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SAVING ENERGY IN OCCUPIED BUILDINGS:
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SAVING ENERGY IN OCCUPIED BUILDINGS:
Results from the Lawrence Berkeley Laboratory Residential Data Bases*

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ABSTRACT

The Buildings Energy Data Group at Lawrence Berkeley Laboratory compiles and analyzes data on the monitored energy savings and cost-effectiveness of conservation and solar measures in buildings. This paper summarizes results to date from the residential portion of our Building Energy Use Compilation and Analysis (BECA) project, comprising findings from several hundred studies of new and retrofitted buildings. We believe that an ongoing data base developed from measured consumption data can help improve energy auditor recommendations, stimulate better energy-efficient design and construction practices, assist homeowner investment decisions, and guide the efficient allocation of utility and government dollars.

For both new and retrofitted homes we discuss: 1) energy savings and the range of savings for given types of measures; 2) cost and cost-effectiveness of various measures; and 3) methodology. In existing residences, data compiled from roughly 70 retrofit projects, with sample sizes that range from 1 to 33,000 homes, strongly indicate that retrofits often significantly reduce annual space heating energy consumption. But, results are highly variable. The maximum energy savings from individual measures installed in different households are 3 to 7 times greater than the median value. Nineteen conservation programs sponsored by utilities achieved annual space heat savings of 38.5 million Btu at an average investment level of $1050. Twenty-nine of 215 new homes in our BECA-A database have detailed sub-metered data that permits normalization of space heat loads for both indoor temperature and internal gains. In these homes, the "standardized" heating energy requirement ranges from 10 to 25 kBtu/ft^2 over various climatic regions, a value that is roughly 50 percent less than current building practice.

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1. INTRODUCTION

For a homeowner deciding whether to invest $600 in attic insulation or a utility planner deciding whether to invest $6 million in a conservation program, the bottom line is the actual energy savings which will result. The Building Energy Use Compilation and Analysis (BECA) project is an ongoing effort to compile databases on measured energy consumption in actual buildings.[1] We seek to provide a consistent framework in which to compare results from a variety of projects, to identify conservation techniques and measures that work in practice, and identify which of the many variables affecting building energy use are important sources of variation among projects and/or significantly affect the actual energy savings a particular investor can expect to achieve.

In this paper we summarize the results from our two residential databases. For BECA-B, the database covering the retrofit of existing buildings, we briefly describe our methodological approach and focus on recent results from 47 retrofit projects (representing over 40,000 single-family homes) and 26 large multi-family apartment buildings. Results from BECA-A, low-energy new buildings, are presented only briefly since they are available elsewhere.[2] Rather, we concentrate on several methodological issues; specifically, the importance of correcting measured data for variations in lifestyles of the occupants and in geographic location.

Using measured consumption data is a useful beginning point in the process of understanding changes over time in household energy use. More detailed information on key physical parameters of buildings in addition to incorporation of behavioral determinants of household energy use is necessary in order to gain a deeper understanding of variations in energy savings among households.

2. RETROFIT OF EXISTING RESIDENTIAL BUILDINGS : BECA-B

2.1 Data Sources and Methodology

We obtained data on the retrofit of residential buildings mainly from evaluation studies of conservation programs and demonstration projects. Additional data comes from utilities, firms providing building energy services, public housing authorities, and state energy offices. Information entered in the database includes: 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. We enter the data in a uniform format to permit standardized analysis. In some cases, this requires adjustment of several key variables (e.g., energy consumption, retrofit cost).

The two major adjustments to the consumption data are:

- 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.

We make the implicit assumption that observed pre-/post retrofit changes in energy use are caused by the retrofit though we recognize that other factors (i.e., life-style of residents, change in the number and age distribution of occupants) are also significant variables. In most cases, we do not have sufficient information to account for possible changes in the amount of 'free' heat (e.g. solar gains, appliance usage) nor changes in occupants' comfort levels or management of heating systems or appliances. However, we eliminate homes from the data set where there is a known change of occupants.

Original retrofit costs are converted into 1983 dollars using the GNP Implicit Price Deflators. In some instances (e.g., in the DOE Low-Income Weatherization Program where only material costs are known), we estimate an equivalent contractor cost.

Given the variety of data sources, the compilation is a 'mixed bag':

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

We divide the data sources into more homogeneous sub-groups having similar structural, demographic, and usage characteristics to permit a more consistent and useful treatment of results. These include:

- weatherization programs directed at low-income single-family houses
- utility-sponsored conservation programs
- research studies and demonstration programs
- retrofit efforts in large multi-unit apartment buildings.

Low-income weatherization programs. Results from the retrofit of low-income homes come from several sources: the CSA/NBS Weatherization Demonstration Research Project, the DOE Low-income Weatherization Program, and several pilot projects funded by the Low-Income Energy Assistance Program that retrofitted oil-fired heating systems.

Utility-sponsored conservation programs. These programs typically represent large-scale efforts involving the retrofit of thousands of homes. Several early utility programs targeted high energy consumers or low-income households. Although recent initiatives are directed at all residential customers, they typically reach single-family, middle-income homeowners who live in structurally sound homes. Most of the earlier programs financed either the installation of attic insulation or low cost/no cost measures (e.g. the insulation of water heaters) whereas later programs offered a large package of measures to eligible households. It is extremely difficult to assess the impact of individual measures because data from utility-sponsored programs are only available on an aggregate basis.

Research studies. Research projects often test innovative retrofit measures or strategies, although cost is usually not a dominant consideration. Sample size tends to be small (fewer than 20 homes) and a control 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 make extensive analysis of the consumption data, including sub-metering of specific end uses.

Multi-unit retrofits. All of the large multi-family buildings currently in the BECA-B data base are located in the northeastern or midwestern portion of the United States. The inhabitants are almost all renters and often low-income. For example, 50% of the buildings are in public housing projects. We have several cases of retrofits performed by energy service companies who contract with building owners to manage building energy systems. They provide an agreed-on level of service (i.e. thermal comfort), with the benefit of conservation investments, at a price no greater than existing energy bills.

2.2 Results

Table I summarizes the data for utility-sponsored and low-income conservation programs. The installed first-cost of conservation measures per building ranges from $296 to nearly $4000, reflecting the diversity in the number and types of measures in our sample. The most frequent retrofit measure is attic insulation (IA). Other frequently installed measures include caulking and weatherstripping (CW), storm windows or double glazing (WM), insulation of walls and floors (IW & IF), and retrofits to the heating system (HS: equipment modification and replacement).

Annual space heat energy savings as a function of the contractor cost of the retrofit are shown in Figure 1 identified by type of project. At any given investment level, there is substantial variation in savings (e.g., savings differ by a factor of 5 for an investment of $2400). The sloping reference lines represent the boundaries of cost-effectiveness for typical residential electricity and fuel prices. Seventy-four percent of the points lie above their respective reference price lines and hence are cost-effective compared to these fuel prices.

Participants in utility-sponsored conservation programs achieved average annual space heat savings of 38.5 million Btu (MBtu) while low-income residents reduced their annual consumption by 35.9 MBtu. The standard deviation of each group is 19.4 and 24.8 MBtu, respectively. The CSA/NBS Optimal Weatherization Demonstration Program achieved space heating energy savings of 31% in the 12 cities. Analysis of individual house data from the program reveals that homes that received retrofit measures designed to reduce building shell conduction and infiltration heat loss saved 23.1 MBtu per year and spent an average of $1700, while homes that installed heating system retrofits in addition to the 'shell' measures reduced their annual consumption by 63 MBtu at a cost of $2380. Hence, heating system retrofits installed in conjunction with 'shell' retrofits were more cost-effective.

Annual resource energy savings from 26 multi-unit apartment buildings are shown in Figure 2. Greater savings per dollar invested are achieved in multi-unit buildings that installed computerized energy management control systems (e.g., data point 02.1) or such measures as furnace de-rating and tuning, burner replacement, and addition of temperature control setbacks to the existing heating system (e.g., all gas-heated buildings).

Figure 3 illustrates the wide range of fuel and electric savings among homes that either installed the same conservation measure or participated in the same retrofit program. The site label, number of homes, and description of the measure or package of measures installed is included below each distribution.

It is instructive to consider one sample (Site Label = G12.1) in Fig. 3 in some detail, since this subset is indicative of the variation in savings that can occur among households in which the same measure is installed. 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 are 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. How do we explain this ten-fold variation in savings? Possibly, the large variation is partly attributable to the area's mild climate (i.e. the long term normal heating degree-day value is 2185); the effects of occupant behavior, particularly indoor temperature preferences, become more pronounced. Yet, similar levels of variation in savings among households are observed in more severe climates (e.g., Site Label G30), though our sample is quite limited. Unfortunately, data on changes in indoor thermostat settings are unavailable as is information on conditioned living space (e.g., floor area). We know little about the houses or their occupants.

Maximum energy savings from individual measures installed in different households are 3 to 7 times greater than the median. For packages of measures installed in either utility-sponsored conservation programs (E9) or in retrofit projects aimed at low-income households (M8), maximum savings are 8 to 10 times greater than the median. The large range in savings indicates the need for more detailed and accurate information on key variables affecting 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.

3. NEW HOMES: BECA-A

3.1 Data Sources and Methodology

3.1.1 Data Sources.

Energy performance in new homes must be analyzed differently than performance of retrofitted homes. Unlike retrofitted homes, there is no "before" and "after" levels of performance from which to calculate energy savings. The costs of conservation features are also more difficult to calculate, because it is hard to isolate the additional investment in conservation measures from other elements of construction cost. In addition, variations in the lifestyles of homeowners are more significant in low-energy new homes. Interpreting measured performance of new buildings therefore requires more detailed data than for retrofitted homes. For this reason, we include only houses with submetered heating energy measurements, and focus our analysis on those homes with measured indoor temperatures and appliance use.

Given these data requirements, our sample is composed largely of houses built and monitored as part of research or demonstration projects. Almost all are single-family dwellings. We intend to expand our coverage of buildings and types of projects, beginning with an effort to analyze sub-divisions of non-submetered, energy-efficient houses, where the data for each house are less detailed, but the number of similar houses is greater and the distribution of occupancy patterns more "typical" than in research houses.

3.1.2 Methodology

Normalizing for Variations in Indoor Temperature and Internal Gains. The effects of lifestyle variations on energy use are more acute in new than in retrofitted homes. A greater fraction of a low-energy home's heat demand can be met by internal gains. For many of the houses in the BECA-A database, internal gains supply more than half of the heat requirement. It would be a serious error to compare them without correcting for differences in internal gains because in these homes the annual internal gains vary from 15-60 MBtu (compared to typical heating requirements of 50 MBtu/year).

We correct measured energy use for variations in indoor temperatures and, for those well-documented homes, we adjust for differences in internal gains. The correction is based on the following equation describing the heat balance of a house (a more detailed discussion may be found in Ribot et al.):

$$Q_{aux} = k(T_{in} - T_{out}) - Q_{int} - Q_{solar}$$

where

Q_{aux} = heat supplied by the heating system

k = an effective heat loss coefficient for the house, determined by regression using actual Q_{aux} and T_{out}

T_{in} = indoor temperature

T_{out} = outdoor temperature

Q_{int} = internal gains

Q_{solar} = solar gains

We choose a standard indoor temperature and internal gain. Using measured values of heating energy and temperature, we find the coefficient "k" by regression, substituting in the equation our standard indoor temperature and internal gain to find a Q_{aux} corrected for variations in these occupant-dependent quantities. Put another way, we are calculating the heating use each house would require if it were operated with the same indoor temperature and internal gains.

Baseline. It is more difficult to define a baseline to which energy efficient new homes can be compared, since it is unusual to find sets of houses which are identical except that some have additional conservation features. Therefore, we select several "benchmark" levels of building energy performance to serve as standard comparison points. They are:

- o average annual heating use by gas heated houses in the existing U.S. stock
- o average annual heating use in typical new houses as described in a survey by the National Association of Homebuilders
- o average annual heating use for homes built according to the Building Energy Performance Guidelines

All are expressed as energy per unit floor area.

Details of the heating energy use calculations for each benchmark may be found in Ingersoll, et al., 1983. [3] It is useful to briefly describe these data sources and the analysis in order to understand the limitations of each and to illustrate the general problem of defining a baseline for new building energy performance.

When the baseline definition work began, the only detailed, randomly sampled national survey of the energy use and construction characteristics of existing U.S. houses was the National Interim Energy Consumption Survey (NIECS).[4] Even this dataset suffers from severe limitations: utility bills are collected for only half of the surveyed houses; floor area is guessed or estimated by homeowners rather than measured; heated floor area is poorly defined; thermostat settings and internal gains are not measured. We therefore use the survey only for estimating heating use in existing houses; the data quality problems, small sample size, and effort required to "clean up" the data for new houses dissuaded us from using it to estimate space heat use in new houses. Our estimates for existing homes are based on a cohort analysis of the NIECS data by Meyers. [5]

For new homes we use building descriptions of typical new houses from the National Association of Homebuilders 1979 survey of its members' construction practices.[6] This survey is not a random sample of all new houses; rather, it represents the building practices in typical houses of those builders that responded to the survey. The survey does not collect actual energy use, hence, we simulated the buildings' performance on DOE-2 with the average NAHB characteristics in several cities. In the simulation, we used the same indoor temperatures and internal gains used in normalizing the performance of homes in the BECA-A database.

This approach offers a modest advantage over using measured energy use in that we can compare the performance of houses in the BECA-A database (when normalized to standard indoor temperatures and internal gains) directly to the calculated NAHB benchmark space heating use. It has the much more serious disadvantage that the simulation of the NAHB house is subject to input errors, errors in algorithms, and the fact that "on-site" construction practices are not always equivalent to specifications at the design stage. The Buildings Energy Performance Guideline benchmark are also DOE-2 simulations. These three benchmarks appear as reference lines in Fig 4.

Cross-climate Comparisons. The BECA-A database includes homes in climates varying from San Diego to Saskatchewan. Obviously, one cannot compare fairly the performance of homes in these two locations without some correction for the differences in severity of climate. A simple correction is to divide the energy use of houses by their respective heating degree-days. Such a procedure may be acceptable for conventional houses in cold climates, where the main driving force of heat demand is the difference between inside and outside temperature, and where the balance point does not vary far from 65°F. But, for very efficient houses and/or mild climates, the results will be misleading for the following reasons.

First, the houses in BECA-A have balance points far below 65°F; as low as 47°F. If the energy use of such a house is divided by the heating degree-days calculated using the actual balance point, we fail to give credit for operation far below the conventional balance point. Dividing the energy use of all houses by the base 65°F degree-days for their respective locations makes the houses with low balance points appear better (as they should). However, we introduce a large bias against houses in some climates. Two locations with the same heating degree days, calculated (for example) to base 65°F, can have a very different number of degree days calculated to base 50°F when the distribution of degree-days differs. Homes with low balance points will perform very differently in the two locations, even if they are otherwise identical; the difference in space heat use can be as large as 70% for the Pacific vs. the Atlantic coast, and easily on the order of 10% between the Midwest and the Atlantic coast. In this paper, we restrict comparisons to a regional basis. We present plots of building energy use vs. degree-days strictly as a climate index and caution the reader against taking comparisons too literally.

In addition, there are variations in climate that are not captured by degree days (solar and wind in particular), but which affect building energy performance. We are attempting to determine the size of the effects due to this second set of problems. For example, it may be that certain types of construction, such as earth-sheltered or superinsulated homes, are relatively insensitive to variations in solar and wind. Space cooling also poses difficult analytical problems that must be confronted.

3.2 Results

The building space heat demand (that is, consumption divided by furnace efficiency) for the 29 buildings for which we could correct for variations in both indoor temperature and internal gains is shown in Figure 4. The plot shows that several construction strategies can produce houses with lower space heat requirements than the existing stock, or even lower than typical new construction. In fact, the Building Energy Performance Guidelines can also be met or exceeded by a variety of construction techniques.

Energy savings versus added cost of conservation for 92 buildings are presented in Figure 5 (changes in energy are calculated from the NAHB 1979 benchmark line). Houses that lie above the fuel cost lines are cost-effective, given the fuel cost and interest rates shown; those below are not. We also include houses for which we could not normalize internal gains; we only correct for variations in indoor temperature. In spite of the small sample size, some trends emerge. Two of the active solar houses (# 15 and 58) do save energy compared to the NAHB benchmark yet are not cost-effective because they greatly exceed the reference electricity price. A number of superinsulated and multi-strategy new homes (#18, 1, 29, and 3) perform well both in terms of energy savings and cost.

Given the limited sample, our conclusions are tentative regarding general cost-effectiveness of different construction types, but the analysis framework provides the tools to increase our understanding of "what works" as more houses are added to the database.

4. CONCLUSIONS

Analysis of energy conservation efforts requires attention to many different variables that affect building energy use. A careful analysis of occupied buildings can help identify those variables which should be included in evaluation of energy conservation programs. In this paper we describe the analysis framework that we use to evaluate a wide variety of new and retrofitted buildings, point out some of the limitations of the analysis, and present results for several hundred projects representing thousands of buildings. Evaluation of the technical performance and cost-effectiveness of conservation efforts based on *measured* energy consumption data is an important and useful tool for various social actors, from a family making decisions about their individual house to a government or utility planner making decisions about thousands of houses. Without this feedback, architects, builders, and policymakers cannot identify successful new designs and retrofit strategies.

We are continuously expanding and revising both of the residential databases, and invite comments and contributions of new data from readers.

5. REFERENCES

1. L.W. Wall, C.A. Goldman, A.H.Rosenfeld, and G.S.Dutt, "Building Energy Use Compilation and Analysis. Part B: Retrofit of Existing North American Residential Buildings" published in Energy and Buildings: Vol.5;3, June 1983.

2. J.C. Ribot, A.H. Rosenfeld, F. Flouquet, and W. Luhrsen Monitored Low-Energy Houses in North America and Europe: A Compilation and Economic Analysis LBL-14788, Lawrence Berkeley Laboratory, March 1983.

3. J.G. Ingersoll, B.S. Wagner, and R.A. Boschen, Fuel Consumption in New and Existing Gas-Heated Single Family Residences, Buildings Energy Data Group Working Paper BED-WR-83-03, Draft, Lawrence Berkeley

4. Energy Information Administration, Residential Energy Consumption Survey: Characteristics of the Housing Stocks and Households, 1978, DOE/EIA-0207/2, Feb. 1980.

5. S. Meyers, Residential Energy Use and Conservation in the United States LBL-14932, Lawrence Berkeley Laboratory, March 1982.

6. NAHB, National Association of Homebuilders Single Family Detached Construction Practices, National Association of Home Builders Foundation, 1979, 1976, 1973. Rockville, MD 1980, 1977, 1974.

6. Acknowledgements.

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TABLE 1. SUMMARY DATA ON UTILITY AND LOW-INCOME CONSERVATION PROGRAMS

LABEL	NUMBER OF HOMES	LOCATION	SPONSOR	HDD (F)	RETROFIT MEASURES	ANNUAL HEAT BEFORE (KWH)	SPACE CONSUMP SAVINGS (KWH)	COST OF RETRO FIT (83$)	CCE (DISC RATE =7%)
E 1.1	69	TENNESSEE	TVA	4436	IA,IF,CW	11270.0	6122.0	705	1.26
E 1.2	105	TENNESSEE	TVA	4421	IA	12383.0	4112.0	296	0.68
E 2	546	TENNESSEE	TVA	4010	IA	10148.0	2211.0	443	1.89
E 4.1	973	OREGON	PACIFIC PWR & LIGHT	4905	IA,IF,WM,DR,CW,WH	12060.0	3980.0	2007	4.25
E 5.1	133	SEATTLE,WA.	SEATTLE CITY LIGHT	5185	IA,IF	17110.0	4180.0	525	1.18
E 6.1	6289	WASHINGTON	PUGET POWER	5500	IA,IW,IF,WM,DR,T,WH	19336.0	7903.0	1444	1.59
E 7.1	300	PORTLAND,ORE	PORTLAND GEN ELEC	4792	IA,IF,WM,DR,WH,CW	11900.0	3500.0	1863	4.47
E 9.2	810	E. WASH./IDAHO	WASH. WATER POWER	6835	IA,IF,DR,WM	18137.0	4349.0	1515	3.29
E 11.1	195	ORE,WASH,MONTANA	BPA/ORNL	5324	IA,IF,IW,DR,WM,CW	15740.0	4130.0	2312	4.96
E 13.1	183	SEATTLE,WA.	SEATTLE CITY LIGHT	5185	IA,WM,IF,WH,IW,ID,CW	14320.0	2380.0	1743	5.71
E 14.1	293	SEATTLE,WA.	SEATTLE CITY LIGHT	5185	IA,IF,IW,WH,ID,CW	10555.0	2555.0	1569	4.87
E 16.1	208	PORTLAND,ORE	PORTLAND GEN ELEC	4792	IA,IF,WM,DR,WH,CW	11880.0	3800.0	1841	4.10
E 17.1	101	BOISE,IDAHO	IDAHO POWER CO.	5833	IA,IF,IW,WM,ID,CW	12080.0	2180.0	1096	4.75
						(MBTU)	(MBTU)		
G 18.1	17	ST PAUL,MINN	CSA/NBS	8159	IX,WM,CW	180.9	39.3	2316	6.47
G 19	30	LUZERNE CTY,PA	DOE/LOW-INC. WEATH.	6277	IA,CW,WM	157.9	23.7	1008	4.67
G 20	89	LOUISIANA	DOE/LOW-INC. WEATH.	1800		48.3	14.2	1230	9.51
G 1	11	WISCONSIN	DOE/LOW-INC. WEATH.	7597	IA,IF,CW,WM,WR,WH	120.3	20.8	1829	9.65
G 21.1	21	KANSAS CITY,MO	DOE/LOW-INC. WEATH.	5161	IX,CW	135.0	20.0	623	3.42
G 21.2	45	KANSAS CITY,MO	DOE/LOW-INC. WEATH.	5161	IX,CW	196.0	44.0	780	1.95
G 21.3	44	KANSAS CITY,MO	DOE/LOW-INC. WEATH.	5233	IX,CW	191.0	52.0	2092	4.42
G 22	138	KENTUCKY	DOE/LOW-INC. WEATH.	4729	IX,WM,DR,CW	118.5	15.7	334	2.34
G 23	30	INDIANA	DOE/LOW-INC. WEATH.	5577	IA,IF,CW,HS,WH	182.1	46.4	1965	4.65
G 28	12	CHAMPAIGN, ILL.	UNIV. OF ILLINOIS	5773	IA,IW	133.7	40.2	1285	2.92
G 30	71	DETROIT,MICH.	MICH. CONSOL. GAS CO	6258	IA	255.2	33.9	521	1.45
G 11	84	RAMSEY COUNTY,MINN	NORTHERN STATES PWR.	8159	IA,CW	156.7	11.8	374	2.99
G 12.1	33	BAKERSFIELD,CA	PACIFIC GAS & ELEC.	2185	IA	83.0	14.9	573	3.63
G 12.2	16	FRESNO,CA	PACIFIC GAS & ELEC.	2650	IA	61.5	19.6	560	2.70
G 13	33000	COLORADO	PUBLIC SERVICE CO.	6016	IA	119.2	19.6	416	2.01
G 14.1	8	OAKLAND,CA	CSA/NBS	2909	IA,CW,WF	76.1	2.2	360	18.31
G 15	18	ST LOUIS,MO	CSA/NBS	4750	IX,WM,CW	174.7	17.4	2342	14.78
G 16	10	CHICAGO,ILL	CSA/NBS	6127	IA,IW,WM,CW,WF,HS,WH,ID,T	264.8	109.7	3086	3.09
G 17.1	16	COLORADO SPRINGS	CSA/NBS	6473	IX,WM,CW,HS	132.0	60.4	2321	4.22
M 5.1	13	EASTON,PA	CSA/NBS	5827	IA,IW,CW,WF,HS,WH,T	121.7	28.6	1190	4.57
M 6.1	14	PORTLAND,ME	CSA/NBS	7498	IX,WM,CW,HS	187.3	81.9	2913	3.90
M 7.1	12	FARGO,ND	CSA/NBS	9271	IX,WM,CW,HS	109.5	43.7	2138	5.37
M 9	65	NW WISCONSIN	CSA	8388	IA,WM,DR,CW	143.0	27.1	355	1.44
M 10.1	59	MINNESOTA	DOE/LOW-INC. WEATH.	8310	IA,CW,DR,WR,WM,IW	110.9	11.3	1295	12.58
M 10.3	19	MINNESOTA	DOE/LOW-INC. WEATH.	8310	IA,CW,DR,WR,WM,IW	103.6	6.9	1214	19.31
M 11	13	WISCONSIN	DOE/LOW-INC. WEATH.	8820		139.3	23.0	1390	6.64
M 12	86	ALLEGAN CTY.,MICH.	DOE/LOW-INC. WEATH.	6801		156.0	44.0	1266	3.16
M 1.1	13	CHARLESTON,SC	CSA/NBS	2146	IX,CW	62.5	21.1	1285	6.69
M 2	8	ATLANTA,GA	CSA/NBS	3095	IX,WM,CW	108.1	14.0	1592	12.49
M 3	4	WASH,DC	CSA/NBS	4211	IX,WM,CW,HS	130.5	61.4	3845	6.88
M 4.1	9	TACOMA,WA	CSA/NBS	5185	IX,WM,CW	168.8	69.0	2376	3.78
O 6	13	VERMONT	DOE/LOW-INC. WEATH.	7876	IA,WM,DR	143.5	43.5	1770	4.47
O 7.1	47	PHILADELPHIA,PA.	IHD/ASE/DOE	4865	HS,OM,T	146.5	27.4	575	2.30

Notes to Table 1

LABEL: This is a projects' identification number. The first letter indicates the fuel type used for space heating (E = electricity, G = gas, O = oil, M = mixed, that is within a sample of homes more than one fuel was used for space heating). The number after the initial letter is simply a counting index to label each different retrofit data sample.

NUMBER OF HOMES: The number of homes for which actual consumption data are analyzed.

LOCATION:

SPONSOR: of the project or program

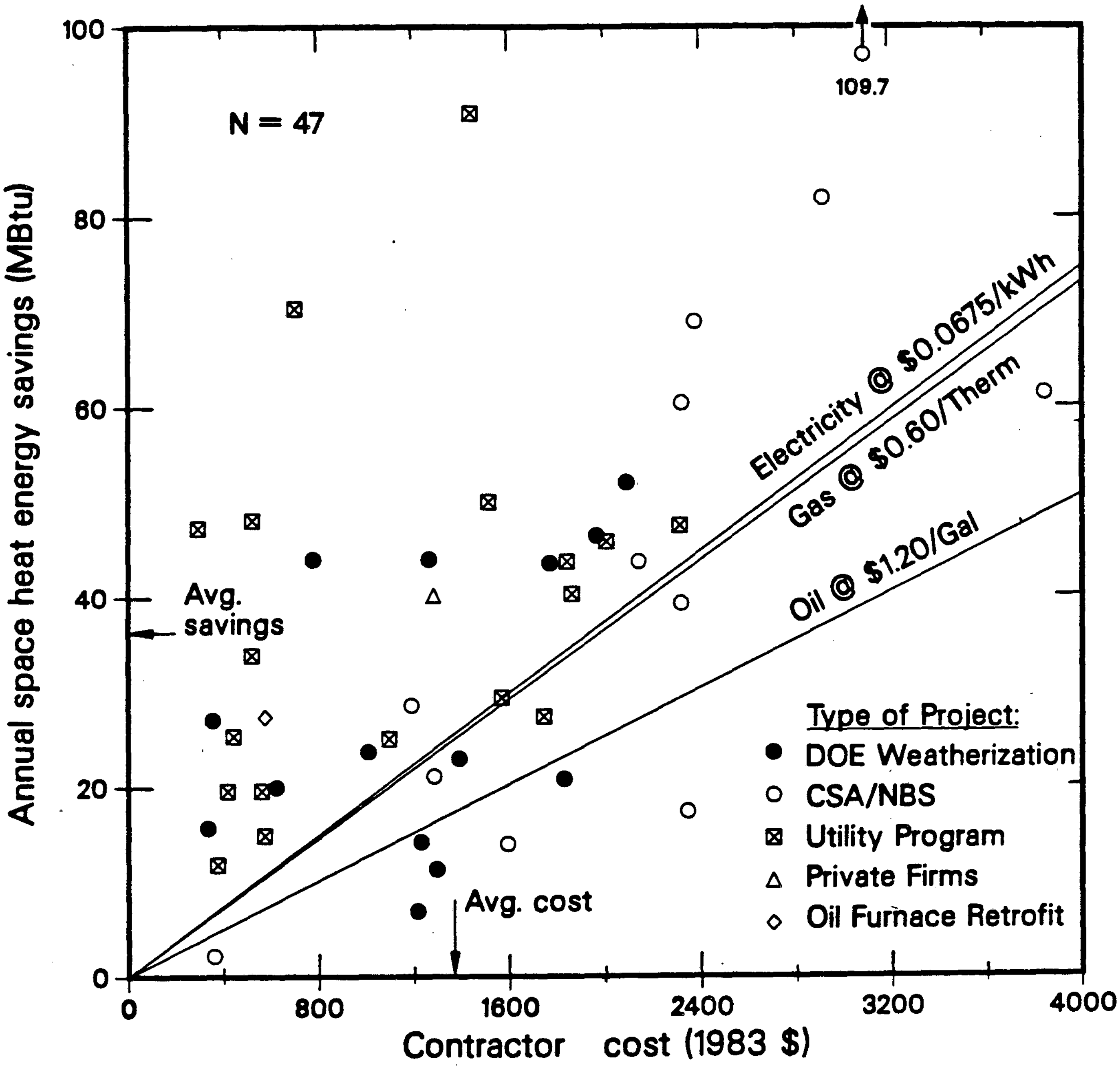
HDD: the long-term value of heating degree-days for that location

RETROFIT MEASURES: The retrofits installed. IA: attic insulation; IW: wall insulation; IF: floor or basement insulation; IX: insulation in other areas, i.e., crawlspace wall or band joist, or location not specified; CW: caulking and weatherstripping; WM: multiple glazing or storm windows; DR: storm doors; HS: equipment replacement or modification of the heating system; OM: operation and maintenance actions to the HVAC system; T: automatic timers or thermostat setbacks (Note: Not all measures listed were necessarily installed in all of the homes in the sample, particularly in the case of utility-sponsored programs. In cases where the information was available from the data source, a measure had to be installed in at least 20% of the homes to be included.)

ANNUAL SPACE HEAT CONSUMPTION (BEFORE & SAVINGS): The space heating portion of total household energy consumption derived from fuel or electricity bills except in those few cases where a specific end use (e.g. space heating) is sub-metered. Expressed in KWh for electric space heated homes and MBtu for homes heated with various fuels (natural gas, fuel oil).

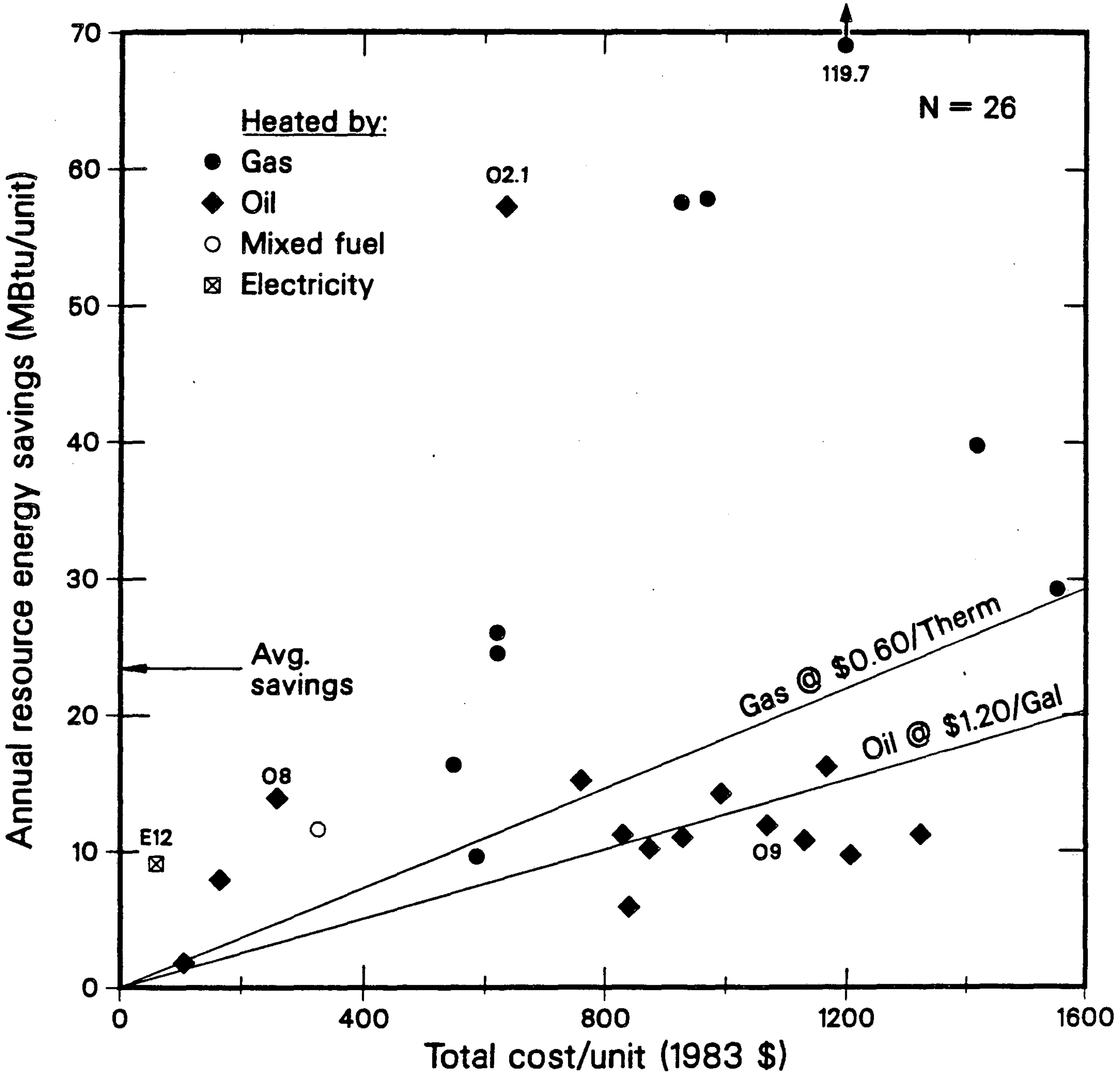
COST OF RETROFIT: the installed contractor cost at the time of retrofit is expressed in constant dollars (1983 $) using the GNP Deflator Index

COST OF CONSERVED ENERGY (CCE): CCE is found by dividing the annualized cost of the retrofit by the annual energy savings due to the conservation investment. The first cost is converted to an annual cost by computing a capital recovery rate using a 7% real discount rate and the estimated useful lifetime for that measure or package of measures. In Table 1, units for CCE are in cents/KWh for electric homes and $/MBtu for fuel heated homes.



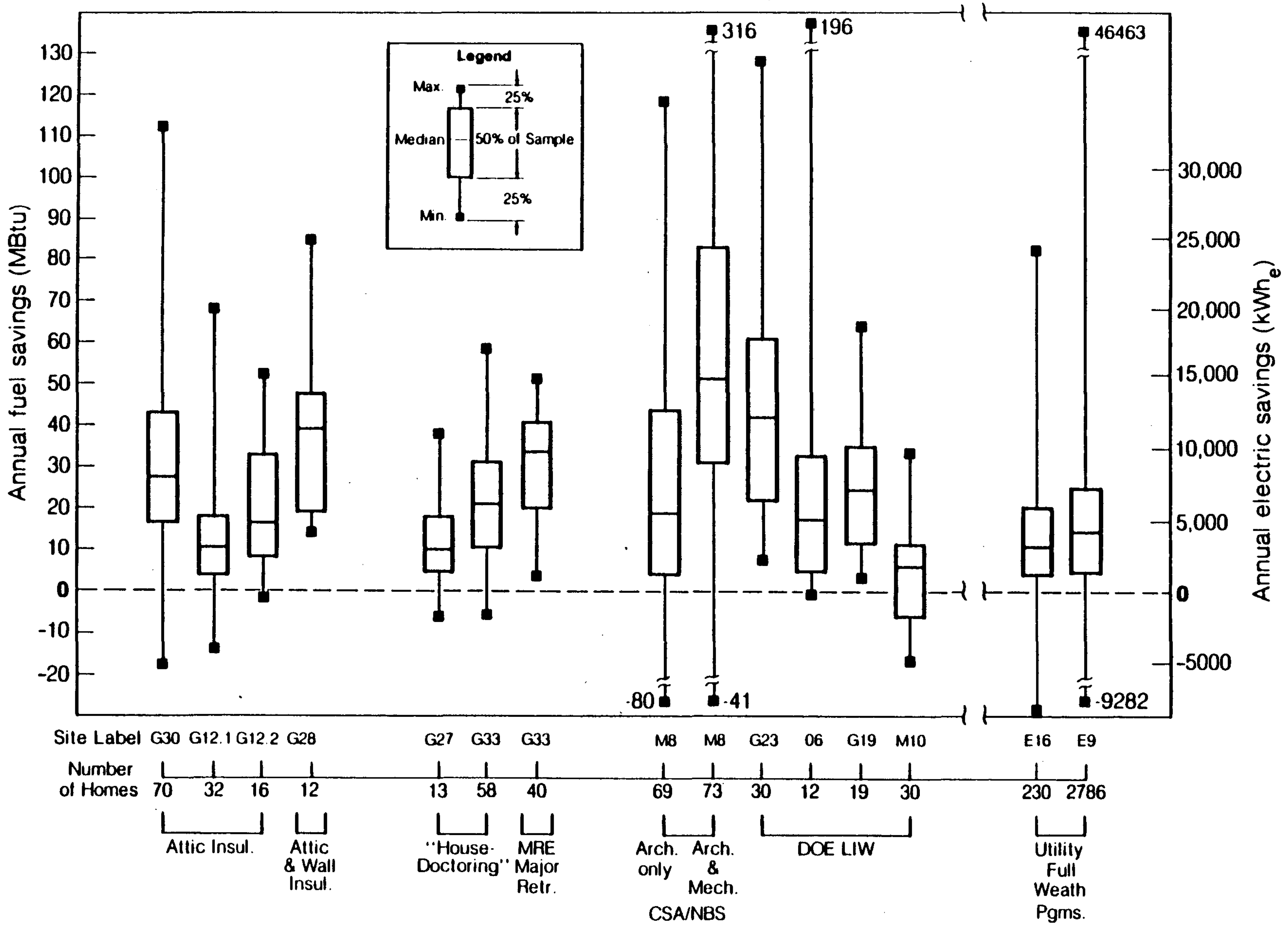
XCG 839-7233

Figure 1. Annual space heat energy savings are plotted against the first cost of the conservation investment for 47 utility-sponsored and low-income weatherization programs. Average space heat savings are 36.3 million Btu (MBTU). 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 are converted to a single present value, assuming 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 price line. Electricity is measured in resource units of 11,500 Btu per kWh sold.



XCG 839-7232

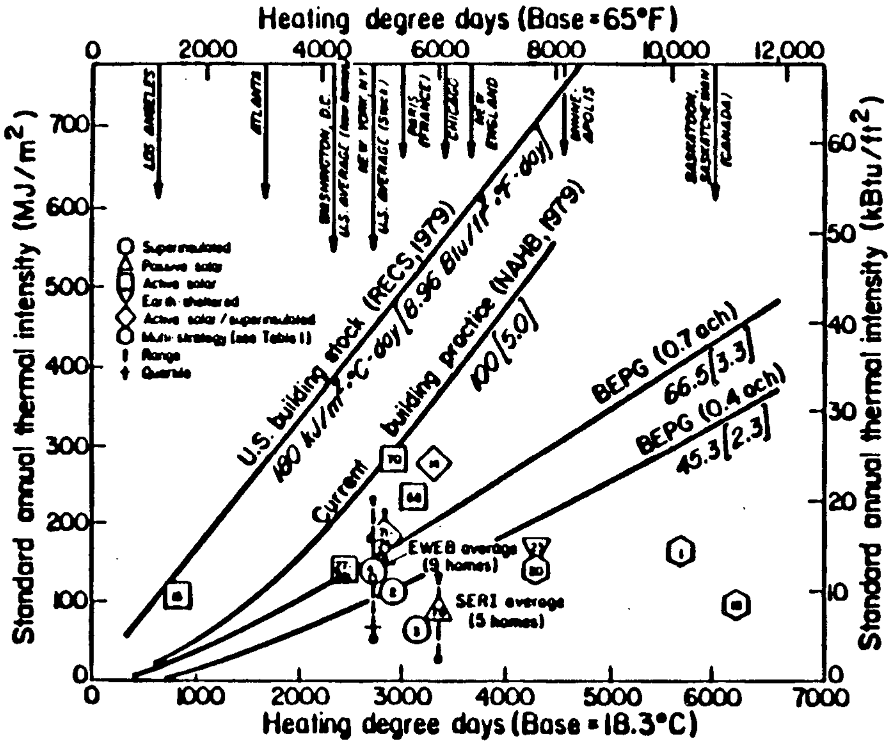
Figure 2. Annual energy savings are compared to the total cost of the investment for 26 multi-unit buildings. The buildings range in size from 5 to 1790 units, but 68% of the sample represents buildings larger than 50 units. Annual mean savings are 23.4 MBtu. In most cases, the savings apply to space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



Range of Fuel and Electric Savings Among Households

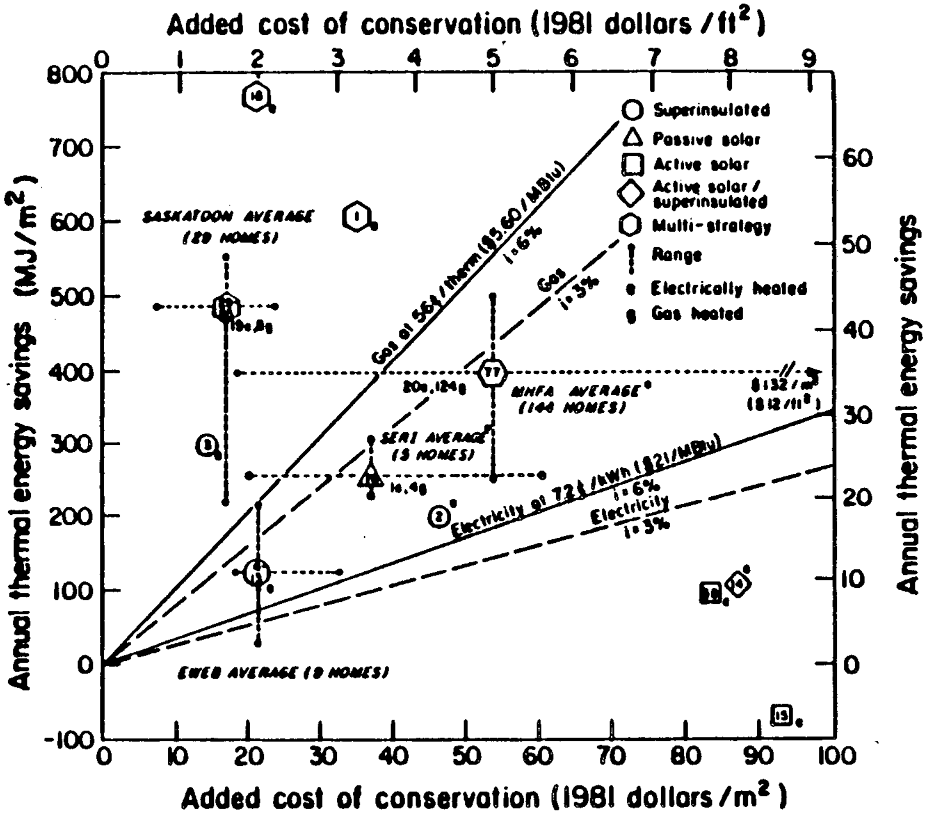
XBL 838-567

Figure 3. The wide range in annual fuel or electric savings among households is illustrated. We note the large variance in energy savings among households that installed the same measure. For example, maximum energy savings are 2 to 7 times greater than the median value among homes in the same area that installed attic insulation or received a 'house-doctor' infiltration-reduction treatment. The wide variation in savings among participants in utility or low-income complete weatherization programs is not unexpected. In these programs, residents have the option of installing from one to many measures; hence, there are varying changes in the structural condition among different homes and wide variation in investment levels.



XBL 827 – 866

Figure 4.
Twenty-nine building scatter plot of "standardized" thermal intensity vs. climate. The various comparison curves are defined in the text. The average thermal intensity per degree-day for our 29 buildings is 46 kJ/m²DDC, or half of the current building practice.



XBL 8211-7301

Figure 5.
Ninety-two building scatter plot of annual energy savings vs. added first cost of conservation and solar features. The energy savings represent the difference between the home's annual thermal intensity and the current building practice line of Figs. 4. The reference lines drawn from the origin represent the boundary of conservation cost-effectiveness against recent U.S. average residential energy prices for electricity (7.2c/kWh) and gas (56c/therm). Since conservation is typically a "one time" investment, the future stream of energy savings for 30 years are converted to a single present value, assuming 6% or 3% real interest rate. The home is cost effective if its point lies above the reference line in question.

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