). The horizontal lines represent prices of purchased energy against which conservation retrofits should be compared. Seventy-seven percent of the data points have cost of conserved energy values less than their respective fuel price. The 47 data sources have an average CCE of $5.00/MBtu; but, for the 19 utility programs, the average CCE is only $2.70/MBtu.

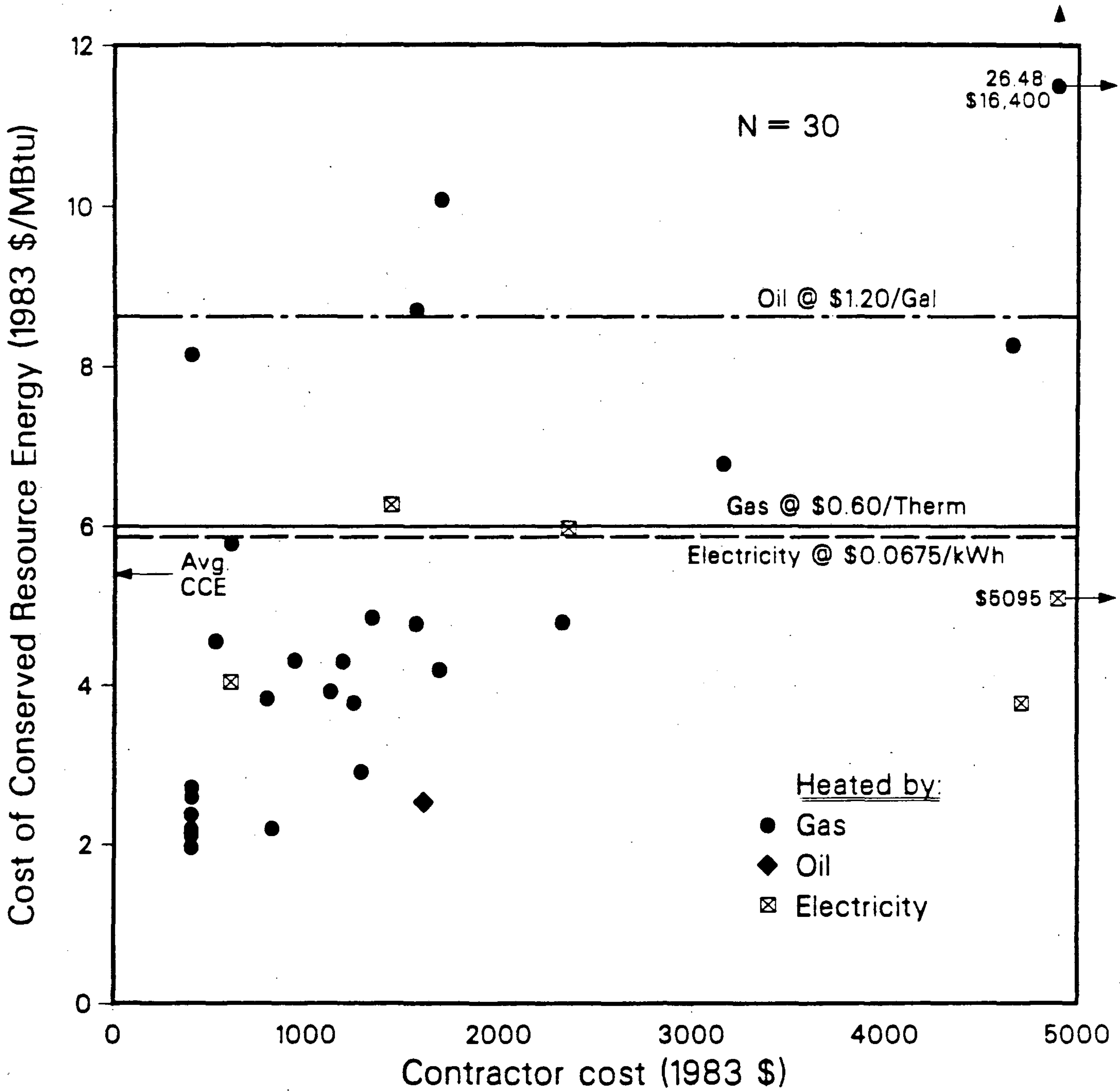

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Fig. 9. The cost of conserved energy as a function of the contractor cost of the retrofit is shown for 30 research studies. Reference price lines are defined as in Fig. 8. The mean CCE is \$5.32/MBtu while the median value is \$4.26/MBtu. Eighteen of 24 gas-heat data points lie below the reference price for gas of \$0.60/Therm. The cluster of gas-heat points with a cost of conserved energy of only \$1-2/MBtu at a first-cost of \$400 represents "house-doctor" treatment results from 6 of the 7 modules in Princeton University's Modular Retrofit Experiment.

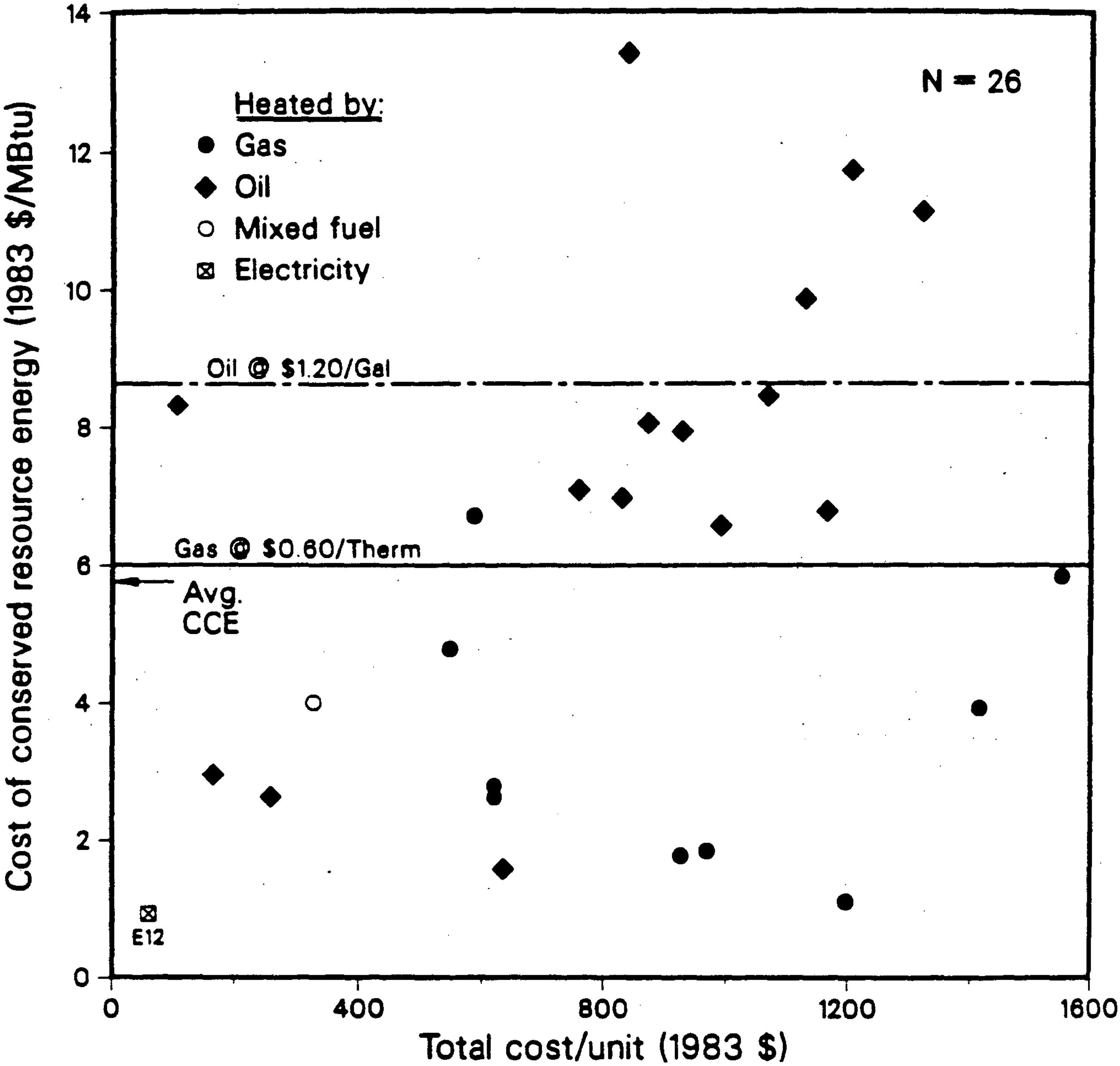

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Fig. 10. The retrofit measures' cost of conserved energy (CCE) is plotted against total cost per unit for 26 multi-unit buildings. Total cost includes installed first- cost in addition to the present value of estimated operation and maintenance expenses. The average CCE for the 26 buildings is $5.70/MBtu. Of the ten gas-heat buildings, nine show a cost of conserved energy of less than $0.60/therm, the approximate 1983 U.S. average residential price for natural gas.

"house-doctoring". This complex retrofit was less cost-effective with CCE's of $4-5/MBtu in research projects conducted by the Bonneville Power Administration and Lawrence Berkeley Laboratory (E8.1 and G27.1). In these projects, researchers concluded that in mild climates it was particularly important to focus "house-doctoring" efforts on homes with high infiltration rates.

Eleven of 15 oil-heated multi-family data points lie below the fuel oil price of $1.20/Gal ($8.63/MBtu) while 8 of 9 gas-heat buildings have a cost of conserved energy less than the average gas price (Fig. 10). Cost-effectiveness as measured by CCE was highly variable at a given investment level. For example, retrofits that cost around $1000 per apartment had CCE values ranging from $2 to 13 per MBtu. A lighting retrofit project (E12) initiated by New York City Housing Authority was very cost-effective. Incandescent hall and stairwell lights were replaced with fluorescent fixtures in a 159-unit building. Post-retrofit electricity consumption declined by 62 percent and the retrofit has a cost of conserved electricity around $0.01/kWh.

4.4. Sensitivity of Economic Indicators

In this section, we discuss the sensitivity of two economic indicators, net present value and internal rate of return, to changes in the lifetime of retrofit measures, discount and energy escalation rates, and revisions in the federal tax laws. The analysis focuses on one major data group, homes that participated in utility-sponsored conservation programs. A base economic case is developed along with several alternate scenarios that allows us to assess the relative attractiveness of investments in conservation under varying conditions.

The base case reflects probable economic conditions and assumes a real discount rate of 7 percent, an energy escalation rate of 4 percent, and includes the 15% federal tax credit. The expected lifetimes for retrofit measures in each program (in most cases, 20 years was used) are indicated in Table 9.

Table 9

Economic Indicators for Utility-sponsored Programs - Basecase

LABEL	SPONSOR	RETR. LIFE TIME	CCE ($/MBTU)	NPV ($)	IRR (%)
G 11	NORTHERN STATES PWR.	20	2.99	354.7	17.3
G 12.1	PACIFIC GAS & ELEC.	20	3.63	1014.8	24.8
G 12.2	PACIFIC GAS & ELEC.	20	2.70	1500.0	32.5
G 13	PUBLIC SERVICE CO.	20	2.01	1527.7	40.7
G 30	MICH. CONSOL. GAS CO	20	1.45	1476.8	33.8
E 1.1	TVA	15	1.10	1762.1	37.5
E 1.2	TVA	20	0.59	1729.2	58.4
E 2	TVA	20	1.65	906.3	27.1
E 4.1	PACIFIC PWR & LIGHT	20	3.69	2012.2	17.8
E 5.1	SEATTLE CITY LIGHT	20	1.03	1124.5	28.0
E 6.1	PUGET POWER	20	1.38	2970.7	27.2
E 7.1	PORTLAND GEN ELEC	20	3.88	606.2	10.9
E 9.2	WASH. WATER POWER	20	2.86	37.7	7.3
E 11.1	BPA/ORNL	20	4.31	- 652.8	2.9
E 13.1	SEATTLE CITY LIGHT	20	4.97	- 547.0	2.3
E 14.1	SEATTLE CITY LIGHT	20	4.24	- 326.7	4.1
E 15.1	SEATTLE CITY LIGHT	10	1.03	54.6	33.6
E 16.1	PORTLAND GEN ELEC	20	3.56	784.4	12.0
E 17.1	IDAHO POWER CO.	20	4.13	210.7	9.4

Retrofit Lifetime : Expected lifetime for set of measures installed in homes

CCE : Cost of conserved energy in $/MBtu. Assumes a 7 percent real discount rate.

NPV & IRR : Net present value and internal rate of return under base economic case (7% real discount rate, 4% real energy price escalation rate, and 15% federal tax credit).

The cost of the retrofit includes only the first-cost.* Homes retrofitted in the nineteen utility-sponsored programs have a median net present value (NPV) of $1015 and the average NPV was negative in only three programs (Fig. 11). The average real rate of return ranges from 2.3 to 58 percent and it is higher than a 7 percent real discount rate in 84 percent of the programs. From a homeowner's perspective, these rates of return are attractive compared to alternative investment strategies.

The consistency of these economic indicators is tested in Fig. 12, a scatterplot of the net present value against the internal rate of return. The economic results in most cases are fairly consistent yet the outlying values illustrate some limitations of the net present value technique. For example, the installation of a hot water heater insulating blanket (data point E15.1) yields a very high rate of return (34%) but a low net present value (partially due to its shorter lifetime). Conversely, retrofit measures installed in homes that participated in Puget Power and Pacific Power & Light conservation programs (E6.1 and E4.1) had the highest NPV, but not necessarily the best rate of return (due to greater initial cost). NPV does not indicate the economic return on an investment dollar and can not distinguish between small and large investments that result in the same net dollar savings.

The average net present value for homes in utility-sponsored conservation programs under conditions specified in cases 1 through 4 is shown in Fig. 11. Case 1 reflects an economic situation characterized by a high real energy price escalation rate (8%) and a lower real discount rate (3%). An 8 percent energy price escalation rate, while high by historic standards, would represent a continuation of the trends of the last decade and is the American Gas Association's high estimate for price increases accompanying the de-regulation of natural gas. As expected, higher future energy prices make investments in conservation more attractive. The average NPV is now positive for homes in every

* Maintenance costs or salvage values were not included for several reasons. Limitations in the data made it difficult to estimate maintenance costs. Moreover, most programs implemented fairly similar measures and thus the inclusion of maintenance costs would not change the relative position of any program.

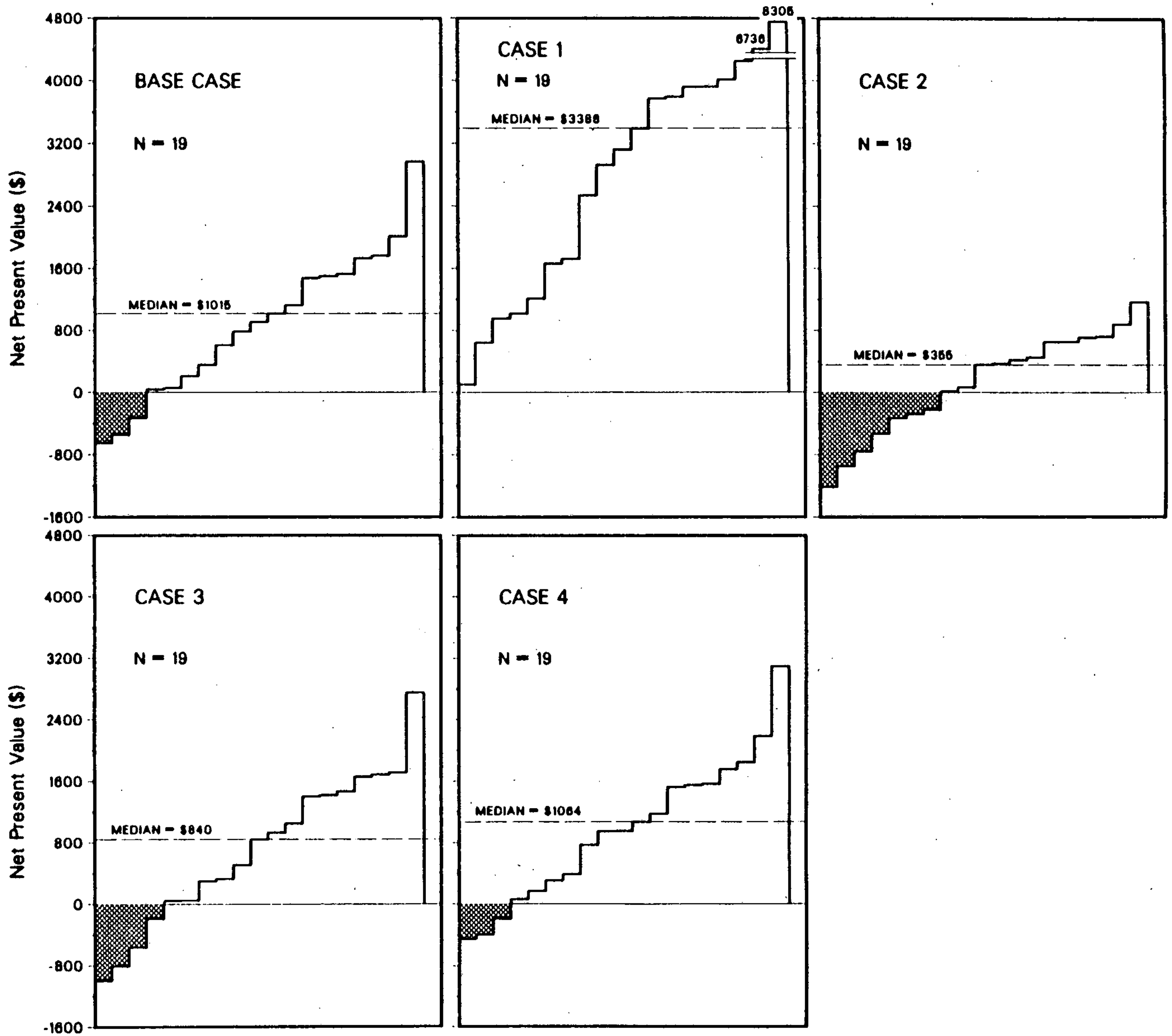

Fig. 11. The net present value of conservation investments for homes that participated in 19 utility-sponsored conservation programs are shown for a base economic case and four alternate scenarios. The base economic case assumes a 7% real discount rate, a 4% real energy price escalation rate, and includes the 15% federal tax credit. Case 1 assumes an 8% energy price escalation rate and a 3% real discount rate; Case 2 assumes that the expected lifetime is cut in half; Case 3 assesses the impact of elimination of the federal tax credit; and Case 4 examines the inclusion of a salvage value equivalent to one-third of the first-cost.

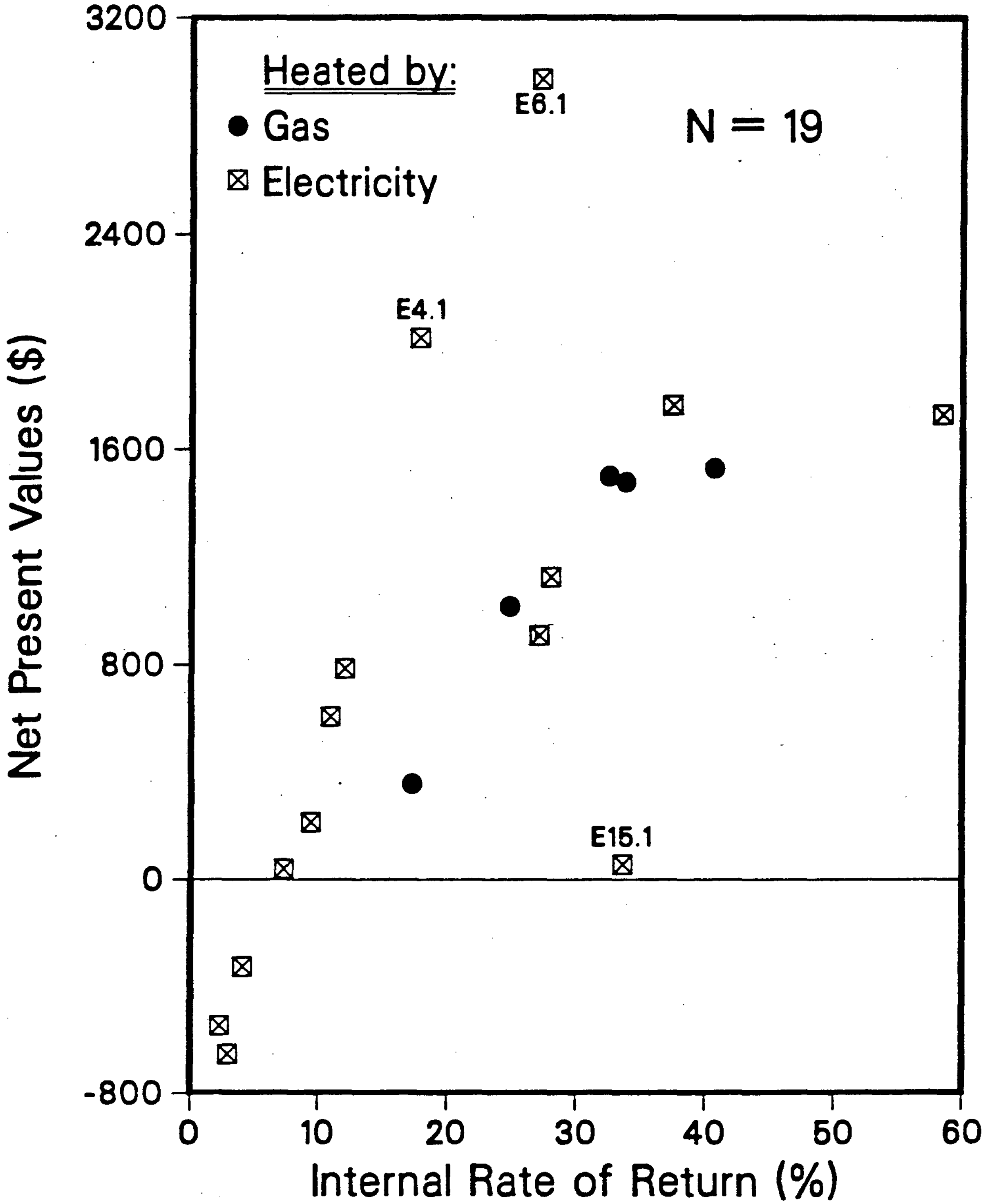

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Fig. 12. Net present value (NPV) is plotted against internal rate of return (IRR) for homes in 19 utility-sponsored conservation programs. Assumptions for NPV and IRR include a 4% real energy price escalation rate and the 15% federal tax credit while a 7% real discount rate is used in the NPV analysis.

program with a median value of $3388 for the entire group.

Case 2 examines the effect of lower than expected retrofit lifetime on the quality of conservation investments. In this case, a set of measures (attic and wall insulation, storm windows, and caulking) which, in the basecase, are assumed to have a lifetime of 20 years now provide energy savings for only 10 years. All other assumptions from the basecase are retained. The effect of reduced retrofit lifetime on the economics of retrofitting are quite dramatic. The median NPV is now $355 for the nineteen programs and the average NPV is negative for homes in seven programs. These findings underscore the importance of accurate determination of retrofit lifetime and suggest the need for long-term tracking of retrofit performance.

Case 3 assesses the impact of removal of the 15% income tax credit for conservation measures on homeowners. It is assumed that all measures installed in utility-sponsored programs are eligible for the tax credit. Other assumptions from the base economic case are retained. The average NPV is negative for homes in 4 programs and the median net present value is $840 for all programs. Elimination of the tax credit is not nearly as critical as shortened retrofit lifetime in terms of the entire life-cycle yet it is an attractive economic incentive that initially helps to stimulate conservation investments.

The distribution of net present values is shown in case 4 for a situation in which conservation investments are assumed to have a salvage value equal to one-third the first-cost. This scenario allows to assess economic conditions in which future buyers place a premium on energy-efficient homes. The economic impact of inclusion of this salvage value is slight. The median NPV is now $1064 but the average NPV is still negative for homes in three programs.

The assumptions used in the basecase are fairly conservative. Because we are evaluating conservation investments from the participant (or homeowner) perspective, savings are valued using average residential electricity or fuel prices rather than the marginal cost to the utility or society of bringing on new energy supply sources. Additional societal and regional benefits that may result from widespread implementation of conservation retrofits have not been incorporated into the analysis. These include a lower level of negative environmental impacts compared to energy supply options and increased employment.[26] In 1980, the U.S. Congress attempted to quantify these additional benefits by passing legislation that mandated that cost-effectiveness of conservation investments be evaluated using a 10% credit (subtracted from the initial cost). [17]

Under the base economic case assumptions, the retrofit measures yield attractive rates of return and have a positive net present value. The variation in results that occurs when retrofit lifetime is shortened suggests that the economic results are particularly sensitive to changes in the expected lifetime. The indicators change less dramatically when either the tax credit is eliminated or a salvage value are included. Higher than anticipated future fuel or electricity prices translates directly into increased attractiveness of conservation investments.

4.5. Predicted versus Actual Savings

Comparison of actual vs. predicted savings is an important topic in the evaluation of a conservation program; an area in which little systematic work has been done. Several million U.S. households have received energy audits, with site-specific information on the costs and savings from energy conserving measures. Yet, there has been relatively little validation of the engineering calculations used or analysis of the consistency and quality of energy audits. Table 10 presents the available data on predicted versus actual savings from various utility-sponsored programs and research studies.

Interpretation of results comparing predicted with actual savings is related to the type of project. For example, in most research studies, predicted savings were, in a sense, estimated after the fact. Most studies calculated estimated savings during the period that the actual consumption data was being analyzed. In contrast, residents participating in utility-sponsored programs received a home energy audit estimating the energy savings from retrofit measures prior to obtaining a utility-

TABLE 10

Comparison of Actual vs. Predicted Energy Savings

SITE LABEL	NUMBER OF HOMES	SPONSOR	ACTUAL SAVINGS (%)	PREDICTED SAVINGS (%)	PRED. METHOD
UTILITY-SPONSORED PROGRAMS					
E 2	546	TVA	22	25	S.S.HEAT LOSS
E 9.1	810	WASH. WATER POWER	14	33/20[a]	WWP REV. METH
E 11.1	195	BPA/ORNL	16	44/22	BPA REV. METH
E 13.1	183	SEATTLE CITY LIGHT	11	20	BLAST SIMUL.
E 16.1	208	PORTLAND GEN ELEC	17	14	S.S.HEAT LOSS
E 6.1	6289	PUGET POWER	26	19	S.S.HEAT LOSS
E 7.1	300	PORTLAND GEN ELEC	17	17	S.S.HEAT LOSS
E 17.1	101	IDAHO POWER CO.	9	13	S.S.HEAT LOSS
MULTI-FAMILY BUILDINGS					
E 12	159	NYCHA	62	67	ENGR. CALC.
RESEARCH STUDIES					
E 8.1	5	BPA/LBL	9	4	CIRA
E 8.2	5	BPA/LBL	16	25	CIRA
E 8.3	4	BPA/LBL	42	36	CIRA
E 10	1	NBS	59	52	MODIFIED DD
G 27.1	13	PG&E/LBL	13	11	MODIFIED DD
G 28	12	UNIV. OF ILLINOIS	24	20	S.S.HEAT LOSS
M 13.6	17	SWEDEN/ROYAL INST.	10	16	S.S.HEAT LOSS
M 13.1	130	SWEDEN/ROYAL INST.	13	15	S.S.HEAT LOSS
M 13.5	111	SWEDEN/ROYAL INST.	7	6	S.S.HEAT LOSS
M 13.4	140	SWEDEN/ROYAL INST.	15	9	S.S.HEAT LOSS
M 13.2	106	SWEDEN/ROYAL INST.	10	12	S.S.HEAT LOSS
M 13.3	105	SWEDEN/ROYAL INST.	11	24	S.S.HEAT LOSS
M 14.2	25	SWEDEN/ROYAL INST.	8	3	S.S.HEAT LOSS
M 14.1	30	SWEDEN/ROYAL INST.	14	10	S.S.HEAT LOSS
CSA/NBS LOW-INCOME WEATHERIZATION					
M 8.1	74	CSA/NBS DEMO.PROG.	40	50[b]	S.S.HEAT LOSS

[a] The first number is the utility's original estimate of annual savings while the second number is their revised prediction (estimated after preliminary analysis of actual consumption data).

[b] Predicted savings were estimated for optimal weatherization (e.g., architectural and mechanical options) before the experiment.

Notes to Table 10

Site Label : This is a project's identification number.

Number of Homes : The number of homes in each project or the number of apartment units in the case of multi-family buildings.

Actual Savings : The values are either percent savings of pre-retrofit space heating consumption or percent savings of pre- retrofit consumption of all end uses of the space heating fuel.

Predicted Savings : The values are the predicted average savings for each project estimated, in most cases, by the sponsors prior to the retrofit. In most research studies, prediction estimates were obtained from computer simulations after the retrofits had been performed. Percent savings were calculated using the formula:

$$\text{Predicted Savings (\%)} = \left[\frac{\text{Est. Savings}}{\text{Pre-Retrofit Consumption}}\right] \times 100$$

Pred. Method : The prediction method used to estimate energy savings.

financed loan. These pre-retrofit audits provide a 'benchmark' against which to gauge the actual performance of retrofit measures in utility-sponsored programs.

Various prediction methods were utilized by project sponsors. Most studies used the standard engineering method (ASHRAE heating degree-day method) and did a steady-state heat loss calculation to estimate the energy savings. Several utilities (Washington Water Power and Bonneville Power Administration) modified this approach by adjusting their original savings estimate by the ratio of the actual pre-retrofit heating load to the estimated heating load. This revision significantly improved the accuracy of their predicted savings estimates compared to the original approach. Lawrence Berkeley Laboratory used its CIRA micro-computer program to predict energy savings in the three-cell Midway project. In two research studies, a modified degree day method (steady state heat loss calculation plus a balance point temperature adjustment) was employed.

Actual energy savings in utility-sponsored and low-income programs fell short of predictions in six of nine projects (Fig. 13). The difference between actual and predicted values are not large but the results are averaged over a large sample of homes. Initial prediction estimates for two utilities (data points E9 and E11) far exceeded actual performance; only the revised predicted savings agree closely with actual savings. In fact, the problem initially surfaced when the utilities were evaluating their conservation program; a good illustration of the positive feedback generated from analysis of measured energy consumption data. The opposite trend emerges from research studies; in nine of 14 cases, actual savings exceed prediction estimates. Except for the Swedish research study, sample size is far smaller than in utility-sponsored programs.

Several utilities observed some interesting trends in comparing estimated versus actual savings at the individual household level. For example, Washington Water Power found that the type of electric heating system in the weatherized home influenced the accuracy of the original savings estimate. Actual savings were 76 percent of the original

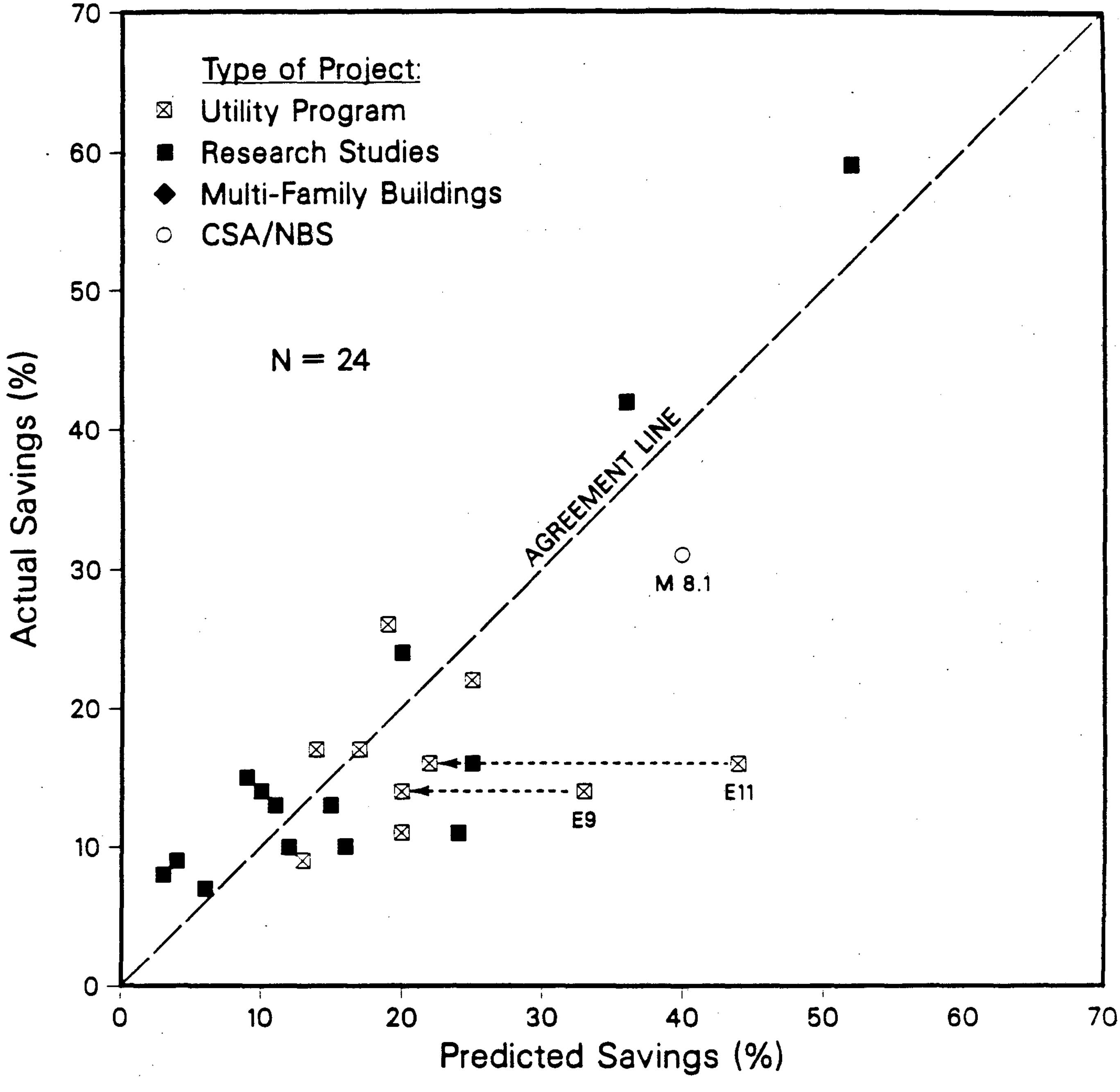

Fig. 13. Actual versus Predicted Savings plotted by type of project for 24 studies. Estimated savings exceed actual reductions in five of eight utility-sponsored programs yet the opposite trend emerges in research studies where this occurred in only 5 of 14 studies. Each utility program data point represents average results aggregated over a large sample (ranging from 100 to 6300 homes). Sample size is generally much smaller in research studies; ranging between 1 and 13 homes in six U.S. studies and from 25 to 140 homes in a Swedish experiment.

estimate in homes with a forced air system; but only 38 percent in homes with baseboard heat.[27] They also noted that their predictive model had greater difficulty in accurately estimating savings in homes that installed several measures. Actual savings slightly exceeded predicted estimates when only one measure was installed but were only 44% of estimated savings when five measures were implemented.

Most large-scale studies found substantial variation across individual households in the agreement between actual and estimated savings. Even though a portion of the variation is attributable to differences in occupant behavior, energy management, and quality control, these results suggest that there is room for improvement in the 'standardized' audit programs used by utilities. Increased feedback to energy auditors working in the field is also needed. The accuracy of building retrofit predictions can certainly be improved, however a certain amount of variation in actual savings from that predicted for a retrofit will probably always be a characteristic feature. [1]

5. CONCLUSION

Several major findings emerge from this compilation of current retrofit experience in existing residential buildings. First, energy savings occurred after retrofit in almost all retrofit projects, irrespective of data category. Annual average resource energy savings range from 23 to 38 MBtu in the four categories. Savings actually achieved were typically 20 to 35 percent of pre-retrofit space heating energy use. These results suggest that most efforts to date have fallen well short of estimates of the identified technical potential.[28] There is little evidence of successful, cost-effective retrofits involving expenditures of more than $2500 per house. In multi-family buildings, average investment per unit was roughly $700 with a maximum of $1650, far lower than the average of $1600 spent in single-family residences.

Second, large variations were observed both in energy savings (absolute and percent) and in costs per unit of energy saved. For aggregate data, representing results from groups of retrofitted homes, savings between various groups varied by a factor of five at any particular investment level. Moreover, there is significant uncertainty in savings estimates that are based entirely on changes in total billed energy use before and after a retrofit. Conservation program evaluation studies rarely sub-meter heating energy use or monitor indoor temperatures; hence possible equipment changes in the house (e.g. appliance replacement or use of secondary heating equipment) or in occupant's behavior (e.g. adjustment of day or night-time temperature) may mask the actual effect of the retrofit. A telephone or on-site survey of occupants can also provide data on other factors which could cause changes in a household's energy consumption; a technique used in only a small fraction of the evaluation studies. The wide range of conservation results indicates that more detailed data are needed, in the hope of explaining why savings and costs vary. Improved quality assurance (inspections, warranties, etc.) in the manufacturing and installation of products and systems possibly could reduce the variance in results among homes installing similar measures.

Third, we can now begin to identify particularly cost-effective retrofit strategies based on actual energy consumption data. It is difficult to determine the relative contribution of individual measures because most retrofit projects collect data at the whole-building level on the combined conservation effects of several physical measures and operation-and maintenance practices. Yet, we offer some tentative conclusons based on several retrofit projects where the effects of individual measures or sets of measures were isolated. The installation of attic insulation, particularly in homes with little or no insulation, produced substantial energy savings and was cost-effective in every retrofit project, irrespective of structural and demographic characteristics or climatic region. Conservation measures designed to reduce domestic hot water usage, typically tank and pipe insulation and/or reduced-flow fittings, were also sound energy-efficiency investments. Varying packages of "shell" retrofit measures (typically including attic insulation and storm windows and often wall or floor insulation) were successful in most single-family electric-space heat homes based on results from utility-sponsored conservation programs. In low-income single-family homes, retrofitting existing gas or oil-fired heating equipment appears to be a very cost- effective complement to "shell" weatherization measures. Results from several pilot programs (i.e., Philadelphia Oil Furnace Retrofit Project) indicate that the cost-effectiveness of low-income weatherization can be enhanced through the development of administratively simple programs that utilize well-trained private contractors who receive a standard fee for retrofit services performed.

The conservation potential in multi-family buildings is large and barely tapped. A variety of barriers, both institutional and technical, hinder the optimal allocation of resources for energy-efficiency investments. Retrofitting existing heating systems to increase their efficiency and installation of measures that improve building temperature control are attractive energy-saving strategies in multi-family buildings and can also provide occupants with a higher comfort and amenity level. Retrofit of the lighting system and separation of domestic hot water consumption from a gas-or-oil fired central boiler also appear to be very cost-effective, though this finding is based on a small sample.

Fourth, from a homeowner's perspective, many conservation measures are attractive economic investments compared to either alternative investment possibilities or continuation of consumption levels at current residential prices for fuel or electricity. Approximately 75-80 percent of the retrofit projects had costs of conserved energy below their respective space heating fuel or electricity price. Sixteen of 19 utility-sponsored conservation programs had positive net present values in the base economic case (assuming a real discount and fuel escalation rate of 7 and 4 percent respectively). We also found that the assumed economic lifetime of the measures and choice of discount rate made a substantial difference in determinations of cost-effectiveness.

Fifth, we presented data on the accuracy of various computer simulation models and simplified techniques used to predict the energy performance of retrofits. The accuracy of predictions for groups of houses tended to be significantly better than predictions for individual houses. Differences between actual and estimated savings can be caused by problems in four general areas: simulation of actual weather, operational description of the building (schedules for thermostat and appliances), physical description (U-values, dimensions, infiltration), or algorithms used in energy analysis.[29] Actual energy savings, averaged over a large sample of retrofitted homes, were greater than or equal to predictions in only three of eight utility-sponsored conservation programs. Several utilities found that the standard engineering method (i.e. steady-state heat loss method) tended to overstate savings, particularly in homes with electric baseboard heating or that installed several measures. Comparisons of predicted versus metered energy use in occupied, uninstrumented houses test model accuracy as well as auditor skill, though it is not possible to determine the relative contribution of these sources of error in the evaluation studies included in this report. Yet, the results suggest that improvement is possible in both areas - better simulation models and more effective feedback to energy auditors.

Finally, this compilation highlights gaps or limitations in the data currently available on the measured performance and cost-effectiveness of retrofits in existing residential buildings:[30]

- There is little data on the effect of residential retrofits on energy consumed by cooling systems. Data are sparse from those regions of the country (i.e., Southeastern U.S.) where cooling accounts for a substantial fraction of total residential energy use.
- We have relatively few results from various retrofit categories. There is a lack of data on retrofits directed at end uses besides space heating. We have few examples of active and passive solar retrofits and want to include studies on the performance and economics of "super-retrofits" that approach the identified conservation potential.
- Measured data that assesses the performance of retrofits in existing multi-family buildings, though increasing, is still inadequate. Successful retrofit strategies noted in this study (improved temperature control within the building, increasing the efficiency of an existing heating system, lighting retrofits) must be tested in other climatic regions and varying building types.
- There is insufficient data on savings trends over a period of years after retrofit. Information on the persistence of initial savings from conservation measures will allow researchers to improve estimates of retrofit lifetime, though long-term tracking via utility bills only presents difficult problems (i.e. occupancy and operating changes, additional retrofits). This is an important area because the economic attractiveness of conservation investments is strongly affected by the assumed lifetime.

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Appendix A

Methodology - A Closer Look

Adjustment of Energy Data

In the optimal situation, the major household energy end uses are sub-metered (e.g., separate monitoring of fuel or electricity used for space heating). Currently, utilities find the cost of obtaining sub-metered data prohibitive, at least in large-scale evaluations. Hence, in most studies, the consumption data consists of fuel or electricity billing data that represents usage for all end uses of that energy source over a specific time period. Sub-metered consumption data are available in only a few research studies.

To a considerable degree, energy consumption for space heating is climate-dependent.* Hence, to analyze changes in energy consumption for space heating, we need the space heating or total fuel usage per day (or month, year) before and after retrofit, the energy use for purposes other than space heating (the "baseload" usage) for the same time periods, the number of heating degree-days during each time period, and the "normal" (30-year mean) value of monthly and annual heating degree-days (HDD's). Typically, fuel use per time interval is regressed against either average outside temperature or heating degree-days.

The two major data adjustments of interest are subtraction of the baseload usage and correction of consumption data for the effects of weather in different years. Possible changes in the amount of "free" heat (e.g. solar gains, appliance usage) or occupant behavior are not explicitly accounted for in this analysis. However, homes were eliminated from the data set where there was a known change in occupants.

The non-space heating portion of total consumption is either derived from the regression coefficients or is estimated by taking the fuel usage during the summer months as the baseload. We estimated an average baseload usage in cases where a baseload correction was not originally made based on conversations with utility conservation program managers or used regional information obtained from either the All-Electric Homes Study or the Gas Househeating Survey.[31,32]

Weather-related adjustments to the space heating data were also made. A reference (or balance point) temperature was determined for each home in many research studies and in the CSA/NBS Weatherization Demonstration Research Project. For example, Princeton University researchers regressed total consumption of space heating fuel (includes all uses for the fuel) against the corresponding degree days based on a variety of reference temperatures. The reference temperature selected is the one that gives the regression with the best least-squares fit. The regression also produces two parameters that characterize the heating ('weather-sensitive') and baseload ('non-weather sensitive') consumption. These parameters, together with the normal-year degree days to the best-fit reference temperature, are used to calculate a weather-

* Consumption of hot water is more closely related to occupancy patterns.

normalized annual consumption (NAC).[33] In the majority of projects, the estimated space heating consumption was scaled by the number of HDD's (base 65°F) during the measurement period and consumption was then normalized to a "standard" year using the 30-year mean value of HDD's (base 65°F) for that site.

Gross vs. Net Energy Savings

The experimental design for most retrofit projects compares pre- and post-retrofit energy use by the same households. Only 40% of the retrofit projects in this compilation used a control group as part of their experimental design. Hence, calculating net energy savings relative to a control group could not be uniformly implemented. Control group energy savings are shown in Tables 3 through 6 but are not incorporated explicitly in the economic calculations. In the economic analysis, gross rather than net energy savings (retrofit group minus control group) are used.

Even among those projects that employed control groups, there were significant differences between control groups. For example, method of selection, knowledge of the experiment, and level of retrofit activity 'independent' of a program were factors that varied widely and tended to argue against uniform treatment of control group results. Control groups were classified into two general categories:

- o "active" control group (denoted by an 'A' in the last column of the site label)
- o "blind" control group (denoted by a 'B' in the site label).

Residents in an active control group were either aware of the retrofit project or knew that they were participating in an experiment. This fact possibly influenced observed changes in their energy consumption. Groups of homeowners that only received an informational energy audit were also included in this category. Homeowners in blind control groups had no knowledge of the evaluation study. For example, a group of non-participating customers in a utility weatherization program or aggregate group data from all residential customers in a service territory would be included in this category.

Interpretation of energy use data for a control group depends on the objective of the analysis. Subtraction of control group savings is appropriate if the purpose is to measure program-specific effects (e.g., the additional energy savings associated with a particular conservation program). However, in analyzing savings associated with a set of retrofit measures, it is very likely not correct to subtract control group savings. In several projects, researchers discovered that homeowners assigned to a control group were installing retrofit measures on their own. In these cases, subtracting control group savings would underestimate the true impact of measures implemented in the retrofit group.

Adjustment of Cost Data

Reliable and consistent cost data are essential for economic analysis of conservation investments. No uniform conventions exist for reporting of retrofit cost data; in fact, in some programs, it is disregarded. Several decision rules were developed in order to standardize the cost data. The direct costs to the homeowner of contractor-installed retrofit measures was adopted as the general accounting framework. If the retrofit was accomplished as part of a research study, the researchers' best estimate of the equivalent contractor's cost (materials, labor, overhead, and profit) was used. If the conservation measures were installed as part of a utility loan program, the retrofit cost was interpreted as equivalent to the loan amount. An exception to this practice was made for cost data from utility programs which indicated that the loan amounts were "bumping up" against program maximums. In these cases, an attempt was made to determine the additional investment outlay provided by the homeowner for the retrofits. Most utility administrative overhead costs were excluded since they are not direct costs to the homeowner, but are paid by all ratepayers. For low-income weatherization programs, we followed the approach of a DOE-commissioned study which estimated that materials, labor, and contractor overhead costs contributed roughly equally to overall costs. [7] On this basis, if only materials costs were available, then total costs were taken to be three times the price of materials. An estimate of the market cost of performing the weatherization work was obtained by using this factor of three. In some cases the bias introduced by this cost adjustment procedure tends to overstate the actual cost of conservation measures. For example, in cases where a homeowner contributes all the labor for a retrofit, total costs would actually be lower than our estimate, as would the estimated cost of conserved energy.

Costs at the time of retrofit were converted to 1983 constant dollars, 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.

Appendix B

Summary of Retrofit Projects in Existing Residential Buildings

Appendix B contains a brief description of each retrofit project included in this study. The summary includes a description of the conservation measures that were installed, a discussion of energy savings and cost-effectiveness, and notes key adjustments to the data. Each data source is identified by a label that indicates the fuel used for space heating (e.g., gas (G), oil (O), mixed (M), and electricity (E)) along with its location and sponsor.

GAS HEAT

G1: Wisconsin - DOE Low-Income Weatherization [34]

The Wisconsin Department of Health and Social Services did a small sample (17 homes) evaluation study of their state's low-income weatherization program in an effort to gain insight into service provider effectiveness (i.e. the local community action agencies). In most cases, degree day data and fuel use data were obtained for two years prior to the weatherization activity and averaged along with one year of post-retrofit data. Typical retrofit measures installed included attic insulation (bringing existing levels to R-38), caulking and weatherstripping, wrapping of hot water heaters, and storm windows and floor insulation (in a several of the homes). The study authors reported annual energy consumption of the space heating fuel and material costs for each home's conservation measures. LBL researchers used 11 of the 17 homes, those that utilized natural gas for space heating and for which a baseload subtraction (using an average summer months fuel usage as the non- space heating portion of total consumption) could be accurately made. Cost data was multiplied by 1.85 in order to estimate the contractor cost of the retrofit (the factor used by Wisconsin personnel). Average annual space heat consumption was reduced by 21 MBtu after the retrofits.

G2: Twin Rivers, NJ - Princeton Univ. [35,36]

This was part of the retrofit research experiments conducted by the Princeton Center for Energy and Environmental Studies (CEES) Group. In a first stage, conventional retrofits such as additional attic insulation and moderate sealing of attic air leaks reduced heating fuel usage by 25% in a townhouse. Second stage "super-retrofits" included insulating shutters for south windows, basement insulation, and sealing additional air leaks. Subsequent to these retrofits, another attic bypass heat loss was discovered, by a convective loop within the masonry party walls. This heat loss was partially corrected by blowing cellulose into the walls at the attic floor level. Net savings in heating fuel increased to 76% in the following years. 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. Many of the window and door retrofits were custom-made, resulting in high retrofit costs.

G3 and G4: New Jersey - Princeton University/HS 11 & 22 [37]

Two occupied houses were retrofitted by Princeton University's CEES Group and local contractors. Additional attic insulation, furnace tune-ups, and sealing air leak convective loops, diagnosed using a blower door and infrared viewer, were the main retrofit measures. These projects had moderate costs with energy savings ranging between 25 and 40%.

G5, G6, G7, G8, G24, G25, G26: Modular Retrofit Experiments in New Jersey and New York [10]

Groups of homes at seven different sites, called "modules," were retrofitted 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 was to make a quantitative evaluation of the "house doctor" concept. Each module consisted 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 and convective loops diagnosed using a blower door and an infrared scanner, the installation of clock thermostats, the wrapping of water heaters with insulation, and sometimes the installation of low-flow shower heads and 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. These included such measures as installation of insulation in attics, walls, and basements, and storm windows. In all seven modules the "house doctor only" group yielded the lowest cost of conserved energy (CCE) for the module, indicating that some of the most cost effective retrofit measures were 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 as well, a trend also seen for the aggregate of New Jersey's gas heating customers.

G9: Saskatoon, Saskatchewan - Energy Conservation Info. Center [38]

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 (NRC) 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 mainly added insulation and storm windows. The five homes that had been sealed and insulated achieved 30% energy savings but at relatively high dollar cost. The NRC found significant variations in the quality of workmanship and materials used in the retrofit work. It should be noted that retrofit costs have been converted from Canadian to U.S. dollars.

G10: Butte, Montana - NCAT [39,40]

This retrofit by the National Center for Appropriate Technology occurred in two steps: attic insulation only was added to a halfway house before the first winter with wall insulation, caulking and weatherstripping, and a south-facing passive wall installed before the second winter. The basic data (consumption, weather, costs) were provided by NCAT and LBL did the calculations. The attic insulation retrofit had a fairly low SPT but the second stage retrofit was not cost effective--a common result in demonstration projects.

G11: Ramsey County, Minnesota - Northern States Power [41]

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. Post-retrofit space heat energy consumption decreased by 8 percent. A 1981 follow-up study on 25 customers in the program (the initial group was reduced by changes in occupancy) found that annual consumption declined further in 16 households and increased slightly in 9 households.

G12: San Joaquin Valley, California - Pacific Gas & Electric [42]

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 installed R-19 and 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. The results were scaled up to reflect a normal winter season. For each location, the payback time was 5.7 and 4.3 years respectively, indicating the cost-effectiveness of the insulation program.

G13: Colorado - Public Service Co. [43]

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 we subtracted a baseload use estimate to derive the space heating component. Approximately 200 therms per customer were saved with an original investment of less than $300. The investment had a average payback time of 5 years and a cost of conserved energy around $2.00/MBtu.

G14, G15, G16, G17, G18: CSA/NBS Optimal Weatherization Demo. Pgm. [9]

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 were presented even though in many cases water heater data had been collected. All consumption data had been weather-adjusted.

As expected, the results vary from site to site because of such factors as: differences in the original thermal integrities of the houses, selection of retrofit options implemented, and the different fuel types. The sites for which both architectural and mechanical options appear to be more cost-effective than those sites for which only architectural options were completed. Absolute savings per house were 44.8 MBtu with 31 percent savings in space heating energy for the composite of 12 cities, reflecting the overall success of the project.

G19: Luzerne County, Pennsylvania [44]

This was 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. A baseload correction was made and the data was adjusted to a normal winter season. Post-retrofit space heat energy consumption declined by 15 percent, yielding a payback time of 9 years.

G20: Louisiana [7]

Results are reported from an evaluation of the DOE Weatherization Program for low-income homes in Louisiana. Data sheets provided by U.S.R. & E. were used as well as 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 were almost 30% but absolute energy savings were small due to the relatively mild Louisiana winters. The retrofit investment had a relatively long payback time of 18 years. We have low confidence in the data because the measures implemented are not known and only one month of pre-and-post retrofit consumption data was available (though it represented 30% of the heating degree days for the season).

G21: Kansas City, Missouri [45]

Kansas City, Missouri conducted several evaluations of the Home Weatherization Program. The programs were implemented with DOE Low-Income Weatherization funds dispensed through the Missouri Department of Natural Resources. Results are reported for three sample groups that received insulation, caulking and weatherstripping during 1977 and 1978. We used the consumption data in the report (3 months winter billing data representing approximately 60% of the HDD in the heating season), and made a baseload correction and weather adjustment to a normal Kansas City winter. Percent savings of space heating energy use for the three groups ranged between 15-27% with a simple payback time of 7 to 15 years.

G22: Kentucky [46]

The Kentucky report on the DOE Low-Income Weatherization Program was very extensive and detailed. It contained 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, only the homes heated by natural gas were included. 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 are shown due to insufficient consumption data. A baseload correction and an adjustment for a normal heating season were made. The conservation measures had a 4.7 year payback time, indicative of the success of the program.

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

Results from the DOE Low-Income Weatherization Program in Indiana are presented. The principal retrofit options were insulation, caulking and weatherstripping, and adjustments of the heating system. Consumption data was provided by U.S.R. & E. We 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 with a payback time of 14 years.

G27: Walnut Creek, Ca. - LBL/P,G & E [47]

In cooperation with Pacific Gas & Electric Co., Lawrence Berkeley Laboratory conducted a demonstration project to measure the incremental savings that result from adding house doctoring to an energy audit. The experiment analyzed the pre-and post retrofit energy consumption of 19 homes divided into 4 groups: a "full retrofit" group (A) that received an audit, house doctoring and conventional contractor retrofits, a group (B) that received the audit and house doctoring, a group (C) that had the audit only, and a blind control (D) which received no treatment. At this stage of the experiment, usage data from Group A includes the results from house doctoring only (the conventional retrofits were done in June 1981) and thus the data from Groups A and B together were combined. The house doctor treatment emphasized the installation of an intermittent ignition device (IID), infiltration-reduction measures using diagnostic equipment, low-flow showerheads, insulating the water heater, and sealing furnace ducts. Though the "house-doctored" group had a larger average value of savings than either the audit only or blind control (11.4% compared to 9.4 and 7.0%), the differences were not statistically significant (at the 95% confidence level) due to the small sample size.

G28: Champaign, Ill. - Univ. of Illinois [48]

Energy consumption data were studied by University of Illinois researchers for 12 households that had wall and attic insulation installed by private contractors in the Champaign area between 1977-80. A unique aspect of the project was the researchers analysis of 'trend data'; several years of utility bills for each home before and after retrofit. They concluded that average energy savings of 22 percent (with a range from 6 to 43%) occurred in these households after installation of conservation measures. LBL researchers calculated annual space heat energy savings using their data on "heating factors" and baseload correction (summer usage in the pre-and post retrofit years defined as baseload).

G29: Denver, Col. - Solar Energy Research Institute [11]

This study analyzed the energy savings from 25 households that participated in a DOE/SERI demonstration project of the 50/50 program. Working with local contractors, SERI adapted the retrofit package to gas-heated homes in Colorado (i.e. included attic insulation and eliminated cooling system and 7 sealing/heating system improvements that were not applicable to gas systems). Thirty low-cost measures could potentially be installed by contractors with estimated savings up to 40%. From 12 to 21 retrofit measures were actually installed in each house, resulting in 19% average annual energy savings, based on extrapolations from 6 months of post-retrofit data. The package of conservation measures had an average payback time of 5 years. A "non-participant" control group of 25 households also reduced their consumption by 14% attributed to rising gas prices and "independent" retrofit action taken by at least 7 of the 25 "non-participants."

G30: Detroit, Mich. - Public Service Comm./Consolidated Gas Company [49,50]

This study conducted by staff of the Michigan Public Service Commission analyzed energy savings from 71 homes that participated in a Michigan Consolidated Gas Company loan program to finance the installation of attic insulation [up to R-19]. The retrofits occurred between 1973-76 and were installed by contractors. PSC staff made a baseload correction of annual energy consumption data and used cost data estimates from local contractors. Consumption decreased by 13 percent after the retrofit with a payback time of 4 years.

G31: Chicago,Ill. -Center for Neighborhood Technology [51]

This study details changes in energy consumption that occurred in eight cooperatively-owned multi-unit buildings after the installation of a series of retrofit measures. The buildings range in size from 4 to 25 units and are all 3-story, 70 year-old structures with built-up roofs and masonry bearing walls. Attic insulation (equivalent of R40) and storm windows were installed at several of the buildings. Measures to improve building temperature control including high limit outdoor stats, thermostatic radiator valves, and air temperature-sensing burner controls with programmable set-backs were also installed. Additionally, extensive efforts were employed to increase the efficiency of the heating system consisting of such retrofits as de-rating and tuning of existing boilers, replacing old burners in 2 of the buildings with higher combustion efficiency, lower firing rate new models, adding flue dampers, and balancing the single-pipe steam distribution system. The study emphasizes the feasibility and cost-effectiveness of these heating system retrofits.

Each multi-unit building was treated separately, with conservation measures, cost, and energy consumption data listed for each building. Costs for the retrofit measures were based on mid-1982 material and labor rates (figured at $40/hr, the current rate charged by a heating contractor, since many of the heating system retrofits were do-it yourself projects done by coop building maintenance staff). Annual maintenance costs were estimated at $50/apt for the retrofit package.

G32: Newark,NJ - Bumblebee Energy Systems [52]

A computerized energy management system was installed by Bumblebee Energy Systems in a 530 unit family apartment complex operated by Newark Housing Authority. The system monitors indoor apartment temperatures, and supplies heat by opening and closing motorized valves dependent on the average of apartment temperatures in each building. Determination of energy savings attributable to the energy management system was complicated by the fact that the central heating plant was totally refurbished during the same time period. This included installation of new boilers, underground piping, control valves, and a separate gas-fired hot water generator. Based on an analysis of several years' consumption data at four other projects, Bumblebee Management concluded that the heating plant modernization did not yield any significant savings. Any potential efficiency improvements were overshadowed by impacts stemming from the proper or improper operation and maintenance of the heating plant and control systems. They apportioned the 26% total annual savings as follows: one-half to replacement of the condensate lines (part of the modernization) and one-half to the Bumblebee energy management system. We used the 14% savings allocated to the energy management control system and the associated cost in estimating savings and cost-effectiveness (disregarding changes in consumption attributable to the refurbishment of the heating plant). An annual operating and maintenance cost of $25,000/year or $40/apt. (Bumblebee's estimated cost for a service contract for the control system) was factored in to the economic calculations. The non-space heating fraction of total consumption was subtracted out using the average of the summer months usage. In addition, we normalized monthly energy usage data to a 'typical' heating season. The retrofit had a simple payback period of approximately 3 years.

OIL HEAT

01: New Jersey - Princeton/HS 21 [31,32]

A 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 an impressive 53% space heat savings in this 1974 house with a 3.1 year payback time.

02: Trenton, New Jersey - Bumblebee Energy Systems/Trenton Housing Authority/HUD [53]

Bumblebee Energy Systems received a HUD innovative energy conservation demonstration grant to install a temperature control system in Page Homes, an urban multifamily housing complex. Indoor temperature sensors were placed in one-third of the units, transmitting periodic readings to a micro-processor. Using this information, the computer adjusted the hot water temperature for the boiler. The hot water heat distribution system was also rebalanced and a separate gas-fired boiler was installed to meet domestic hot water requirements. Fuel savings in the complex were an impressive 44%. The pre-retrofit energy consumption was comparable to that found in other buildings operated by the housing authority yet it would be considered an 'energy guzzler' in comparison to the overall residential housing stock. The retrofit was very cost-effective with a payback time under one year and a calculated cost of conserved energy around $1/MBtu (at 14.2% capital recovery rate). Annual operation and maintenance costs were estimated at $4000/ year or $25/apt., based on Bumblebee System's service contract charges. Eight other similar apartment complexes, used as a control group, showed almost 16% savings.

03, 04, 05: Scallop Thermal Management [12]

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 implemented include: 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 no changes are made to the thermal envelope. Results are given for a two year period after retrofit for three multifamily residential building complexes under thermal services contract. A 521-unit Washington, D.C. multifamily complex showed 6.7% savings. A 752-unit Maryland apartment complex attained only an average of 2% savings over two contract years. Finally, a 60-unit cooperative building in New York City achieved annual fuel savings of 9 percent.

Scallop estimated continual manpower requirements (operation & maintenance) at several hundred hours per year for each building, calculated at a rate of $30/hour. The annual operation and maintenance cost for the heating system improvements were large relative to the original investment. To illustrate this fact, simple payback time with original investment cost only and with the annual maintenance costs capitalized at a 7% real discount rate for 10 years was calculated. Considering only the initial investment yields payback times of between 1-2 years for the three buildings. If annual maintenance costs are factored in, the payback time ranged from 6 to 20 years.

06: Vermont [6]

Data from the DOE Low-Income Weatherization Program in Vermont were provided by Mark Cooper of CECA. The 23 dwelling sample included trailers, apartments and single family homes, but only the single family houses were included in this study. The principal retrofit options implemented were 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 payback time of 4.1 years.

07: Philadelphia, Pa. - Oil Furnace Retrofit Program [54]

A 200-home pilot program was conducted by the Alliance to Save Energy, the Institute for Human Development, and the Department of Energy during the winter of 1980-81 to demonstrate the feasibility and cost-effectiveness of oil furnace retrofits in low-income homes. The retrofit measures included a new flame retention head burner, a furnace tune-up that had to achieve a minimum steady state efficiency of 80%, an automatic setback thermostat, and new combustion chamber if necessary. Private fuel oil dealers performed all the work, guaranteed its quality for one year and received $500/home. Energy savings were determined using two methods: 1) fuel consumption was measured for six consecutive winter weeks after retrofit and a k factor (degree days/actual consumption) was calculated and percent savings was determined through a comparison to the pre-retrofit value and 2) changes in pre-and-post retrofit steady state efficiency was measured and percent fuel savings were estimated through multiplying by a factor of 1.4 (based on experimental results from Brookhaven National Laboratory). Using the first method, energy savings of 18.6 percent were obtained for a 47 home sample while a 45-home control group reduced their consumption during the same period by 2.6 percent. The retrofits appear to be very cost-effective with a 2.4 year payback time.

08: New York City, NY - NYC Housing Authority [55]

In the winter of 1976-77, the NYC Housing Authority undertook a demonstration study program to determine the energy savings resulting from the installation of non-electric thermostatic modulating radiator valves (TRV) in steam-heated buildings controlled as a single zone. The measure was installed in multi-unit dwellings at 4 sites and changes in consumption were compared against four similar control buildings at the same site. Daily pre-and-post retrofit space heat energy consumption values were obtained from condensate meters at the eight buildings. A conversion factor of 980 Btu/lb (assuming low pressure steam at 10 psia, 240^{o}F minus saturated water at atm. pressure) was used and NYCHA's estimate of 70% boiler efficiency in calculating annual energy consumption.

Significant reductions in energy usage occurred in 7 of the 8 buildings, making causal attribution difficult possibly due to factors such as the experiment's short time period (the pre and post retrofit consumption data were collected during the same heating season) and likelihood of 'independent' occupant retrofit measures and practices (i.e. apart from the study). Tenants did report increased levels of occupant comfort (more even distribution of heat in buildings). The study authors estimated energy savings of 6.8% specifically attributable to the TRV retrofit, obtained by calculating the percentage savings of the difference between three of the four study and control buildings weighted by the number of valves installed in each building. The authors ignored the results from the Ocean Hill site because the control building had greater reduction in consumption than the study building.

09: New York City - NYC Housing Authority [56]

The New York City Housing Authority has an on-going program for replacement of steel casement windows with double-hung, double-glazed thermal break aluminum windows in order to save fuel and reduce maintenance costs. The original building windows were vulnerable to air infiltration, required substantial amounts of maintenance and were frequently subject to glass breakage during windy weather. Pre-and post retrofit weather-adjusted fuel oil consumption were available for 9 housing projects. The window replacement retrofit achieved average savings of roughly 18 percent with a 15 year simple payback time for the 9 buildings. The Housing Authority also estimated that the retrofit reduced operation and maintenance costs by $30/dwelling unit or $30,000/year for a typical 1000-unit complex. This lowers the payback time to roughly 11 years (assuming a 20 year lifetime and 7% real discount rate).

010: Long Island, New York - Brookhaven National Lab/DOE [57]

Brookhaven National Laboratory (BNL) conducted field tests in 250 homes that installed various retrofit measures designed to improve residential oil burner efficiency. The principal objectives of the study were: to measure the fuel savings of several retrofit options and combinations of options, to examine the variation in savings of a given type of measure(s) over a number of similar houses, and to identify service problems associated with these retrofits. The homes were divided into

10 groups: group 1 had a retention head burner (RHB) installed in a boiler while group 2 measured the same conversion with an optimized installation; groups 3 and 4 added a boiler temperature programmer and a vent damper respectively to the optimized RHB retrofit; groups 5 through 8 compared the savings obtained when refitting a conventional burner with a stack heat exchanger, double setback thermostat and boiler temperature programmer; and groups 9 and 10 examined the impact on oil furnaces of the optimized RHB alone and with a vent damper. Fuel oil delivery data were analyzed for two heating seasons prior to retrofit and for one year afterwards with consumption corrected for seasonal weather differences and normalized to a 'standard' year.

Major findings from the project were: 1) the median savings for the optimal retention head burner retrofit in boilers and furnaces were 18 and 11% respectively, 2) the optimized installation procedure increased fuel savings by 6% (Group 2 vs 1); in terms of simple payback time alone, 3) the double setback thermostat had the quickest return on initial investment (Group 7); and 4) while the flue gas heat exchangers installed in conventional burners achieved 10% median savings, it had the longest payback time with additional maintenance requirements (soot buildup) and thus the retrofit did not compare favorably with the retention head burner.

O11: Minnesota - Inst. for Human Dev./Minn. Dept. of Econ.Security [58]

The Institute for Human Development provided technical assistance to the state of Minnesota's Low Income Energy Assistance Program by instituting an oil furnace retrofit program that was complementary to existing weatherization efforts. The experimental design consisted of four groups: Group 1, households whose heating systems were retrofitted with flame retention burners and tuned up to achieve at least 80% steady state efficiency; Group 2, homes that were weatherized (e.g. infiltration reduction measures, attic and some wall insulation, storm windows and energy-related minor repairs); Group 3 that received weatherization plus heating system retrofit, and a control group in which no retrofits were installed. Major objectives of the project included: assessment of the additivity of savings between weatherization and oil furnace retrofit, the relative cost-effectiveness of the different treatments, and analysis of the correlatation between changes in fuel use and changes in steady state efficiency. After the measures were installed, fuel use for each house was determined from 8 weekly oil tank dipstick measurements taken during mid-winter from which a regression equation was estimated. Results were compared to a schedule of oil deliveries from the previous year (Sept. 1981 - Sept. 1982). For almost one-half of the houses only total annual usage was available for the pre-retrofit period. The authors concluded that average usage decreased by 22.3% in Group 1, consumption declined by 12.4% in Group 2, Group 3 showed a 29.2% reduction and the control group's usage remained virtually unchanged.

MIXED FUELS. In some cases, the main heating fuel differed among a group of houses that were part of a retrofit project. This occurred most often in low-income weatherization projects. If the experiments were carefully done, we included their results.

M1 through M8: CSA/NBS Optimal Weatherization Demo. Pgm. [9]

The CSA/NBS Program was discussed earlier (see Label G14-G18) and overall results are listed there. The mixed fuels for M1 through M8 include natural gas, heating oil, propane, and electricity. There were few electrically heated homes in the sample (small numbers in Atlanta, Charleston, Easton) except in Tacoma where 25% of the homes used electric heat. Natural gas was the main fuel in the Atlanta and Tacoma groups, whereas homes in Charleston used mainly propane. Gas and oil usage were almost equal in Easton and Fargo homes. Oil was the dominant fuel in the Portland, Maine, and Washington, D.C. groups. Wide variance in energy savings and economic indicators was observed for individual houses in these sites.

M9: Northwest Wisconsin [59]

An evaluation of the CSA (Community Services Administration) Weatherization Program in the northwest quarter of Wisconsin was conducted by University of Wisconsin researchers. 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 aggregated the consumption data for the various types of fuel and adjusted to a normal heating season. Space heat energy savings of 19 percent were obtained with a payback time of 2.4 years.

M10: Minnesota [60,61]

Mid-America Solar Energy Center analyzed changes in consumption in low-income households participating in the DOE Weatherization Program 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 homes with wood heating were eliminated. Roughly 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 experimental 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 a 2-year average of 6.9 percent.

M11: Wisconsin [6]

Results are reported from an 1979 evaluation study of the DOE Low-Income Weatherization Program in Wisconsin. The 13 home sample group mainly used natural gas for space heating but several homes were heated with propane or fuel oil. Total consumption data was provided by Cooper and LBL staff made a baseload correction to determine space heating consumption. Average energy savings were 16.5% and the resulting CCE was approximately $6/MBtu. Retrofit measures were not specified and the consumption data were suspect and thus a "D" confidence level rating was assigned to the results.

M12: Allegan County, Michigan [6]

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 were 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. a baseload correction was made for the gas users and all consumption data was adjusted for a normal heating season (based on the 30-year average for heating degree-days). The 28% space heating savings resulted in an attractive payback time of 3.9 years. Significant missing elements in the data led us to assign a "D" confidence ranking to the results.

M13,14: Sweden - Royal Institute of Building Technology [62,63]

The Swedish government has sponsored an extensive program of home loans and grants for the installation of various conservation measures in existing residential buildings. The Royal Institute of Technology performed an in-depth analysis of several hundred single and multi-family houses. Houses included in the final analysis met the following criteria: no change in occupancy during the study period, no other conservation measures were performed by the residents, no other structural changes to the building, and multi-unit buildings had 5 or more apartments. Sample homes were drawn from throughout the country to reflect different climate zones. A principal objective of the study was to compare actual and theoretical savings for different measures and combinations of measures. Fuel bills for a period of at least one year before and after the retrofit were analyzed for each house and actual consumption was normalized to the long-term average value for heating degree days.

The data is presented by grouping the regional data (from the 5 counties) by measure or combination of measures. In calculating average values for heated dwelling area, energy consumption, and predicted theoretical savings, we weighted the above values by the number of houses from each region to estimate the mean. Unfortunately, cost data were not collected for the project and thus it is not possible to assess cost-effectiveness of the program and/or specific measures.

M15: St.Paul, Minnesota - St. Paul Housing Authority [64]

St. Paul Housing Authority received a HUD innovative energy conservation grant to install a computerized energy management system in three high-rise properties inhabited by elderly tenants. Many existing controls were tied into the computer. The system's main functions included issuing preventative mantenance orders, reducing electrical demand charges by minimizing peak usage, malfunction alarms, and lighting and temperature control in public areas. Prior to this retrofit, the

Housing Authority had a rather extensive conservation program in operation and had undertaken many low cost/no cost retrofits (showerflow restrictors, reduced hot water temp. to 120°F, insulated pipe ducts, etc.) plus various retrofits designed to improve heating system efficiencies (e.g. new burners on boilers). The system went into operation during the 80-81 heating season. We compared fuel consumption from the 78-79 heating season (before) to 81-82 usage, normalizing the raw consumption and heating degree day data to the long-term average value. According to the Housing Authority, the system also provided 404,000 KWh electricity savings in all three buildings which LBL staff converted to fuel-equivalent units and added to the pre-retrofit usage (thus increasing the overall savings). The electricity savings substantially reduced the simple payback time for the investment to roughly 4 years.

ELECTRICALLY-HEATED HOMES

E1, E2: Tennessee - Tennessee Valley Authority [65-67]

The pilot phase of TVA's Home Insulation Program targeted low-income families with high electric heating bills. Participating households initially had little or no attic insulation, used electricity for space heating, and had an annual income under $6000. The evaluation examined changes in consumption for two groups: 81 homes that received attic and floor insulation, caulking, and weatherstripping from private contractors and 138 homes that had attic insulation installed by TVA personnel. Only 69 of the 81 homes and 105 of the 138 homes were included in a data summary sheet provided by TVA. In both groups, the savings were adjusted to correspond to a normal winter (using the 30-year average for heating degree-days). Cost data were unavailable for the households that were retrofitted by TVA personnel and hence were estimated using cost/ft^2 data from the first group. Space heat energy savings were 54% and 33% respectively with payback times of 3.5 and 2.2 years.

A study of the early part of TVA's Home Insulation Program was made by ICF, Inc. The principal 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 - Johns-Manville Co. [68]

Johns-Manville did 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 group of homes served as a blind control. A blower door was used to pressurize the houses. In the retrofit group caulking and sealing (a glass mat was used for a complete wall covering) were done and the infiltration rate was reduced by 30%. The individual house savings did not correlate with reduced air leakage as measured by the fan method. This is not surprising given the number of significant actions reported in each homeowner's log that affected consumption (i.e. in the retrofit group, 17 homes lowered their thermostat settings and 5 homes added storm windows). During the post-retrofit period, the homes were sub-metered to record electric energy for heating only. Johns-Manville reported results space heat savings of 16% in the retrofit group, 14% savings for the active control group, and 12% savings in the blind control group. The payback time for the retrofit group was around 8 years.

E4: Pacific Northwest - Pacific Power & Light [69,70]

Over 14000 customers have participated in Pacific Power & Light's Weatherization Program through 1982. A study of early participants (1896 homes) found space heat savings of 20 percent (reported in BECA-B, LBL-13385). PP & L recently completed a more extensive evaluation of their Home Energy Analysis (HEA) and Weatherization Program. During the audit, cost-effective weatherization measures are recommended and, if desired, a water heater blanket is installed free of charge. Principal measures financed under the weatherization program include: R-38 ceiling insulation, R-19 floor insulation, storm windows and doors, caulking and weatherstripping, wrapping of ducts and pipes, and timed thermostats. The utility analyzed pre-and-post program consumption data for customers who had an HEA and/or been weatherized during 1979 throughout their service territory (parts of six Pacific Northwest states). In addition, energy savings were estimated for a control group that consisted of all single-family electric space heat customers (69,000 homes) who had not been involved in any company-sponsored program from 1978-80. Actual savings were weather-adjusted for four basic customer groups - home energy analysis and weatherization customers with and without water heater wrap. The analysis revealed that homes that had a water heater blanket reduced their consumption on the average by 480 KWh, homes that had an audit only saved roughly 1700 KWh, and customers who participated in the weatherization program had average savings of 4450 KWh.

E5: Seattle, Wash. - Seattle City Light [71]

From November 1978 to December 1980, Seattle City Light offered 6% interest loans as part of a pilot Residential Insulation Program. Program evaluation focussed on the energy savings observed in 133 full-electric heat homes that installed attic and floor insulation. Using utility survey data, LBL researchers made a baseload correction and adjusted actual savings based on six months billing data for both the pre and post retrofit period to a normal heating season. The space heat savings were 24% with a payback time of 5.1 years. A blind control group of 551 full electric customers showed a 13% drop in space heat consumption. Significant differences were observed in the initial consumption levels of the weatherized and nonparticipant group and thus the control group was weighted to approximate the same customer usage distribution as the weatherized group.

E6: Western Washington - Puget Power [72,73]

Since Dec. 1978, Puget Sound Power & Light Company has offered a zero interest loan weatherization program to single-family electric-heat customers. Effective January 1982, customers could alternatively receive a grant outright from the utility in an amount equal to 71.8% of the loan amount. Puget Power monitored the actual energy savings from all weatherized homes and reported results from 6289 homes. They have updated and revised the preliminary program results presented in LBL #13385. The principal retrofit measures included insulation of attic, floor and wall, storm windows and doors, free water heater wrap and clock thermostat. Each home was individually adjusted and had at least one year of billing history after retrofit but no attempt was made to delete non-weather sensitive KWh consumption. Space heat consumption per home decreased by roughly 8000 KWh after retrofit, a 41% reduction. Actual savings exceeded the utility's predicted estimates by 30%, attributed to increased use of wood stoves or fireplace inserts and dramatic rate hikes in the last three years.

E7: Portland, Ore. - Portland General Elec. [74]

In July 1978, Portland General Electric implemented a zero-interest weatherization program (ZIP) to encourage better insulation in existing single-family residences that used electricity as their space heating fuel. Upon customer request, an audit was conducted to determine which covered actions were needed. If cost-effective, PGE would finance the following retrofit measures: attic insulation to R-30, floor insulation up to R-19, storm windows and doors, and caulking and weatherstripping. In 1980-81, PGE analyzed pre-and post retrofit consumption data from the first 300 ZIP customers along with a control group of 200 ZIP- eligible but non-participating households. The utility developed a sophisticated weather-adjustment model that incorporated heating degree days and wind speed and that matched billing consumption data with weather happening specifically during the billing periods. Actual usage was then normalized to a 'typical' heating season. Under normal weather, the ZIP group's annual consumption declined by 3937 KWh while the control group's usage remained virtually unchanged. Estimated savings were derived from engineering estimates of the first 818 ZIP customers, a larger sample than included in this evaluation study.

E8: Midway, Washington - BPA/LBL [75]

The Bonneville Power Administration (BPA) retrofitted 18 houses over a three-year period (only 14 are included in the final analysis). Evaluation of energy savings and cost effectiveness of different conservation retrofits were the principal study objectives. Houses were divided into three different groups. Cell 1 homes received an extensive infiltration-reducing weatherization using a blower door to find air leaks. 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 <u>flat</u> monthly fee for electricity regardless of their energy usage, and thus the normal market signals (i.e., changing prices affecting demand) were not operative. Second, all 18 houses were owned by BPA, thus making it easier to ensure that the retrofit work was identical. Storm windows and infiltration reduction decreased effective leakage area by 14 and 27% respectively. Energy savings ranged between

9% for infiltration reduction to 42% from installation of storm windows and insulation.

E9: Eastern Washington/Idaho - Washington Water Power Company [76,77]

Starting in 1978, Washington Water Power (WWP) sponsored an extensive zero-interest loan program for its single-family electric heat residential customers. The company analyzed the fuel bills of 1030 participants and 251 customers selected at random (control group) to determine energy savings and to evaluate the accuracy of their energy prediction methods. Possible retrofit measures for which loans were available included ceiling and floor insulation, storm windows and doors, and insulation of the hot water tank. The data has been disaggregated by retrofit measure and we calculated the space heat savings for 810 homes that installed measures designed to reduce space heat usage only (no water heater wrap). LBL researchers used WWP's baseload estimate of 1000 KWh/month in determining the space heating fraction of total electric consumption. The entire participant group (1030 homes) obtained annual weather- adjusted savings of 4448 KWh, only 51 percent of estimated savings (using ASHRAE steady state heat loss calculation). A revised method, using the ratio of a home's pre-retrofit actual heating load to the load estimated using steady state heat loss calculation to adjust the new savings estimate, proved to be far more accurate in predicting actual energy savings.

E10: Bowman House, Maryland - National Bureau of Standards [78]

This was the first extensively monitored residential retrofit on record. The National Bureau of Standards retrofitted a wood-frame structure in three stages: reduction of air leaks, addition of storm windows, and installation of floor, ceiling, and wall insulation. Bowman House was unoccupied but occupant behavior (i.e. lighting, appliance usage) was simulated. Pre and post retrofit annual heating loads (e.g. delivered heat to the house) were calculated from a least-squares regression of daily average heating loads correlated with outside average temperature. We calculated annual space heat fuel consumption based on the efficiency rating (92%) given for the house's electric resistance heater. The retrofits resulted in significant reductions in space heat usage (59%) but did not reduce the house's cooling energy requirement. NBS researchers concluded that installation of storm windows was the most cost-effective measures at that site.

E11: Oregon, Wash.,& Montana - BPA/ORNL [79,80]

The Bonneville Power Administration (BPA) operated a pilot program with 11 small public utilities in the Pacific Northwest for almost three years that provided residential energy audits to 6000 electrically-heated homes and financed weatherization of roughly half those homes with a zero-interest loan program. Oak Ridge National Laboratory conducted an extensive evaluation of the program that encompassed estimation of energy savings attributable to the program, comparison of key characteristics among three groups of households (audit plus weatherization, audit only, eligible non-participants), and a cost/benefit analysis. Retrofit measures financed included attic, wall and floor insulation, storm windows and doors, caulking and weatherstripping, the insulation of heating ducts and hot water heaters. Major findings that emerge from the evaluation study are: 1) electricity savings of roughly 3500 kWh per weatherized home attributable to the BPA program 2) total annual savings of 4500 kWh/home 3) actual savings were much less than predicted levels, resulting in significant changes in estimation methods 4) households receiving an audit only showed no reduction in electricity use relative to nonparticipants and 5) homes in the audit plus loan group consumed substantially more electricity prior to the program than the other two groups. Study authors developed several approaches to the problem of estimating program energy savings. LBL researchers used results obtained from a 3 parameter (reference temperature, weather-sensitive slope coefficient, nonweather-sensitive intercept) regression model of monthly electricity consumption developed for each household (Model 3) in our analysis. We calculated the space heat fraction by subtracting the baseload usage estimated by the regression model from total electricity consumption. The authors assumed a constant 60°F reference temperature for each of 449 households (total of the three different groups).

E12: New York City - New York City Housing Authority [81,82]

The New York City Housing Authority replaced incandescent hall and stairwell lights with 20-watt fluorescent fixtures in 13 buildings. Electricity billing data were obtained from one housing project (830 Amsterdam), indicating annual energy savings of 62 percent. A cost of $50 per fixture was used in calculating retrofit cost, determined by examining the installation contracts, yet the payback time was only 1.4 years. The longer lifetime of the fluorescent bulbs led us to estimate an annual reduction in operation and maintenance costs of $5/apartment.

E13: Seattle, Wash. - Seattle City Light [83,84]

In early 1981, Seattle City Light initiated the Home Energy Loan Program (HELP) to provide weatherization loans to residential customers who reside in single-family to fourplex units. The program weatherized 864 homes in its first year of operation, offering ten-year, zero-interest loans with payments deferred for the first five years to electric space heat customers. Eligibility is contingent on willingness to install several mandatory measures (attic insulation to R-30, underfloor insulation to R-19, the installation of water heater and pipe insulation, and R-6 heating duct insulation) with financing also available for optional retrofits such as storm windows, caulking and weatherstripping, and automatic setback thermostats. In order to reduce the 'self-selection' bias, the utility employed two comparison groups, customers who received an audit only, but had not applied for weatherization and a group of 'non-participants', electric heat customers who expressed interest in but had not yet received an audit, in addition to the group of weatherization customers. Pre-and post-retrofit consumption data was available for only a portion of the heating season (Jan.-June). Total annual electricity consumption for each group was obtained by scaling the ratio of estimated space heating usage per actual heating degree day to the long-term normal value for heating degree days (5185 HDD) combined with an estimate of annual baseload consumption (approximately

12000 KWh or 50% of total consumption). For a 'typical' heating season, post-retrofit consumption declined by roughly 3000 KWh in the weatherized group with an increase of 450 KWH observed in the non-participant group. The evaluation study noted that measured electricity savings were only 60-70% of the utility's predicted forecast.

E14: Seattle, Wash. - Seattle City Light [85]

The Seattle City Light Conservation and Solar Division conducted an evaluation of their Low-Income Electric Program (LIEP). The program provides free home weatherization grants to qualified low-income customers. The retrofit package includes similar mandatory measures as the HELP program (see E13) along with such optional features as R-11 wall insulation, caulking and weatherstripping, smoke detectors, and up to $250 of weatherization-related home repairs. Complete electricity billing data were obtained for 377 of 557 homes weatherized in 1981 in addition to a control group of 208 non-participants, drawn from customers who received LIEP weatherization the following year. We did a somewhat crude weather-adjustment on bi-monthly electricity consumption data, estimated the space heating fraction of total usage using SCL's estimate of the baseload (50% of total annual consumption or 10,500 KWh/yr) and normalized the data to a 'typical' heating season. Consumption declined by 3000 KWH in a 'weather-typical' post-retrofit year in the participant group and increased by 300 KWh in the control group.

E15: Seattle, Wash. - Seattle City Light [86]

The Evaluation Unit of the Seattle City Light Conservation and Solar Division published an evaluation of their Home Energy Check Program. They compared program performance data (number of audits/yr, conservation actions taken, and energy savings in audited homes relative to a control group) against program objectives. From 1978 through 1980, the Utility completed 11,000 audits, performed 4800 hot water tank wraps and 6600 thermostat setbacks on water heaters. Electricity consumption before and after the audit was examined for a sample of 518 audited homes (66 with electric space heat and 452 non-electric space heat). The electric space heat homes showed average net savings (test minus control group) of 1534 KWh per year while usage in the non-electric space heat residences declined by 516 kWh. SCL looked closely at two sub-groups of audited homes: those that had a hot water tank wrap and/or thermostat setback and those audited homes that did not take either of these actions. LBL researchers used these results in the analysis. Annual electricity consumption declined by 465 KWh in those homes that reported taking actions to reduce hot water energy consumption. We assumed a contractor cost of $30/home for these measures, yielding a 3.8 year simple payback time.

E16: Portland, Oregon - Portland General Electric [87-89]

In Sept. 1982, Portland General Electric (PGE) released a more extensive evaluation of their zero-interest weatherization audit and financing program (ZIP). A principal focus of this later study was analysis of the portion of weather-adjusted gross savings that could be assigned to either weatherization, a change in the use of wood for space heat, appliance replacements, or other factors. Conservation measures eligible for ZIP financing include: insulation of attics, floors, walls, and heating ducts; addition of storm windows and doors, caulking and weatherstripping, and wrapping of hot water tanks (free of charge at time of audit) and pipes. PGE's evaluation drew heavily on an in-depth survey of 758 homes that sought information on actions that potentially could lead to changes in consumption from mid-1978 to early 1981. The study defined four participant-level categories: non-electric space heat customers (ineligible for ZIP) and groups of electric space heat non-particpants, ZIP audit only customers and ZIP audit and finance households. Each individual household's consumption data was weather-adjusted with separate adjustments made in the before and after period. The utility also collected two years of post-retrofit data in order to examine the persistence of savings and customer behavior patterns. Using several multiple regression models, PGE apportioned the first year's annual weather-adjusted savings (4041 KWH) for the audit and finance homes as follows: weatherization, 2627 KWh; use of wood heat, 782 KWh; appliance replacements, -191 KWh; and other factors, 823 KWh. The reduction in consumption due to increased use of wood heat was in the 700-800 KWh range for all three groups of electric space heat customers. The study found that expected savings from performed actions exceeded actual savings attributable to weatherization (3475 KWh vs. 2627 KWh). Possible explanatory factors cited include: audit overestimation of expected savings (calculated for a 'typical' house), lifestyle factors that the audit did not incorporate (zoning), and customer relaxation of various conservation practices in the initial period after weatherization. The reported cost data for the weatherized homes is an overall program average for that time period.

E17: Idaho - Idaho Power Co. [90,91]

Idaho Power Co. conducted an evaluation of their Zero Interest Loan Program with the primary objective of comparing actual energy savings with engineering estimates obtained from audits. The conservation program finances the installation of attic, wall and floor insulation, storm windows, caulking and weatherstripping, and clock thermostats. Their study analyzed pre and post retrofit consumption data for 101 single-family electric space heat customers who particpated in the ZIP program along with a matched sample of 48 control homes. Actual savings in the test group fell substantially short of predicted savings based on the audit. Possible explanations include shortcomings in the audit program (double-counting of savings from measures) and problems in the evaluation design (in some homes, installation of retrofits occurred during the time period defined as pre-retrofit, thus yielding lower savings because the before period includes a portion of the retrofit savings impact). We normalized the actual consumption data to a 'typical' heating season and made a annual baseload subtraction of 11,000/KWh (using the utility's estimate) to estimate the space heating portion of total consumption.

Appendix C

Economic Analysis: Indicators and Assumptions

The economic analysis of conservation investments involves several parameters that cannot be as definitively determined as the energy savings. Estimating the economic lifetime of a set of measures, choosing an appropriate discount rate, or projecting future energy prices are all parameters for which there may be a fairly wide range of reasonable guesses. Sensitivity analysis is often used where there is significant uncertainty in key assumptions. It brackets the range of likely outcomes and provides an estimate of a project's potential cost-effectiveness under varying conditions.

Lifetime of Retrofit Measures

The expected lifetime of measures is probably the most poorly- documented major variable affecting the economics of conservation retrofits.[92] This is a troublesome problem because the economic attractiveness of many measures is strongly dependent on reliable and consistent performance over a fairly long time period.

Typically, investments are amortized over the loan repayment period or the physical lifetime of the measure. In many cases, loans taken out by homeowners to finance retrofits would be repaid over a period shorter than the measure's useful lifetime. In this study, we amortize conservation investments over the measures expected physical lifetime. Estimates used for the expected lifetime of various retrofit measures were developed from several sources. These included a literature survey, lifetime estimates used by the original authors, and estimates from several LBL research groups (Energy Performance of Buildings estimates used in their Computerized Instrumented Residential Audit [CIRA] and the Building Energy Data Group). The superior structural condition of most middle-income homes relative to low-income dwellings and unacceptably high uncertainty levels beyond 20 years (in forecasting future energy prices) are factors that were also considered. Retrofit lifetimes chosen for individual measures, sets of measures, and conservation programs are shown in Table C1.

Discount Rates

A discount rate is that rate of interest which reflects the time value of money. The discount rate is used to bring future costs and savings back to the present in order to compare retrofit options on a equivalent basis. The nominal value of dollars generated 10 years from now by a conservation investment (i.e. reduced energy bills) are not worth as much as the dollars required to continue purchasing energy today. Hence, future benefit streams must be discounted to reflect the time or opportunity cost of the delay. A real discount rate is expressed in constant terms; that is, current dollar values have been corrected for reduced purchasing power due to inflation. The formula for calculating the real discount rate is:

$$d = \frac{(i - k)}{(1 + k)}$$

TABLE C1

Expected lifetime of retrofit measures

RETROFIT MEASURE	LIFETIME
Attic Insulation only	20
Storm Windows	15
Double-glazed thermal-break aluminum windows (not removed)	20
Caulking and Weatherstripping	5
Measures associated with 'House-doctor' treatment	10
Storm Doors	10
Insulating Blanket on Hot Water Heater	10
Thermostatic Radiator Valve	10
Heating System Retrofits - retention head burner - vent damper - furnace tune-up - flue gas heat exchanger	15-20[a]
Energy Management Control System	10
Lighting System changes (incandescent to fluorescent - ballasts)	10
SET OF MEASURES IN VARIOUS PROGRAMS INSTALLED[b]	
DOE Low-Income Weatherization	15
CSA/NBS Low-Income Weatherization Demonstration Research Project	15
Utility-sponsored Conservation Programs (insulation, storm windows & doors, some weatherstripping)	20
Modular Retrofit Experiment (contractor retrofit plus house-doctor treatment)	20

[a] Range of lifetimes for some of the more common heating system retrofits. Range is partially dependent on overall lifetime of the heating system

[b] Lifetime for set of measures is weighted by estimated savings and lifetime of individual measures along with an assessment of the basic structural condition of the housing stock.

where:

d is the real discount rate;

i is the interest rate; and

k is the inflation rate.

Economists from the National Bureau of Standards argue that homeowner discount rates are bounded on the lower side by the rate of return on alternative investments and on the upper side by the cost of borrowing.[93] It is important to note that benefits derived from conservation investments are not subject to income taxation (in contrast to many other types of investment); hence after-tax rates of return for alternative investments should be used in determining the appropriate discount rate. One possible investment comparison is the tax-exempt All-Savers certificate whose yields have varied from 8 to 12 percent. Real rates of return probably range from 0 to 3 percent. Banks often regard many retrofit investments as fairly risky, placing them in a category similar to home improvement/renovation loans. In recent years, real interest rates for home improvement loans range from 7 to 10 percent. The Energy Security Act of 1980 specifies the use of a 7 percent real discount rate in the evaluation of U.S. government conservation and solar applications' investments. [17] A real discount rate of 7 percent was chosen in the base economic case; rates of 3 and 10 percent were utilized in the sensitivity analysis.

Energy Price Escalation Rate

Potential increases in the nominal and real dollar value of future energy savings must also be accounted for explicitly. This necessitates a reasonable estimate of future prices for fuel and electricity in the residential sector. In recent years this has been an extremely frustrating and fruitless exercise, given the wide fluctuations in the world oil market. Yet, most analysts maintain that energy prices in the 1980's will be far more stable and 'predictable' than in the last decade. In their latest mid-term forecast, the Energy Information Administration projects a 3.5 percent annual increase in real residential energy prices through 1990. [4] The American Gas Association estimates varying real fuel price escalation rates of 4 and 8 percent for natural gas.[94] Given the 'official' estimates, a real energy escalation rate of 4 percent was selected for the base economic case. A high energy price scenario was also tested which used an escalation rate of 8 percent.

Economic Indicators

A variety of economic indicators and associated decision rules have been developed to evaluate the worthiness of potential conservation investments. It is useful to consider their typical application as well as potential shortcomings.

Simple payback time is a measure of the length of time required for the cumulative savings from an investment to pay back the initial cost. It can be expressed as:

$$SPT = \frac{I}{\Delta E \cdot P} \tag{1}$$

where:

I = initial investment

ΔE = energy savings

P = local energy price

Though SPT is easily understood and widely used, it neglects temporal changes in energy prices, the expected life of the investment, differential operations and maintenance costs, and the time value of money. The indicator's failure to account for key economic variables means that simple payback time often gives biased and misleading investment signals to the homeowner. For example, SPT ignores any changes in conditions after the payback time has been achieved. Two retrofit measures with the same payback time may have very different physical lifetimes; hence one measure produces additional energy and dollar savings while the other requires replacement.

The cost of conserved energy is found by dividing the annualized cost of the retrofit by the annual energy savings due to the investment. The cost of conserved energy (CCE) is particularly useful if one wants to compare conservation investments to purchases of fuel. The comparison price will vary depending on the investor's perspective. For example, a homeowner would most likely compare the cost to save energy against the average residential energy price (or adopt the more sophisticated approach of comparing CCE to the fuel price in the appropriate rate structure tier). A utility might evaluate CCE against the marginal (avoided) cost of supplying energy from new sources (in the simplest case). It is worth noting that comparing the cost of conserved energy to today's energy prices is equivalent to assuming that real energy prices will remain unchanged over the retrofit lifetime (i.e., a zero percent real energy escalation rate). [19] CCE can be expressed as:

$$CCE = \frac{I}{\Delta E} \cdot \frac{d}{1 - (1 + d)^{-n}} \qquad (2)$$

where:

I = total investment

ΔE = energy savings

d = discount rate

n = lifetime of measure

CCE provides an effective means of rank-ordering conservation investments by cost-effectiveness. Though attempts have been in recent years to popularize this indicator, the concept is still unfamiliar and CCE is not yet widely accepted as an investment statistic.

Net present value analysis calculates the difference between a retrofit measure's discounted benefits and costs. For conservation retrofits, the energy saved and the cost of obtaining those savings are valued over the lifetime of the measure(s). An investment with a net benefit greater than zero is considered worthwhile; the measure having the highest NPV is the best investment. The general formula for net present value (NPV) is:

$$NPV = \sum_{j=o}^{n} \frac{B_j - C_j}{(1 + d)^j} \qquad (3)$$

where:

n = lifetime of measures

B_j = annual (for year j) economic benefit (1983$)

C_j = annual cost (1983$) of measures

d = discount rate

This formula sums the difference between the discounted benefits and costs each year over the lifetime of the measure. In practice, the present value of future energy savings are traded off against the total investment cost (which in many cases requires a substantial initial investment).

The calculation can be simplified somewhat by using general discount formulas which allow us to find the NPV at the end of the specified lifetime: [17]

- o present worth factor (PWF) - used to find the present time equivalent of a future amount, such as replacement cost
- o uniform present worth factor (UPW) - used to find the present-time equivalent of an annually recurring amount, such as maintenance cost
- o energy escalation factor (EEF) - takes into account the rate of escalation of the periodic payment that is being discounted over N years. This accounts for the yearly fuel price escalation rate (above and beyond the general inflation rate) in addition to discounting the yearly savings.

The formula for NPV then becomes:

$$NPV = (\Delta E)(P)(EEF) + TI - [\, FC - SV(PWF) + MC(UPW) + RC(PWF)\,] \qquad (4)$$

where:

ΔE = energy savings

P = local energy price

TI = tax incentive or credit

FC = first-cost of conservation investment

SV = differential salvage value

MC = differential maintenance costs

RC = differential replacement cost during investment lifetime

The NPV technique is best suited for comparing conservation investments with equal costs. It is also useful in determining the economically efficient size of a conservation investment. If the net present value decreases when a homeowner is considering incremental conservation investments, then it is not wise to increase the investment. Hoewever, this indicator does not distinguish between large and small investments that result in the same net dollar savings. NPV is biased towards large investments that produce substantial net dollar savings over their lifetime but which do not necessarily provide the highest return per dollar invested.

The internal rate of return (IRR) finds the economic return on an investment. Typically, IRR is solved through an iterative process that finds the interest rate for which the net value of the investment is equal or close to zero. The IRR is then compared to the investor's minimum acceptable rate of return to determine the quality of the investment. The IRR requires an estimate of future energy prices and a measure's expected lifetime but no specification of a discount rate. The internal rate of return i is the solution to the following equation:

$$I(1 - TI) = \sum_{j=1}^{n} \frac{\Delta E \cdot P_j}{(1+i)^j} \quad (5)$$

where:

I = total investment

TI = tax incentive

ΔE = annual energy savings (equal to first year savings)

P_j = energy price in year j

n = lifetime of measures

This indicator is capable of reflecting the relative economic efficiencies of alternative investments and can be used to rank competing projects. The IRR has the disadvantage that it is cumbersome to calculate and in some instances gives indeterminant or non-unique solutions. [13]

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