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ABSTRACT

The need for actual consumption data to track accurately the improving energy efficiency of buildings is being addressed by the Buildings Energy Data (BED) Group at Lawrence Berkeley Laboratory. We summarize results to date from our Building Energy Use Compilation and Analysis (BECA) studies, which include time trends in the energy consumption of new commercial and new residential buildings, the measured savings being attained by both commercial and residential retrofits, the cost-effectiveness of buildings energy conservation measures, and the validation of building energy computer programs. We also examine recent comparisons of predicted vs. actual energy performance, and present the case for building energy use ratings.

1. INTRODUCTION

In 1981, 35 percent of U.S. resource energy consumption was used by the buildings sector. For existing buildings, it has been estimated that half the current energy consumption could be saved by careful

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retrofitting [SERI 1981]. In the case of new construction, commercial buildings and houses can be designed to use one-half or less of the energy of the pre-1975 stock [SERI 1981]. In this article, we wish to discuss how much progress has been made in the past few years towards energy-efficient buildings.

Much of the research conducted by the Energy Efficient Buildings (EEB) Program at Lawrence Berkeley Laboratory (LBL) [EEB Program 1982, 1983] can be classified under the heading of "Methods of Assessment of Buildings Energy Use," which is the subject of Session 8 at this Congress. The assessment research can be roughly divided into three parts: simulation tools, collection of primary data, and compilation of energy performance data. The first two of these are briefly mentioned below whereas the third topic is treated extensively in this paper.

There have been numerous contributions by the EEB Program towards the development of computer simulation tools for building energy design and retrofit purposes. Some examples are as follows [for detailed references, see EEB Program 1982, 1983]:

- o the public-domain computer program DOE-2.1 and its predecessors (Cal-ERDA, DOE-1.4, and DOE-2.0) with the capability of very detailed studies of building energy use analysis;
- o analytical models for daylighting such as QUICKLITE, SUPERLITE, and DOE-2/DAYLIGHT;
- o the public-domain microcomputer program, CIRA (Computerized Instrumented Residential Audit), which is designed to give fast and accurate residential audits.

The development of new measurement and diagnostic techniques and the collection of primary data from field studies and component tests are also important elements in the assessment of energy use. Some samples of the applicable work by the EEB Program are listed [for detailed references, see EEB Program 1982, 1983]:

- air infiltration and house doctoring measurements in houses throughout the country (Midway, WA, Eugene, OR, Rochester, NY, Walnut Creek, CA, etc.);
- controlled field tests of fenestration system performance by use of the MoWiTT (Mobile Window Thermal Test) facility;
- measurements of indoor air quality in residential and non-residential buildings;
- the development of a low-cost (approx. $500), microprocessor-based, solid-state data logger called the ESM (Energy Signature Monitor) that can make long-term measurements (up to 10 channels of data and unattended for 5 weeks) of energy utilization in buildings.

The analysis of energy usage data to assess progress in the energy efficiency of buildings is being conducted by the Buildings Energy Data (BED) Group at LBL. Metered values of energy consumption are necessary to determine the performance of new buildings and the savings due to retrofits. Good cost data are needed to assess the cost-effectiveness of conservation measures. In the past there has not been a systematic tracking of measured data in order to determine what progress has been made towards the goal of energy-efficient buildings. The BED Group is concentrating its efforts in that direction, establishing a series of data bases that deal with new and existing commercial and residential buildings, appliances and equipment, and the validation of computational tools for estimating energy usage. These data bases provide the factual data needed for load forecasting, policy and program design, and the evaluation of conservation efforts in the buildings sector. In this paper we summarize the major results from our buildings energy data bases.

2. THE BECA DATA BASES

Millions of existing buildings have now been retrofitted and a significant number of new buildings designed and built to save energy compared to conventional construction. Good quality, measured data on actual building energy performances, actual energy savings, and costs of achieving low-energy performance or retrofit savings are necessary to assess the progress that the U.S. is making towards more energy-efficient buildings.

The need for compiling actual building energy performance and cost data, critically analyzing it, and periodically publishing the results is being addressed by the Buildings Energy Data Group at Lawrence Berkeley Laboratory. We have initiated the five-part BECA (Building Energy Use Compilation and Analysis) series which consists of the following:

- BECA-A analyzes new residential buildings;
- BECA-B concentrates on residential retrofits;
- BECA-C covers progress in new and existing commercial buildings;
- BECA-D deals with energy-efficient appliances;
- BECA-V assesses the accuracy of building energy computer programs.

In the following sections, we introduce results from the BECA data bases to discuss time trends in the energy performance of new commercial and new residential buildings, the level of success of recent retrofits in both the commercial and residential sectors, comparisons between predicted and actual energy performance, and the case for building energy-efficiency ratings.

2.1 Trends in New Commercial Buildings

In this section we present energy data for office buildings, which have been examined more thoroughly than other types of commercial buildings.

The energy intensity of office buildings grew significantly between World War II and the 1973 Oil Embargo, for three main reasons: 1) the great popularity of glass facades (mainly single-glazed); 2) very intensive area lighting (up to 6 W/ft^2); 3) very large and inefficient HVAC systems. This trend began to change in 1975 when ASHRAE passed its now-famous voluntary Standard 90-75, which recommended a factor of two reduction in annual resource energy use, down to 250 $kBtu/ft^2$-yr, as shown in Figure 1. In many new buildings constructed in the late 1970's this was cheaply accomplished by countering the three trends mentioned previously.

Standard 90-75 was so successful that it was voluntarily revised in about 1980. Recommended lighting power was reduced to no more than 2 W/ft^2, and supplemented with task lighting. The point marked "1985", at 110 $kBtu/ft^2$-yr, was originally proposed by the Carter Administration as a mandatory Building Energy Performance Standard but was recast as a voluntary guideline by the Reagan Administration. The point marked "Optimum" at 70 $kBtu/ft^2$-yr is the estimated Life-Cycle-Cost minimum using 1980 technology, with considerable attention to daylighting and thermal storage. Its first cost is $\$1\text{-}2/ft^2$ (i.e., only a few percent) more than today's typical costs. The buildings need almost no space heat--the 70 $kBtu/ft^2$-yr of resource energy is almost all electricity for lighting, ventilation, and equipment. Also it is reassuring to note (as shown in Fig. 1) that the Swedes are following a similar path, but are a few years ahead of us, and never reached the excesses of our worst buildings. New Swedish office buildings, of which the first of its class was the Farsta Folksam building (plotted at 90 $kBtu/ft^2$-yr), have enough thermal storage to get through a long Stockholm winter with only 6 kWh/ft^2-yr of electricity for routine lighting and equipment, and 20 kBtu/ft^2-yr of district heating.

Also on this graph (Fig. 1) we plot (denoted by "X's") 7 recently-constructed (between 1977 and 1980) U.S. office buildings for which we have actual consumption data. They represent the forefront in energy-efficient commercial buildings and range roughly between 100 and 150 kBtu/ft^2-yr in resource energy usage. These same office buildings are shown as "X's" on Figure 2 where the fuel usage in kBtu/ft^2-yr is plotted versus the site electricity usage in kWh/ft^2-yr. We see that 5 out of the 7 buildings are all-electric, a trend followed by many of the new commercial buildings. Points representing the Swedish, French, and U.S. stocks and the ASHRAE standards are shown for comparison in Fig. 2.

In Figure 3 we display average annual cost of energy per sq. ft. plotted against floor space for three different age groups of office buildings. These data were extracted from the 1982 BOMA Experience Exchange Report [BOMA 1982] for downtown and suburban U.S. office buildings. There were 3 other age groups (20-29 yrs, 30-39 yrs, 40-49 yrs) that were not included because of small sample sizes. We note the following trends:

- o within the same age category, energy costs increase with size over the range shown;
- o comparison of the 0-9 yrs and 10-19 yrs groups shows that for each size category the energy costs are less for the more recently constructed buildings;
- o except for the very large buildings (>600 kft^2), the old buildings (>50 yrs) have lower average energy costs than the more recent buildings (perhaps due to lower comfort levels or fewer amenities).

2.2 Trends in New Single-Family U.S. Homes

In Figure 4 where annual space heating fuel intensity is plotted versus the year of construction, we notice the improving space heating efficiency of U.S. single-family homes over the last ten years. The energy consumption data for new low-energy residences compiled in the BECA-A study at LBL [Ribot, et al. 1982] correspond to annual fuel intensities in the 5 to 25 kBtu/ft^2-yr range. The design techniques include active solar, passive solar, earth-sheltered, superinsulated, and several combinations. For comparison there are points and/or lines representing the U.S. Stock, the average amounts of energy used for appliances and for hot water, NAHB (National Association of Home Builders) new home surveys, and the cost-effective Building Energy Performance Guidelines (BEPG).

With adequate insulation (i.e., 6 inches of fiberglass in the walls and 12 inches in the roof) and double or triple glazing, but no real innovation, the cost-effective fuel intensity today is about 18 kBtu/ft^2-yr. By reducing the natural infiltration from 0.7 air changes per hour (ach) to 0.3, and then supplying 0.4 ach mechanically through a heat exchanger, the cost-effective optimum drops to about 10 kBtu/ft^2-yr. An interesting development is the superinsulated house, consuming about 5 kBtu/ft^2-yr. It uses all the features mentioned so far, plus even more insulation (typically 10 inch walls), has its windows concentrated to the south, and often has insulating window shades for use at night. Even in Canada, where such homes are increasing commonplace, they do not need a conventional central heating system. Instead they use baseboard electric heat, or use tiny radiators supplied by hot water from the domestic water heater.

We see that some of the new homes in the BECA-A compilation are achieving the low consumption levels corresponding to cost-effective optimum practice (15-22 kBtu/ft^2-yr) and superinsulated dwellings (5-10 kBtu/ft^2-yr), and are much more energy-efficient than today's conventional construction, according to NAHB.

In Figures 5 and 6 (taken from LBL's BECA-A publication [Ribot, et al. 1982]) a subset of individual homes in our compilation are displayed in plots of standard* annual thermal intensity vs. heating degree days (Fig. 5) and annual energy savings vs. added cost of conservation (Fig. 6). As before, comparison lines are drawn in the first plot (Fig. 5). We see that the data points generally lie below the current building practice (NAHB) curve, and a number of them are even below the cost-effective (BEPG) curves. In Fig. 6 the annual energy savings, on the vertical axis, is the difference between the annual thermal intensity of each home and the corresponding climate point on the NAHB new building practice curve. There are reference lines representing the boundaries of cost-effectiveness using current residential energy prices. A home is cost-effective if its plotted point lies above the appropriate reference line. From our present limited sample of new homes, it appears that superinsulated and superinsulated/passive homes are the only clearly cost-effective ones.

2.3 Commercial and Residential Sector Retrofits

There is considerable potential for improvements in the energy efficiency of the existing U.S. stock in both the residential and commercial sectors. The initial retrofit efforts are summarized in the present editions of BECA-B [Wall, et al. 1982] and BECA-C [Ross and Whalen 1982].

The picture pieced together from the compilation of "first generation" commercial retrofits is as follows: they are mainly low-investment "proven" retrofits which cost less than $\$1/ft^2$, save approximately 20% in resource energy, and have relatively fast payback times (less than 3 years) and low costs of conserved energy (less than 1981 energy prices). In Figure 7 we see that almost all of the buildings included operations and maintenance (O & M) as part of the retrofit. The second most

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* i.e., normalized for indoor temperature settings and internal gains from appliances and occupants.

popular measure was lighting (mainly delamping and replacements of fluorescent tubes with more efficient ones). The energy savings/ft^2-yr vs. pre-retrofit usage/ft^2-yr are displayed in Figure 8. There is a vague general trend toward increased savings with increased energy use. Wide variations in percentage savings are quite evident. Figure 9 shows the distribution of simple payback periods for the subset of the overall compilation which had complete cost data (excluding "failed" retrofits). Almost 90% of the sample achieved payback periods of three years or less. The median value is in the 1 to 2 year range.

The data base for existing residences includes over 65 retrofit projects (typically aggregates of homes). In Figure 10 the annual resource energy savings are plotted against contractor cost. The sloping reference lines represent the boundary of cost-effectiveness for typical residential energy prices. The conservation retrofit is cost-effective if the data point lies above the purchased energy line for that fuel. We see that a substantial majority of the retrofit projects are cost-effective. The percent savings of space heating energy is plotted against contractor cost in Figure 11. The median value of space heating energy savings is 24% of the pre-retrofit consumption. The data suggest that a $1000 investment in conservation retrofits, on the average, reduced a house's space heating energy consumption by about 25%; a $2000 investment reduced annual consumption by roughly 40%. Figure 12 shows the distribution of simple payback periods for the retrofit projects in the compilation. The median payback time is 7.9 years. Preliminary results reveal that attic insulation, sealing bypass and infiltration losses using pressurization and infrared diagnostic techniques, and wrapping hot water heaters with an insulating blanket are cost-effective retrofit measures.

2.4 Validation of Energy Analysis Computer Programs

BECA-V [Wagner and Rosenfeld 1982] evaluates the accuracy of computer programs in predicting measured building energy use. For commercial buildings, detailed computer programs were accurate to within about 10%

when correct input data were available. Figure 13 summarizes the results of three studies of predicted (DOE-2 and BLAST) vs. measured site energy use in commercial buildings. The eleven buildings represent a wide variety of building types, locations, and HVAC systems. For residential buildings, the accuracy tended to decrease as the quality of the input data decreased, but for buildings with submetered data or detailed audit data the predictions were within 10 to 15% of the actual usage. This is illustrated in Figure 14 where the predictions from DOE-2, CIRA, and HOTCAN are compared with measured usage for residential buildings with no submeters or monitoring. The results are still preliminary since they are based on a small sample: 12 data sets and 50 buildings thus far. Standard weather and occupancy were used to compute the predicted energy usage. We found that input errors can easily swamp algorithm accuracy. Thus far the BECA-V effort has focused mainly on overall heating and/or cooling performance, not on savings or component contributions.

Numerous energy audits have taken place throughout the country for the purpose of estimating costs and savings which would result from retrofitting a commercial or residential building. Little study has been done in comparing the predicted versus actual savings. We present some preliminary results of small samples of buildings taken from our BECA-C and BECA-B studies. Figure 15A displays a plot of predicted vs. actual energy savings for a well-documented subset of 18 individual commercial buildings in the overall retrofit data base. There appears to be no significant correlation between estimated savings and measured results, as is true for the overall group of 60 buildings for which predictions were available. A comparison of actual vs. predicted savings for 9 residential retrofit projects (all but one are aggregates of homes) is shown in Figure 15B. The agreement is reasonably good. Predictions for aggregates of buildings are found to be much better than for a single building. However, the samples thus far are too limited to allow generalizations about the accuracy of energy audit procedures used to estimate savings for commercial and residential retrofits.

2.5 Building Energy Use Ratings

Present U.S. residential building practice, on the average, lags many years behind current cost-effective and achievable levels of energy performance. Part of this delay is due to a lack of credible information about home energy efficiency. Building energy efficiency ratings (or labels) are an attractive tool for providing this information and could play the same role for homes as have "miles per gallon" stickers for automobiles and energy use ratings for appliances.

There has existed a well-established tradition, within utilities and the building industry, of labeling and advertising energy-related features of a home (e.g. "Gold Medallion" homes) but in the past most of these features involved increased energy intensity. In 1979 LBL collaborated with Pacific Gas & Electric Company (PG & E) in designing the first quantitative, comprehensive ECH (Energy Conservation Home) Rating Program: an energy point system based on exceeding the State of California Title 24 building standards. The program was quite successful as approximately 66% of the newly connected homes in 1981 (the last year of the program) qualified for the "ECH" rating. Figure 16 plots trends in energy use for newly built homes in PG & E's service area prior to the ECH program, compared to the energy use of an average ECH home or of an optimum home.

Presently there are a number of rating and labeling systems employed. Their accuracy, adequacy, and usefulness still needs to be thoroughly examined. Rosenfeld and Wagner (1982) at LBL propose to use an absolute rating scale (reference point of zero) with the homes labeled in actual energy units or actual dollars instead of "points". They estimate the potential impact of ratings on the market value of efficient homes to be substantial (± $2500). Ratings can be utilized for both new and existing homes and can be updated as the building undergoes changes. Figure 17 displays a sample rating, calculated using LBL's CIRA program for a real house in Walnut Creek, CA. The label is designed to illustrate the home's current rating and offer the homeowner a variety of "target" ratings available to him, and the energy savings resulting from improvements he might choose to make.

Every rating relies on a specified test procedure. There is the standard urban or highway cycle for automobiles and there are standard conditions for testing a refrigerator and other appliances. Likewise the standard use of a home must be defined in terms of number of occupants, appliance usage, thermostat settings, weather, etc. Rosenfeld and Wagner suggest a certification process for rating tools and users and an ongoing monitoring process to support the certification. They believe that the next step should be a pilot project to field-test the whole rating process. Meanwhile the good news is that "Freddie Mac" and "Fannie Mae" (the major wholesale mortgage lenders) have agreed to lend additional money for energy-efficient homes, specifically to raise the "debt/income" ratio from 28% to 30 or 32%.

3. CONCLUSIONS

It is evident that progress is being made in improving the energy efficiency of buildings in the U.S. New products such as heat mirror windows, high-frequency solid-state ballasts for fluorescent lamps, efficient light bulb replacements, and microcomputer control systems are available in the marketplace. Useful analytical methods and models along with computer simulations have enabled scientists, engineers, and architects to gain an understanding of the energy needed for particular end-uses and to design efficient structures. Techniques such as earth berming, superinsulation, thermal storage, and innovations in HVAC systems and controls have decreased the energy requirements for buildings. Better operation and maintenance procedures have reduced energy consumption. Possible problems associated with "tightening" buildings, such as indoor air quality, are being carefully examined.

Preliminary analyses of actual buildings energy consumption data confirm the progress in energy efficiency. New commercial and residential buildings use less energy than the existing stocks. Time trends indicate a steady improvement in the energy efficiency of new construction.

Retrofits in both the commercial and residential sectors have shown a wide range in energy savings and costs but most have been cost-effective--although modest and "conventional" investments. Comparisons of predicted vs. actual results indicate that the prediction tools are generally reliable in the aggregate, but poor for individual buildings. The use of building energy efficiency ratings may be the approach needed to decrease the lag time between actual building practice and cost-effective construction methods.

Collection and analysis of metered energy consumption data for buildings of all types in climate zones throughout the country, for multiple years, are needed to accurately evaluate what progress is being made in the energy efficiency of buildings. Better cost data would improve the economic analysis. We at LBL solicit your data, your references to other possible data sources, and your suggestions so that we can greatly increase the scope and accuracy of our data compilations.

4. ACKNOWLEDGEMENTS

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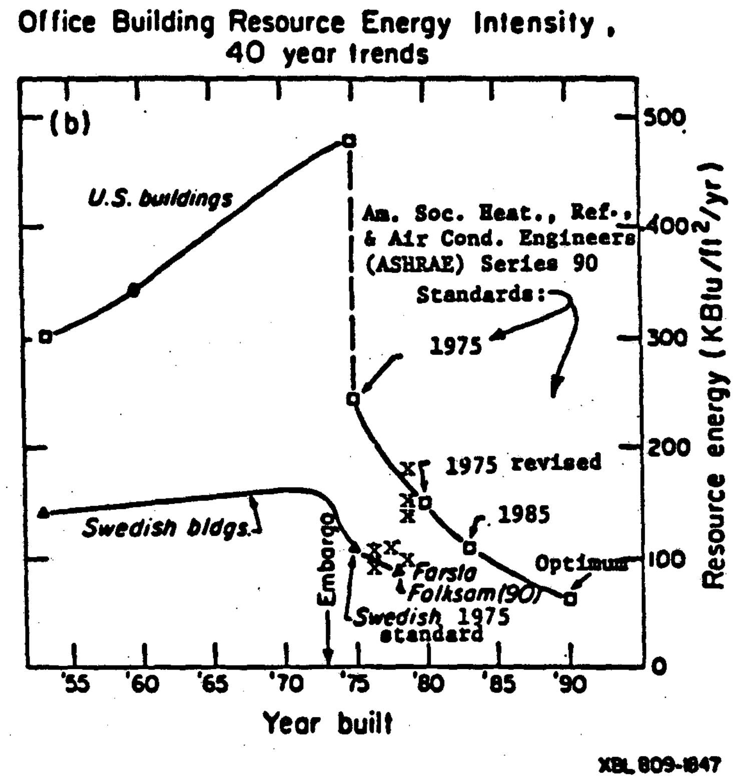

Figure 1. Forty-year trend in annual energy use per unit floor area of new U.S. and Swedish office buildings. Seven recent energy-efficient U.S. office buildings are represented by "x's". Electricity is counted in resource energy units of 11,500 Btu per kWh.

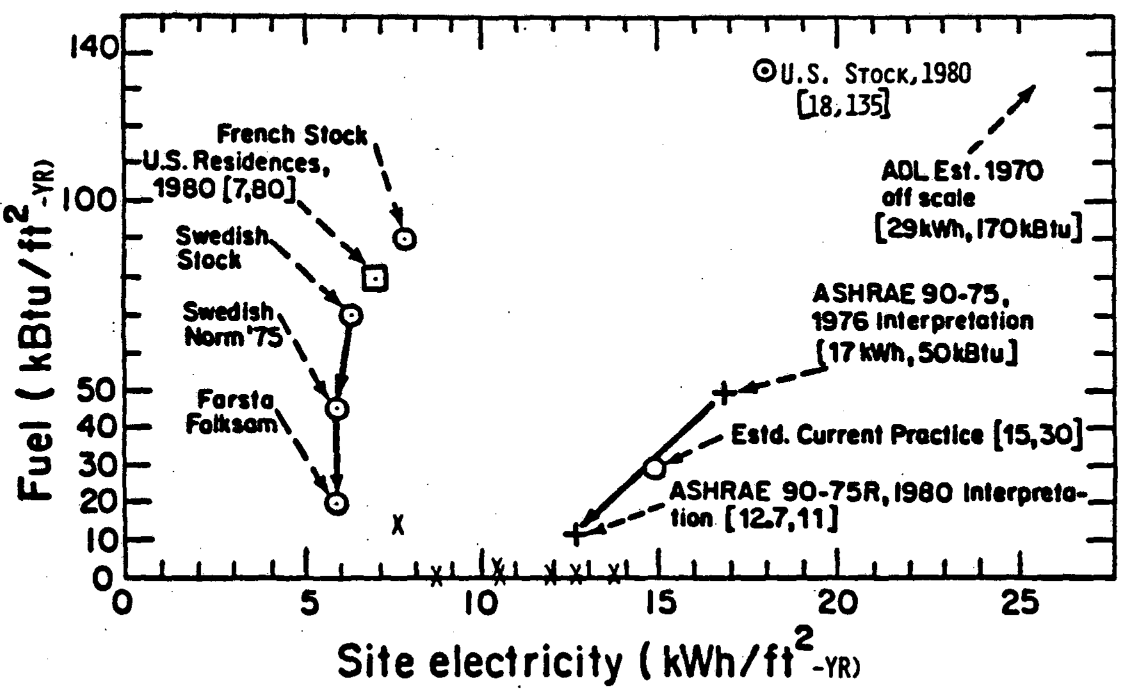

Figure 2. Energy use of existing and new U.S. office buildings. Progress in Swedish building efficiency is shown for comparison. Seven recent energy-efficient U.S. office buildings are represented by "X's".

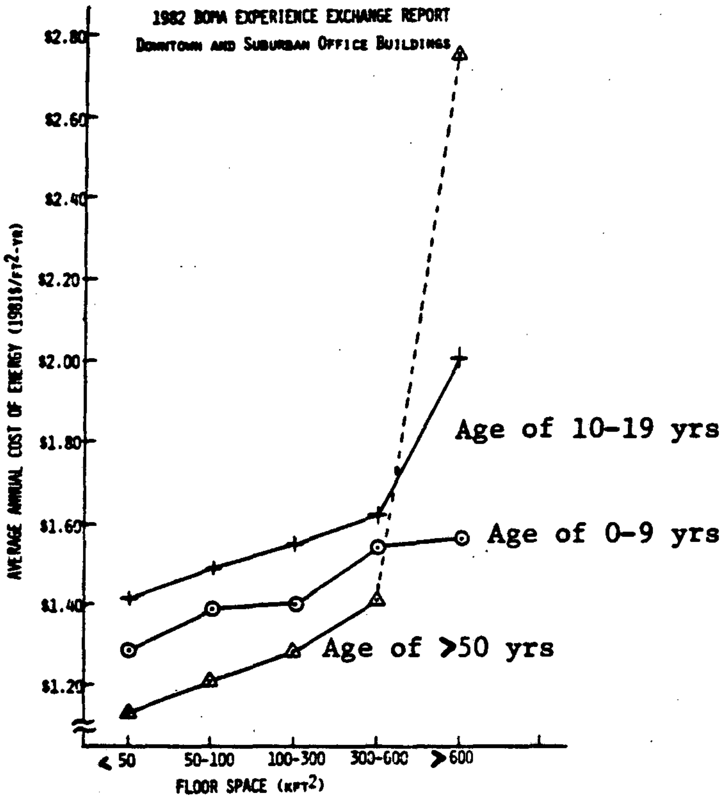

Figure 3. Average annual cost of energy vs. Floor space for three different age groups of BOMA office buildings.

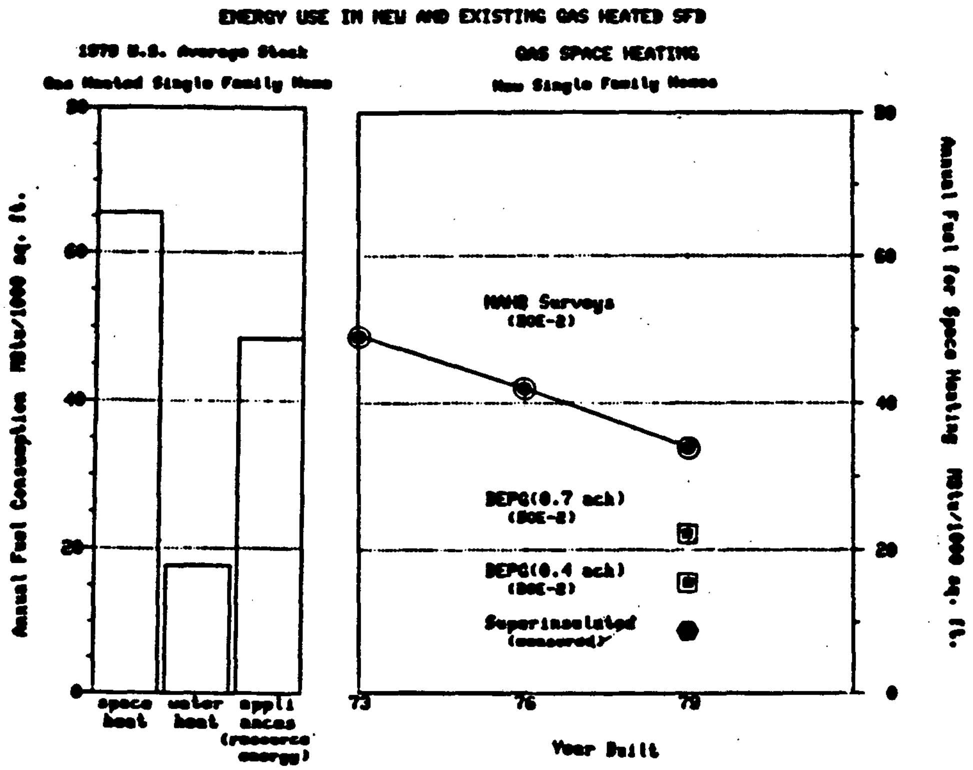

Figure 4. Time trend in annual fuel for space heating in new U.S. single-family homes.

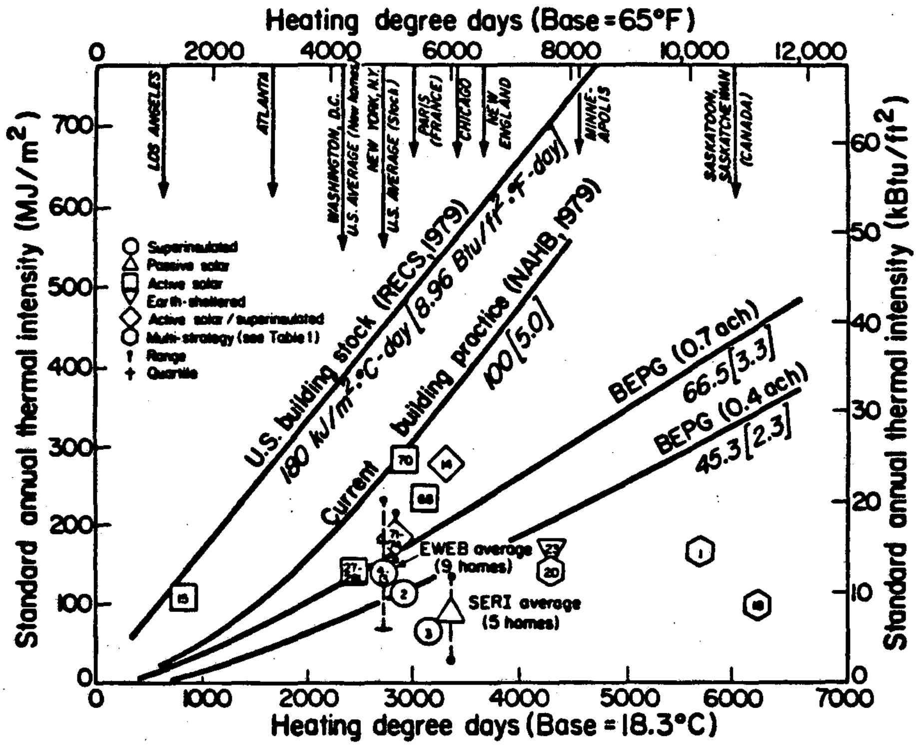

Figure 5. Scatter plot of Standard annual thermal intensity vs. Heating degree days for new U.S. homes contained in BECA-A data base. Various comparison curves are displayed.

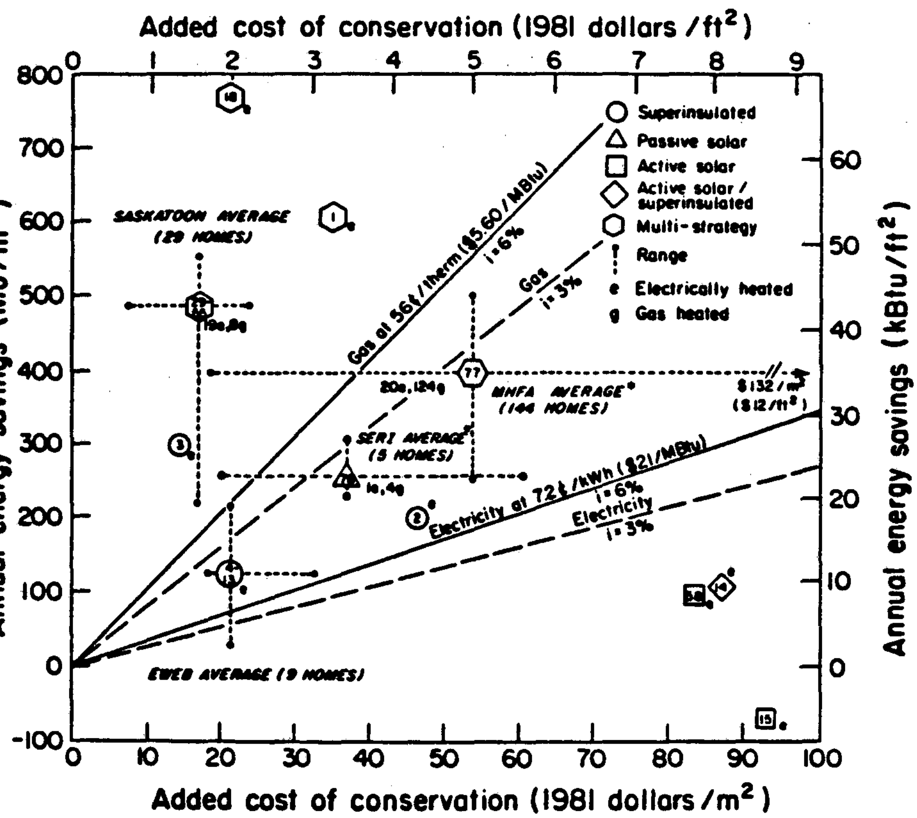

Figure 6. Scatter plot of Annual energy reduction (savings) vs. Added cost of conservation for new U.S. homes contained in BECA-A data base. Cost-effectiveness boundary lines are drawn for reference.

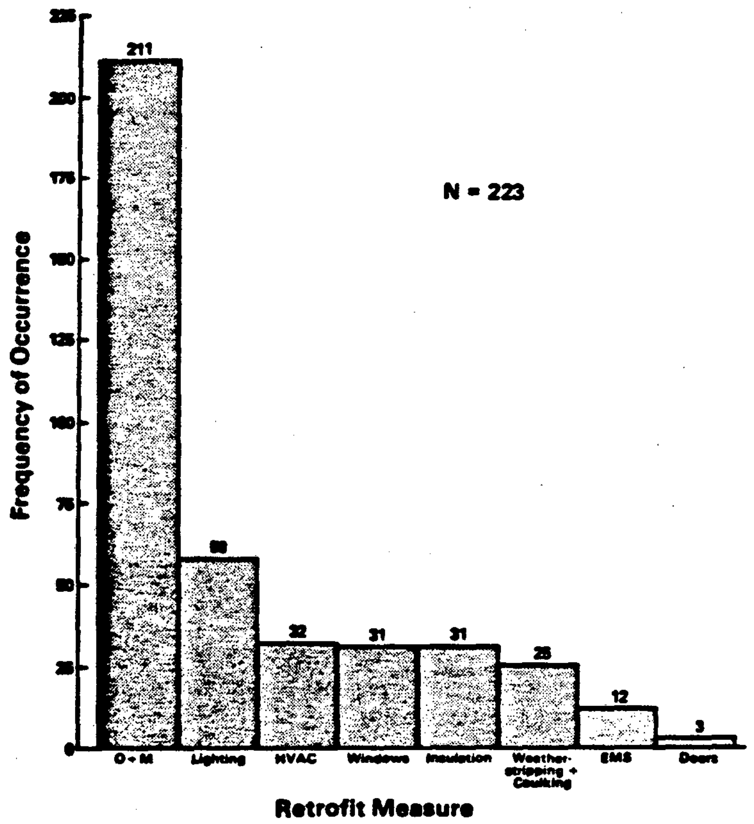

Figure 7. Histogram of installed measures for commercial building retrofits contained in BECA-C data base.

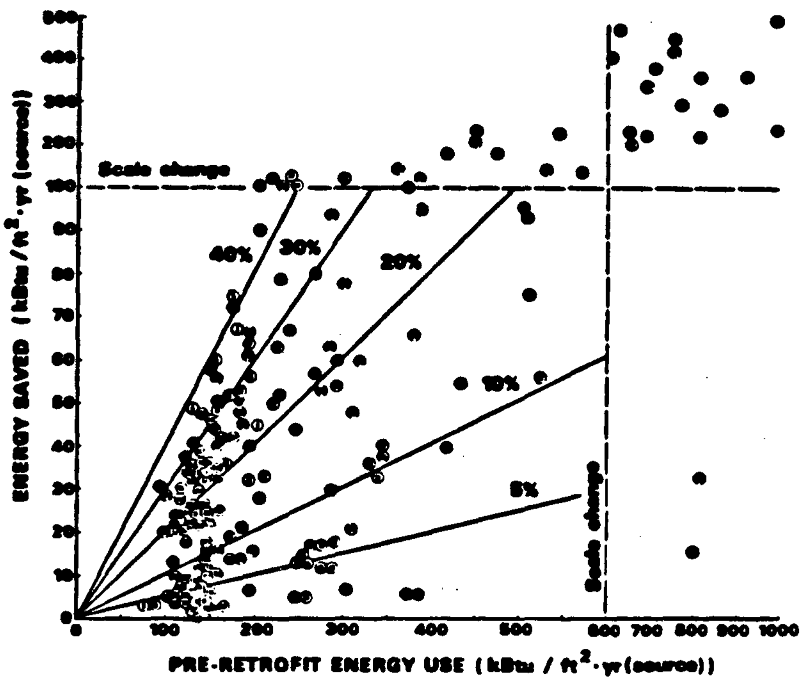

Figure 8. Energy savings vs. Pre-retrofit energy use for commercial building retrofits contained in BECA-C data base. Beware the scale change on the figure. Reference lines corresponding to 5% through 40% savings are drawn.

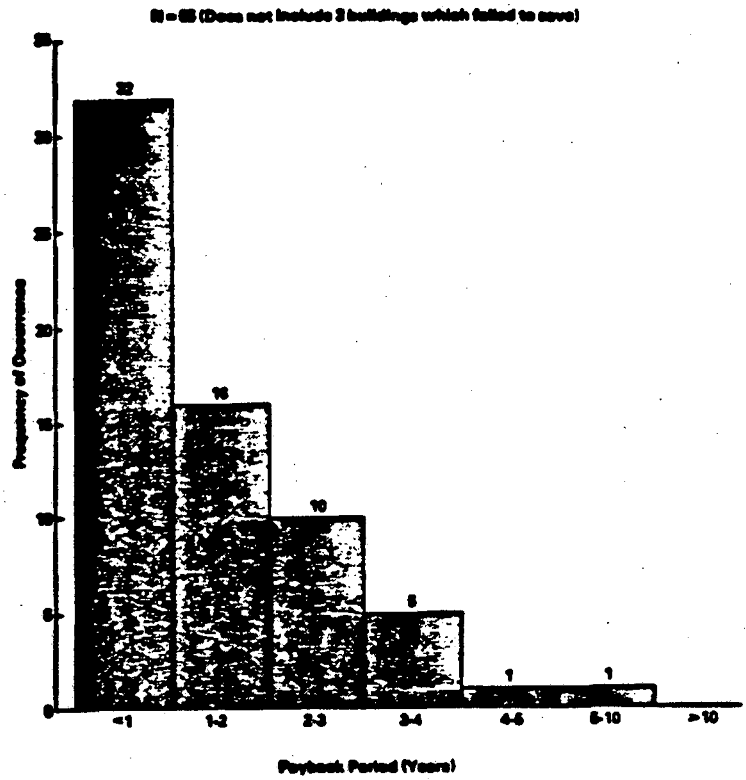

Figure 9. Histogram of simple payback periods for the subset of commercial building retrofits from BECA-C which have complete cost data.

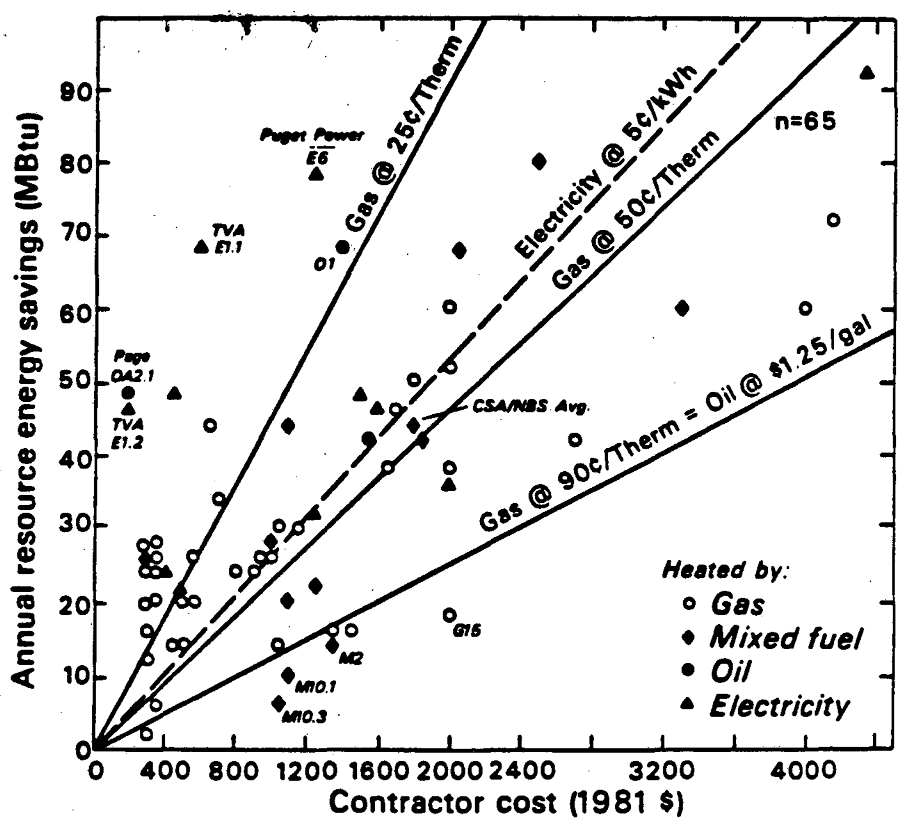

Figure 10. Scatter plot of Annual resource energy savings vs. Contractor cost for the residential building retrofit projects contained in the BECA-B data base. Cost-effectiveness boundary lines are drawn for reference.

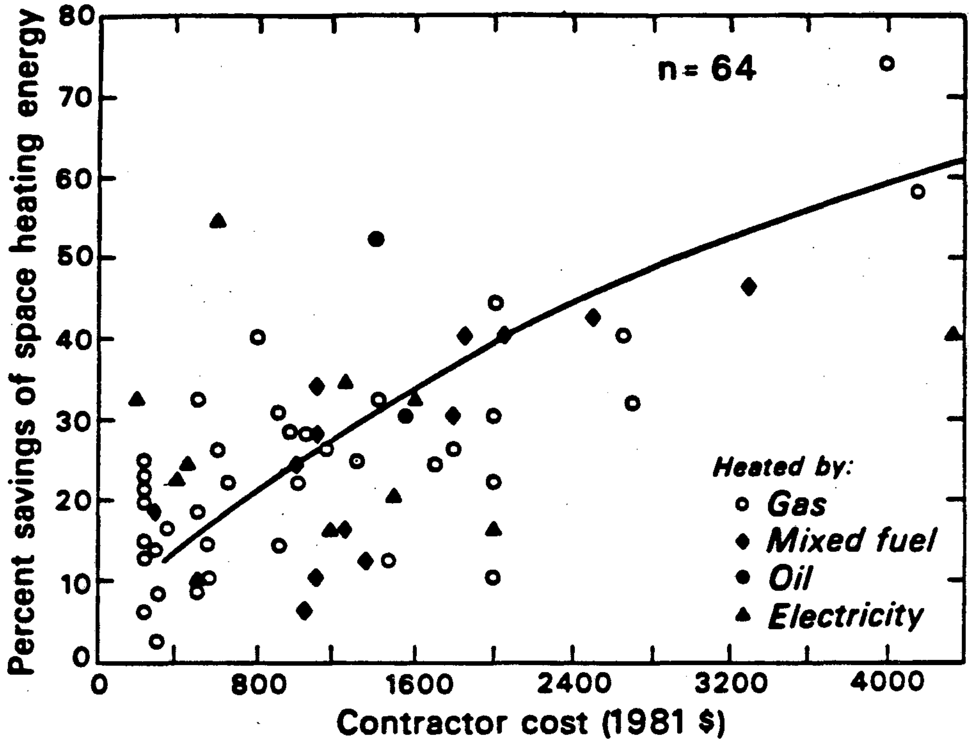

Figure 11. Scatter plot of Percent savings of space heating energy vs. Contractor cost for the residential building retrofit projects contained in the BECA-B data base. An "eye-ball" fit for the data is drawn.

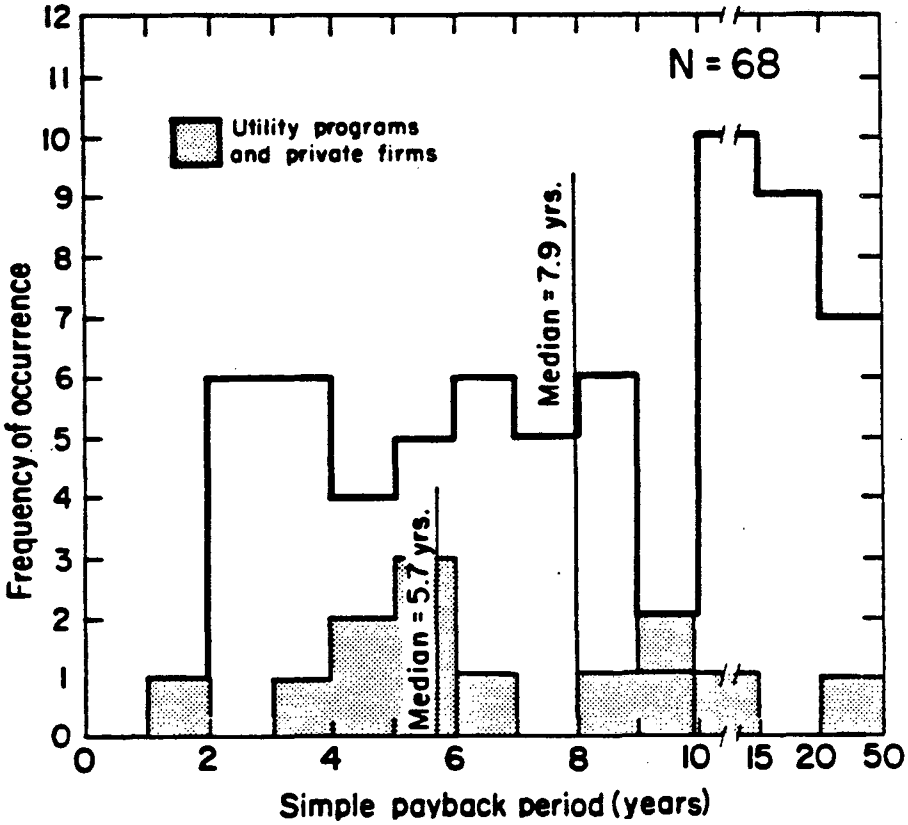

Figure 12. Histogram of simple payback periods for the residential retrofit projects contained in the BECA-B data base.

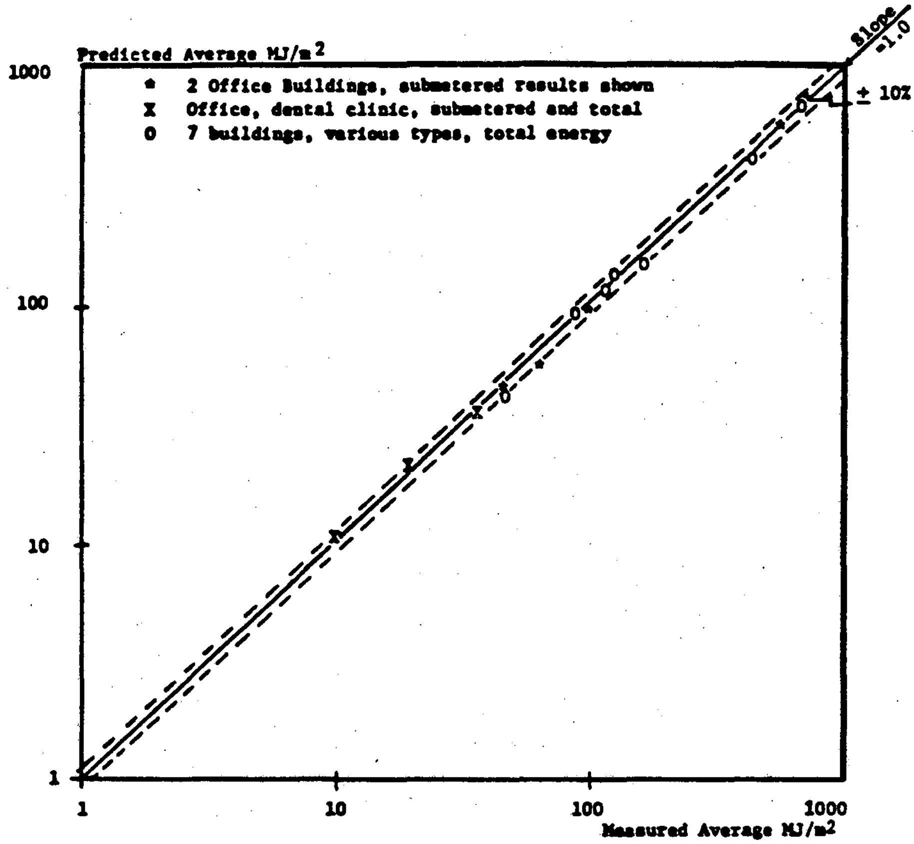

Figure 13. Predicted (DOE-2 and BLAST) energy use vs. Metered site energy use, averaged over metering period (1 month to 1 year), for commercial buildings contained in the BECA-V data base.

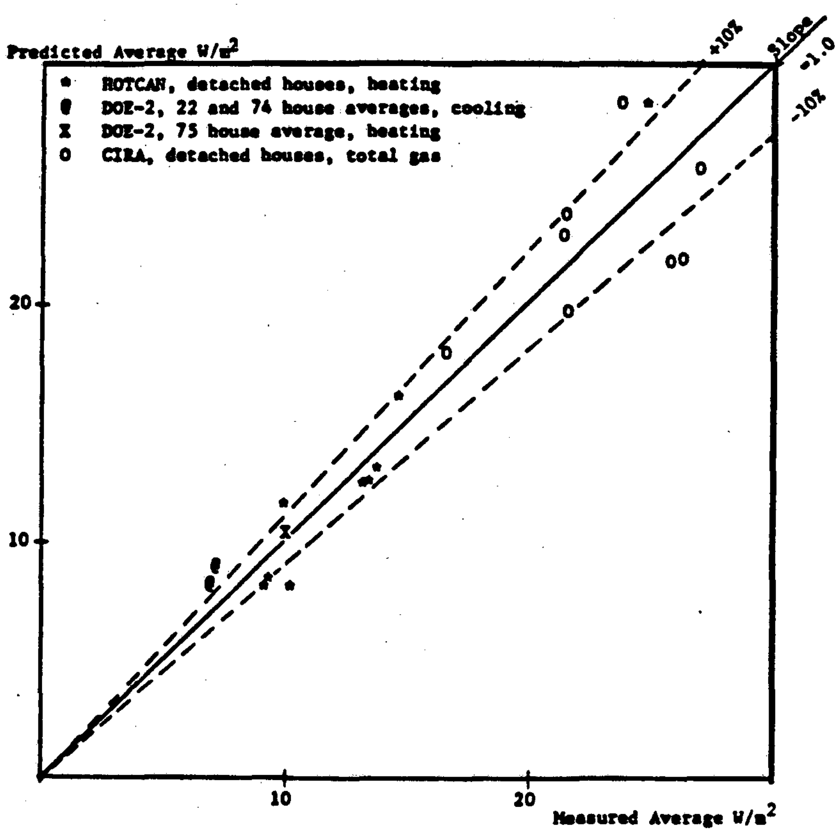

Figure 14. Predicted energy use vs. Measured site energy use, averaged over monitoring period (3 months to 1 year), for residential buildings contained in the BECA-V data base.

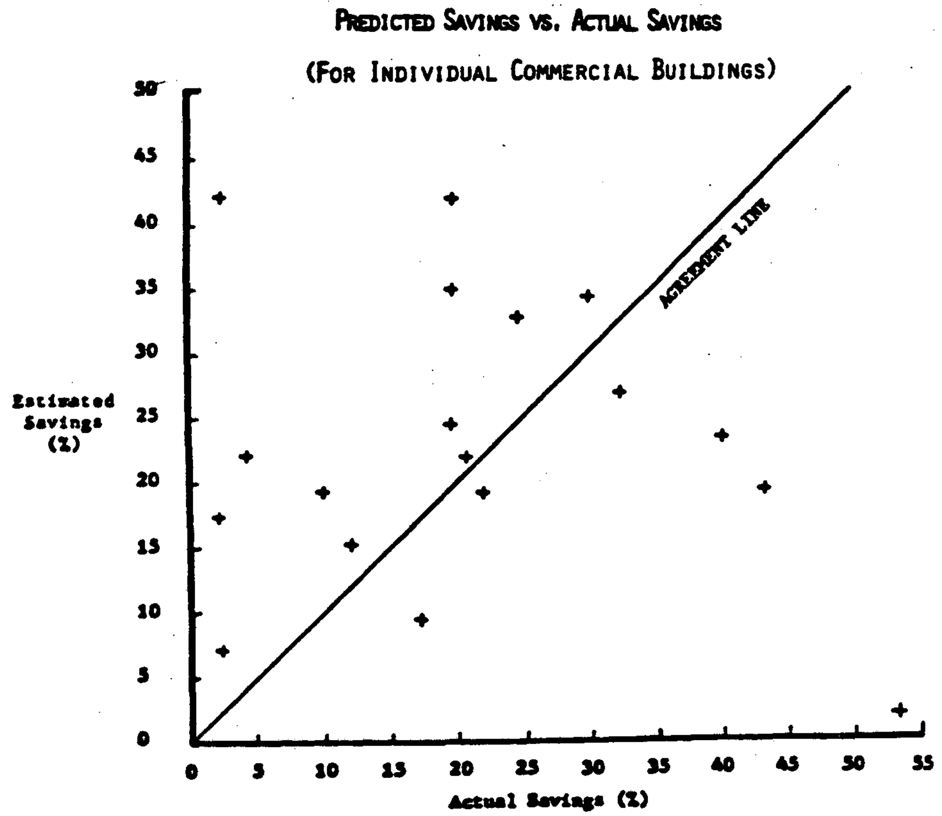

Figure 15A. Predicted vs. Actual energy savings (percent) for 18 well-documented commercial building retrofits, showing little correlation between predictions and measured results. The data points represent single buildings.

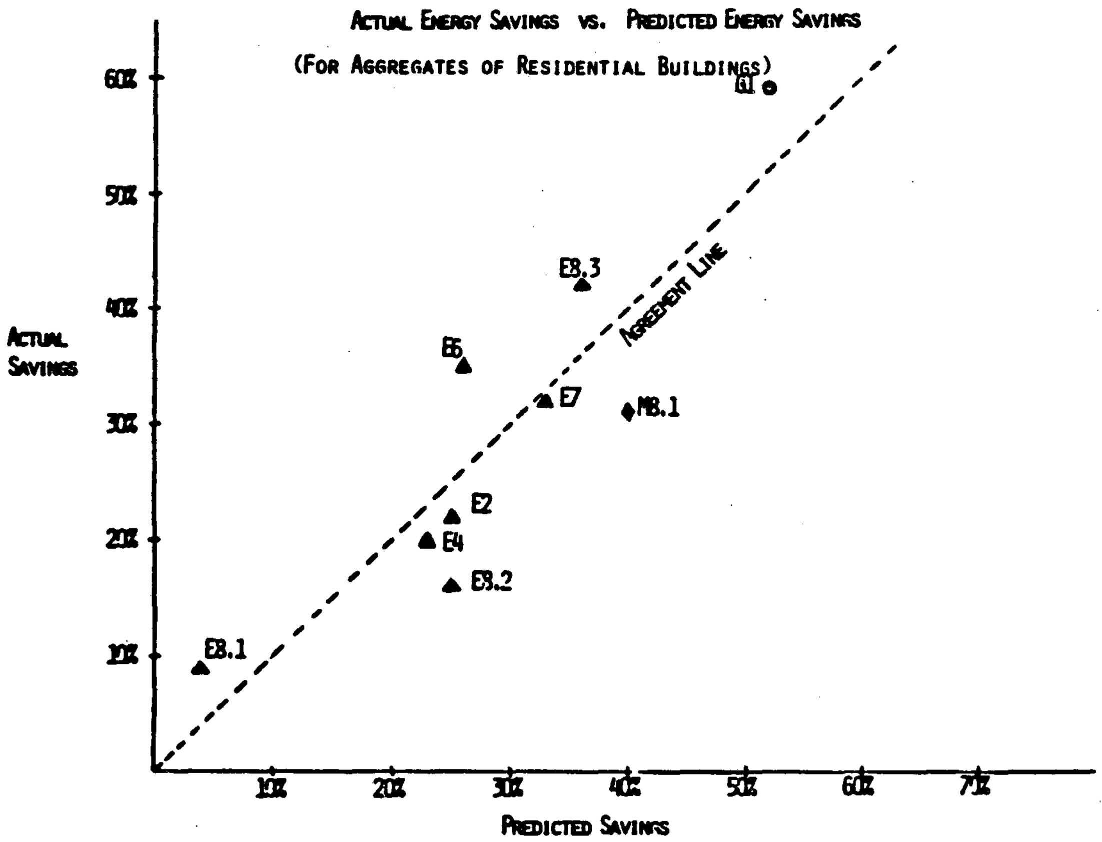

Figure 15B. Actual vs. Predicted energy savings (percent) for 9 residential building retrofit projects, showing reasonably good correlation between predictions and measured results. The data points, except for G1 which is a single residence, represent aggregates of buildings varying in number from 4 to 8802.

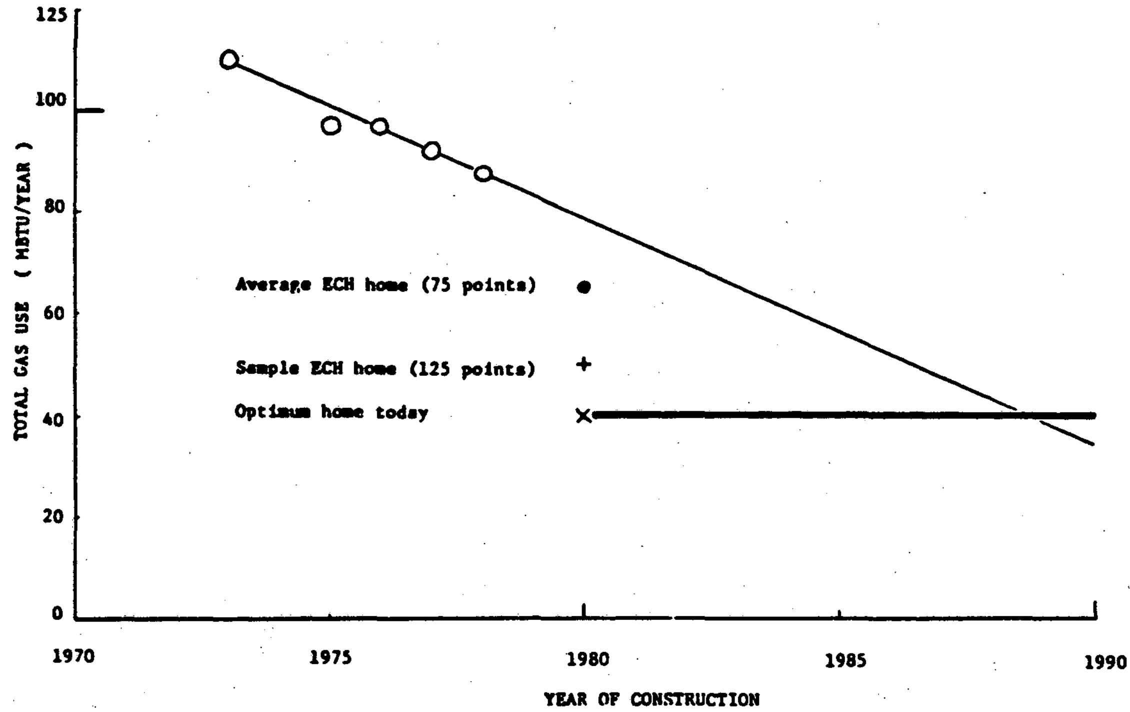

Figure 16. Time trend for total gas use in new homes located within Pacific Gas & Electric Company's service area. Points representing an average ECH home and an optimum home are plotted for reference.

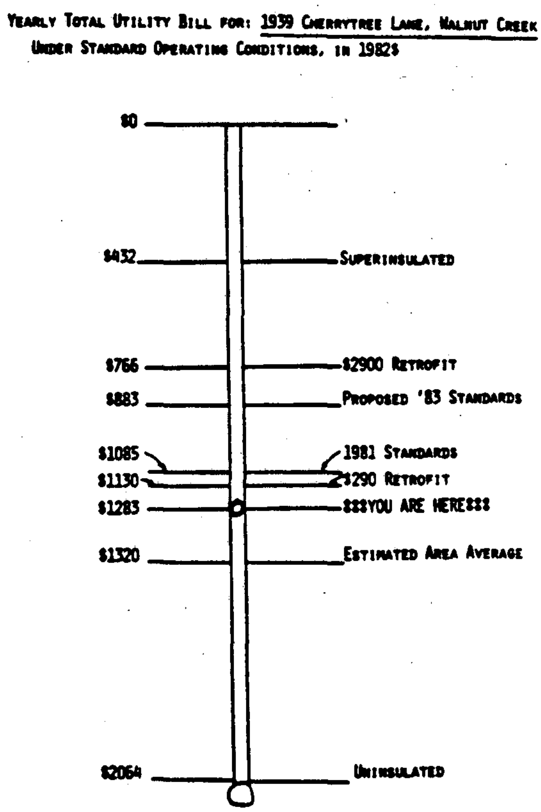

Figure 17. Sample building energy use rating expressed in annual cost of energy for house located in Walnut Creek, CA.

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