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Author
Harris, J.P.

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J.P. Harris

May 1983

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THE ENERGY EFFICIENCY OF CALIFORNIA BUILDINGS:

TECHNICAL POTENTIAL AND PROGRESS

Jeffrey P. Harris

Energy Efficient Buildings Program
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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THE ENERGY EFFICIENCY OF CALIFORNIA BUILDINGS: TECHNICAL POTENTIAL AND PROGRESS

Jeffrey P. Harris
Buildings Energy Data Group
Energy-Efficient Buildings Program, 90-H
Lawrence Berkeley Laboratory
Berkeley, California 94720
(415) 486-4362

Abstract

Estimates of the technical potential for improved energy efficiency in U.S. buildings range up to 50% of current or projected consumption; this is comparable to estimated potential in French buildings. Several "conservation potential" studies in California show varying estimates of savings, but generally less than 50%. Targets for "achievable" conservation in California, used in forecasting future energy demand and planning conservation programs, are even lower. Still, they represent potential savings of hundreds of millions of dollars in fuel costs and utility capital investments.

It is difficult to find hard data on how much of this conservation potential in California has actually been realized. Most reports are based on judgmental estimates or computer models, rather than measured data. Some measured results are available from other states. The Buildings Energy Use Compilation and Analysis (BECA) data base at Lawrence Berkeley Laboratory now has data from several thousand new and retrofitted buildings. These data are summarized, and compared to building trends and conservation targets in both California and France.

The data show that cost-effective conservation has been widely demonstrated in both new and retrofitted buildings. Yet today's conservation practice has still not achieved the level of savings justified by current technology and energy prices. For the U.S., the most efficient new homes and commercial buildings use only about 1/3 to 1/2 of the energy required by typical construction of a few years ago. Median savings from retrofitting existing buildings are 20-25%. For California buildings we can not draw such conclusions from the available data.

By comparing conservation potentials and savings actually achieved we can identify areas needing more effort. Even among new buildings and appliances that meet California's strict standards, there is a range of efficiencies on the market. This suggests that further savings are possible from non-regulatory approaches (labeling, incentives) and more emphasis on research and product development.

The data show large variations both in energy savings (percent and absolute) and in costs per unit of energy saved. The reasons for this variation are not yet well understood. Also, predicted savings often differ from actual savings, especially for individual buildings. This points to a need for improved models, better quality data, and more effective feedback to building designers, energy managers, and policy-makers on conservation results in actual buildings.

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Introduction

For nearly ten years, California's state and local governments, along with utilities and business firms, have actively encouraged energy efficiency improvements and increased use of renewable energy sources (solar and geothermal heat, wind-generated electricity, and fuel obtained from urban or agricultural wastes). Residential and commercial buildings, although accounting for only about one-third of all energy use, have so far received the most emphasis in energy conservation programs. This may be because of historically high growth rates in both floorspace and building energy use. Also, compared with industrial processes, energy use in buildings is considered easier to analyze and regulate. In contrast to new automobiles, the energy efficiency of buildings is not regulated at the federal level, and is presumably slower to improve as a result of market forces and normal stock replacement.

This paper summarizes several studies of technical opportunities for conservation (including use of solar energy) in California buildings. We then examine the evidence on how much conservation has actually been achieved, and conclude with some comments on remaining conservation opportunities and the need for better data.

Background Data

To put the next sections in perspective, we will briefly compare energy use patterns in California and France, based on published data.[1] In 1981, California's 8.6 M households used a total of 1.08 quads (10^{15} Btu) of resource energy (1130 PJ, or 130 GJ/household). French data for residential energy use a year earlier, in 1980, shows 41.2 Mtep (1 Mtep = 10^6 tonnes equivalent petrole) of resource energy (1725 PJ) for 19.1 M households, or about 90 GJ/household. Reasons why the average French household uses only two-thirds as much energy as a California household include the smaller average floorspace and greater prevalence of multi-family residences in France, lower heating season temperatures (17.8 - 19.5 ^oC), and somewhat lower appliance saturations.

Average annual centigrade heating degree-days (base 18.3^{o}C) in California range widely, from 550 HDD (1000 ^{o}F-HDD, base 65^{o}F) in the Mojave Desert to 4550 HDD (8200 ^{o}F-HDD) at Lake Tahoe. The two biggest population centers are Los Angeles, with about 1100 ^{o}C-HDD and San Francisco, with about 1650. Since Paris, for comparison, has about 2950 ^{o}C-HDD annually, on a population-weighted basis the French climate is significantly cooler than California's.

California commercial buildings, with an estimated 322 M m^2, used about 0.82 resource quads (865 PJ) in 1981, while 1180 M m^2 of French commercial buildings (1979-80) used 19.9 Mtep (833 PJ). This means that the average California commercial building, at about 2.7 resource GJ/m^2, is almost <u>four times</u> as energy-intensive as the typical French building, at 0.7 GJ/m^2.

Part of this difference, however, is due to accounting for energy in resource units, combined with the greater use of electricity in California commercial buildings (where over two-thirds of resource energy is electricity, vs. about one-third in France). The remaining difference is probably due to the prevalence of air conditioning and higher lighting levels in California buildings, less efficient building shells and equipment, and different hours of operation.

Average energy prices for the residential and commercial sector in California (1981) and France (1980) are shown in Table 1. Comparisons should be made with caution, however, since tax levels differ, and the tables do not reflect energy rate structures (time-of-use, peak demand charges, or multiple tiers).

The factors noted above should be kept in mind when comparing conservation potentials or accomplishments in California and France.

California's Conservation Efforts

There are no readily available estimates of how much money is invested each year to improve energy efficiency in California buildings. It is even difficult to define the baseline from which these "additional investments" should be counted. For example, does one include all construction costs related to the State's Title 24 building energy code, or only the cost of features that exceed the code requirements? A second example: how efficient (and how expensive) is the theoretical "average refrigerator" that would have been sold in California in the absence of appliance standards?

Despite these difficulties, I will risk an estimate that: (1) government and utility expenditures for conservation and solar use in California buildings are over $400 million per year (about two-thirds from utilities), and (2) additional private spending by households and businesses is at least $700 M annually[2]. To put these sums in perspective, Californians spend approximately $9.2 billion per year on energy (fuel and electricity) for buildings[3], and total personal income in California was about $265 B in 1981.[4]

Is this substantial investment--over $1 billion/year--a "success" or not? The answer depends on whether current efforts are compared with the extremely wasteful energy practices of the past, or with the identified technical potential. Also, to objectively judge the success of California's conservation efforts requires a carefully documented data base--little of which now exists.

From an aggregate point of view, at least, California's "alternative energy path" appears to be successful. Total annual growth in electricity demand for California buildings was 5-7% prior to the 1974 Arab oil embargo, but future growth from 1980 to 2000 is now projected by the Energy Commission at less than 2% per year.[5] Even including new construction, residential electricity use has actually declined by about 10% over the past five years, while commercial use has increased only slightly. According to Energy Commission projections, residential and commercial natural gas demand will stay constant or even decline slightly over the next twenty years despite 1.5 % annual growth rates in the building stock.

But what do these aggregate demand trends mean for individual buildings? How much has energy demand growth slowed because of improved technical efficiency, rather than better management of buildings or reductions in comfort, amenity, or other energy-related services? And how do energy savings achieved to date compare to the potential savings that might still be achieved (at a cost per unit saved lower than the cost of purchased energy)?

Unfortunately, many of the data to answer these questions for California do not exist. Most studies have had to rely on computer model results or "informed guesses." For example, at present there are no measured data (even at the level of monthly utility bills) on the performance of typical new homes or commercial buildings that meet the Title 24 building code. Also, despite the hundreds of millions of dollars spent each year to retrofit homes and commercial buildings, data on actual energy savings are only now beginning to be collected and analyzed.[6] Appliances and water heaters sold in California must be certified to meet minimum standards of efficiency, but there has been no effort to see how test results compare to efficiency in actual use. As part of a large utility demonstration project, a few such measurements are beginning to be made for solar water heating systems.

As indicated below, in many cases it seems easier to find "hard" data on energy savings and cost-effectiveness of conservation from other states, despite California's widely perceived leadership in energy conservation policy. Paradoxically, this may be because energy efficiency and renewable resources in California have been so widely accepted among consumers, utilities, and political leaders that there has been too little insistence on well-documented evidence of results.

<u>Technical Potential for Efficient Buildings</u>

If data on actual results are scarce, there is no lack of studies of conservation potential. One report analyzed the potential for improved efficiency and renewable energy use in all U.S. buildings by the year 2000.[7] Compared to a baseline projection that anticipated buildings energy use increasing from about 27 quads of resource energy (28.5 EJ) today to 34 quads in 2000, the study found that a 50 % reduction in that year 2000 estimate was technically and economically feasible (see Figure 1). This target for the year 2000 also represents an absolute reduction of about one-third below today's energy use in buildings, despite annual additions to the building stock of almost 2 % and an assumed 2.5 % (constant-dollar) annual growth in GNP.

Over two-thirds of the potential savings in the year 2000 would be in electricity use: a reduction of 11.4 resource quads (12 EJ), or the equivalent output of about 228 baseload, 1000 MW_e powerplants.

Lawrence Berkeley Laboratory prepared a similar detailed study of technical opportunities for conservation in the existing stock of California homes.[8] This study identified a potential to save about 35 % of today's residential gas use and 22 % of electricity use (see Figure 2).

A non-profit environmental group recently completed an extensive, well-documented analysis of conservation and renewable energy opportunities in California.[9] The study recommended aggressive actions, by state and local governments and utility companies, to achieve a 1995 scenario of almost no growth in commercial and residential gas use, and growth of only 0.6 % per year in electricity use (almost all in commercial buildings). This slow growth in energy demand was projected despite net annual additions to the building stock of 2.4 % (residential) and 2.6 % (commercial).

In response to requirements by the California Public Utilities Commission, the four large regulated utilities in California have each conducted detailed studies of technical potential for energy conservation in their service areas, and used the results to set goals for their programs.[10] Comparisons among these utility studies is difficult, due to different assumptions about baseline growth in energy demand, some differences in the criteria for estimating conservation potential and goals, and varying approaches to fuel substitution between gas and electricity.

With these cautions in mind, here are examples of the savings shown in the utility studies:

- Between 1980 and 2000, there is a potential to reduce average electricity use per household (for all purposes) by 12-17 %, and average commercial electricity use per square meter by 15-35 %.

- The PG&E study finds that, by the year 2000, space heating and cooling energy for the average existing 1975 home could potentially be reduced by 30 %, while savings in new homes could be as much as 63 %.

- The So. California Gas Co. study projects a potential reduction of 55 %, by the year 2000, between the baseline ("no conservation") forecast and the "maximum conservation" forecast for both residential and commercial buildings.

- The SCE conservation goals for 1987 call for achieving 50 % of the maximum potential savings in commercial building electricity use; this would mean an average annual demand growth of 1.7 %, compared with about 3 % growth in floorspace.

The California Energy Commission is directed by law to forecast future energy demand for the State, including conservation which is "reasonably expected to occur." The Commission has also made various estimates of additional conservation potential which might be achieved with added incentives or regulations. Because the Commission's forecasts are used mainly in regulatory proceedings, as one factor in determining the need for additional powerplants, there has been much controversy over interpretations of how much conservation is "reasonably expected," and how much "additional conservation potential" exists.

Each year since 1977, the Commission's demand forecasts have shown successively lower growth rates. The latest forecast shows both residential and commercial energy use remaining nearly constant from 1980 to 2002 (electricity and gas combined), despite annual growth rates in the building stock of 1.5 to 2 %.[11]

An alternative scenario presented in the same report suggests that additional conservation and solar energy use might lead to an absolute reduction of energy demand by the year 2000, equal to about 15 % in the residential sector and 12 % in commercial buildings. In other words, compared with 1980 levels, this alternative scenario implies a 40 % reduction in both average energy use per household and average energy intensity per square meter of commercial space.

For comparison, one French report estimated that the long-term potential savings in both new and existing buildings could be as much as 50 % compared to current practice.[12] In terms of savings actually achievable in the buildings sector by 1990, through conservation programs and response to energy prices, the same study estimated that the baseline projection of 88.5 Mtep (3.7 EJ) could be reduced by 25 % to about 67 Mtep (2.8 EJ).

Energy Savings Achieved

Conservation estimates. In the face of these studies identifying large potential savings in California, how much has actually been achieved? Most of the numbers cited in response to this question are based on estimates rather than measurements. Moreover, aggregate energy use numbers are more common--but less informative-- than component estimates.

The California Energy Commission estimates that, due to a combination of energy prices and conservation programs, residential energy use in 1980 (weather-adjusted) was about 10 % lower than it might otherwise have been.[13] This would imply that about one-fifth of the CEC's identified potential has been accomplished. The total residential savings estimated for 1980 were 2850 GWh of electricity and 860 M therms (91 PJ) of gas.

For comparison, the California Public Utilities Commission has compiled, from utility reports filed each year, the utilities' own estimates of energy saved as a result of their programs. According to the utilities, the cumulative impact of their efforts in the residential sector was savings of 1460

GWh and 500 M therms (53 PJ) in 1981.[14]

These aggregate conservation estimates are generally made up of estimated savings for various building types and measures. An example will illustrate how much these component savings estimates can vary.

Table 2 shows several recent estimates of savings from installing six common retrofit measures (attic, duct, and water heater tank insulation; weatherstripping; caulking; and low-flow showerheads) in an average single-family, gas-heated California home. As the table shows, there is some range of opinion about how much energy would actually be saved in the average home, especially in the milder Southern California climate.

This range of estimated savings is not surprising, both because actual energy savings in homes do vary, and because the numbers in Table 2 are all based on computer models or simplified heat-loss calculations, with many built-in assumptions. In the absence of measured data on retrofit savings in California, there will be little basis for resolving differences between the Energy Commission estimates and those of the utilities.

Legislation proposed in California (but not passed) would have required that these six measures be installed in every existing home, upon resale. There has been resistance from both building owners and real estate agents to a mandatory retrofit-upon-resale law; some cities with their own local retrofit requirements also objected to pre-emption from a statewide requirement. But one other factor in the defeat of this legislation may have been the absence of "proven" (measured) savings from retrofitting actual houses. In the next section we will consider some of the measured data on energy saved in buildings (mostly outside of California), and compare these data with various California goals and savings estimates.

Measured results. The data summarized below are drawn from a project at LBL, funded by the U.S. Department of Energy, to compile and analyze measured savings from energy conservation in occupied, new and retrofitted buildings. For each buildings sub-sector we have created a "BECA" data base (for Buildings Energy Use Compilation and Analysis).

Retrofitted buildings (BECA-B, -CR). Figures 3 through 7 summarize the retrofit results from over 2000 U.S. residences (68 project locations) and over 220 commercial buildings.[15]

Figure 3 shows residential retrofit energy savings vs. installed costs of the conservation measures (mostly shell insulation and glazing improvements, with a few heating system retrofits). Although the data show a lot of variation, median costs are $1100/household and median energy savings about 28 MBtu (29.5 GJ), or 24% of space heating energy use before retrofit. Median simple payback time for the retrofits shown is 7.9 years. The reference lines drawn on Figure 3 show the minimum energy savings that must be achieved, for each level of investment, if the retrofit is to be cost-effective at the unit energy cost shown (assuming that retrofit investments are amortized over 15 years at 7 % real interest).

Only three of the data points are from California, but many new points may be added when the results of a California study of the Residential Conservation Service (RCS) program become available.

For comparison, the California statewide estimate for savings resulting from six common retrofits (see above) is shown by the (+) on Figure 3 (34 MBtu [35.9 GJ], $832). This point seems reasonably consistent with the measured data, until we note that most of the measured retrofit results are from colder states. On a percentage basis, then, the California estimates are relatively high compared with measured results.

This is illustrated on Figure 4, which shows percentage savings in heating energy vs. retrofit costs. The California estimate (24-30 % for an $832 investment) is at the upper end of measured retrofit savings at comparable levels of investment.

Figure 4 also illustrates how little evidence there is of successful, cost-effective retrofits involving expenditures of more than about $2000 per house, or savings of more than about 35-40 %. Yet the Energy Commission's latest Biennial Report estimates savings of nearly 60 % in a gas-heated home from adding wall insulation and storm windows to the six retrofits listed above (and in Table 2). Clearly, there is a need for good empirical evaluation of such savings before placing great reliance on this estimate for either program planning, allocation of public funds, or energy demand forecasting.

Commercial building retrofits are shown in Figure 5.[16] Again, there is a large variation in energy savings, in absolute and percentage terms. We should note that the buildings shown are not representative of the entire commercial stock: 75 % of those in the sample are schools or offices (three times their fraction of all U.S. buildings), and large buildings are over-represented. Of these 223 data points, four are from California (and two from France). We now have underway an effort to add data on retrofitted state-owned buildings in California, and to obtain California utility company data on the results of their commercial audits and incentive programs.

Median savings are slightly less than 20 % (resource energy), as shown in the histogram on Figure 6. This can be compared with a California Energy Commission goal to save 20 % of current (1979) energy use in the entire commercial (and industrial) sector by 1985.[17] However, 9 % of the buildings in the sample used more energy after retrofit than before; changes in building occupancy or operation, weather, or actual "failure" of the retrofit may all have contributed. Better data are needed on such "failures"; they may be even more instructive than the successes.

Most of the commercial building savings resulted from operations and maintenance changes or from simple, low-cost measures. Median payback times, shown in Figure 7, were about 15 months, while median investments were only about $\$6.00/m^2$ (compared with about $\$16\text{-}20/m^2$ paid for energy each year). This suggests that commercial retrofits, like those in the residential sector, have not by any means exhausted the technical potential.

<u>New residential and commercial buildings (BECA-A, -CN)</u>. Data on over 200 new, low-energy residences are summarized in Figures 8 and 9.[18] Two of these homes are in California, but additional California data will be added as a result of a current project at LBL, sponsored by the University of California Energy Institute.

Six of the data points shown on Figure 9, all of them active solar homes, are new French buildings (numbers 27, 28, 58, 60, 61, 67). It has proven difficult to obtain good data on active solar homes in the U.S., but most active solar homes appear far less cost-effective than either super-insulated homes, or those combining good insulation with "passive" solar gain from moderate amounts (less than 12 % of floorspace) of south-facing glass.

The best of the homes in the data base use only about 1-2 Btu/ft^2/degree-day (^oF, base 65) for space heating, or 20-40 kJ/m^2/degree-day (^oC, base 18.3). This is less than one-third the heating energy used by the stock of existing U.S. homes, and about one-half the energy required by a typical new home, as indicated in Figures 8 and 9.

Also note that space heating energy in an efficient new home can be less than the energy required for water heating, typically around 11-15 kBtu/ft^2 (125-170 kJ/m^2). The new California building standards require a maximum water eating load of 10.8-11.6 Btu/ft^2 (123-132 kJ/m^2), as shown in the Figures (assuming that the energy use budget is based on a 75 % efficient gas water heater).

For comparison, the space heating energy budget level for new California homes in three locations (San Diego, Fresno, and San Francisco) are plotted with a (+) on the Figures. Heating energy budgets specified in California's latest revised Title 24 standards have been converted to the building loads shown on the Figures, assuming a 70 % efficient gas heating system. Note that these standards appear quite stringent, compared with measured performance of actual homes--but that the standards are also for design energy budgets, which may not reflect the actual usage of occupied buildings.

There is clearly a need for better data on the actual energy use of houses built in conformance with the State's standards. Even fewer measured data are available on cooling load performance, in California or elsewhere.

At present, the performance data for new commercial buildings are more limited than for residences. Our data base now contains 80 commercial buildings, of which 40 are offices and another 20 are schools.[19] However, for three-fourths of the buildings, we have not yet obtained actual energy use data--only design budgets. Typically, energy systems in a new building will require some "shake-down" time, so measured energy use for a minimum of 3-4 years will be required. Of these 80 buildings, two with actual data (and ten more with design data only, at this point) are located in California.

Figure 10 shows the distribution of site energy intensity for 43 new office buildings, including those with actual use data and those with design predictions only. Median site energy consumption is 40-50 kBtu/ft^2 (450-570 MJ/m^2). This is roughly one-third the energy intensity of new U.S. offices built in the early 1970's. It is slightly below the design energy budgets recommended by the ASHRAE 90-75 (revised) guidelines, and the proposed Federal Building Energy Performance Standards (BEPS), now voluntary guidelines. A sub-sample of these new office buildings, with measured energy performance, are shown in Figure 11, along with estimated trends for U.S. and Swedish office buildings, and the ASHRAE and BEPS budget levels. Note that Figure 11 shows energy use in resource energy rather than site energy--an important difference since many new U.S. office buildings are all-electric.

For comparison, two sets of California building standards for low-rise offices in three climate zones (San Diego, Fresno, San Francisco) are shown in Figure 11. Again, note that these are design energy budgets, which may differ from usage in occupied buildings. Under the existing state standards, low-rise offices must use less than 180-196 resource kBtu/ft^2/year (2.0-2.2 GJ/m^2). The proposed new state standards would reduce this to about 100-134 kBtu/ft^2/year (1.1-1.5 GJ/m^2). If the design budgets are representative of actual consumption, these proposed new California standards call for all new office buildings to meet the performance achieved to date only by the best new construction. This may be a stringent criterion to meet.

Appliances and Equipment (BECA-D). The BECA data base on appliance performance has not yet compiled enough data to report. However, we might note the evidence for considerable potential to increase efficiency beyond the levels required by California's appliance standards. For example, the standards require that a typical new, frost-free refrigerator with volume of 18 ft^3 (510 litres) can use no more than 1630 kWh/year.[20] However, the best refrigerator of this size and type now offered for sale is a model made by Amana, rated at only 867 kWh/year, or 47 % less than required by the standard.[21] For other typical sizes and types of refrigerators, the best model now on the market uses 30 to 40 % less than the standards require.

Data on the efficiency of new refrigerators actually sold in California are difficult to obtain, but by definition the average refrigerator sold will be more efficient than the minimum level required by the standards. The Energy Commission recently estimated the average usage of a newly purchased refrigerator at 1400 kWh.[22] If all purchasers were to buy an available model that was 30 % more efficient, the annual savings after only five years of normal appliance turnover would be about 1113 M kWh, worth $63 M per year to consumers, at today's electricity prices.[23]

But this estimate is based only on models currently for sale; prototype 500 litre frost-free refrigerators now being tested are operating in the range of 650 kWh/year. Once introduced to the market, they would double the potential savings (beyond current California standards) noted above.

For other categories of appliances, slightly less dramatic savings, beyond the existing California appliance standards, are available from models now on the market. For example, the best available 115-V room air conditioners have energy efficiency ratios (EER) of 11.0,[24] compared with a standard that requires 8.7. This represents a 21 % savings of both energy use and peak electrical demand.

Predicted vs. actual energy savings (BECA-V). The final two figures, 12 and 13, give an indication of the current state of the art in predicting building energy performance and energy savings from retrofits. Both figures compare predicted values with actual energy use recorded in the buildings. At one end of the spectrum, Figure 12 shows the accuracy that can be achieved with a well-designed computer simulation model, used by people who are familiar with the model and have access to fairly detailed, high-quality data about the physical characteristics, occupants, and operating practices of the building--as well as local weather data.[25] Generally, predictions can come within + 10 % of actual energy use.

In contrast, Figure 13 compares savings predicted by energy auditors with savings actually achieved, for a small subsample of the retrofitted commercial buildings in our data base (all located in the same community in Maryland). Even though average savings for the buildings, as a group, were close to predicted levels, predictions for most of individual buildings were very inaccurate.

If additional data indicate that this situation is typical of energy audits in commercial buildings, it would help to explain why building owners, facing such uncertainties, are reluctant to invest in more than a fraction of the measures recommended to them--and very few with paybacks longer than 1-2 years. This also emphasizes the importance of improving the analytical tools and building data available to auditors, and the need to obtain and disseminate better data on actual savings, in order to increase building owners' confidence in predicted savings and their willingness to invest to achieve them.

Conclusion: Program Issues, Opportunities, and Data Needs

The previous sections illustrated the value of having better quality data on how well energy-saving technologies and practices actually work (and how much they cost) when they are tried in real buildings with people in them. In practice, though, such data have rarely been collected. Where they have been collected, there remain problems of accuracy, consistency, and public accessibility. Through our buildings data base program at LBL, in collaboration with a broad mix of utilities, government agencies, industry groups and building owners, we hope to make a long-term contribution to this effort.

At this conference we are interested in comparing with our French counterparts our experience in compiling and then disseminating building energy performance data.

Even when we look beyond California, to buildings elsewhere in the U.S., there are many gaps in the existing data. It is important to begin filling these gaps, but in the meantime, what can the data tell us about near-term choices for energy conservation policy and programs?

First, we should look at the structure of these programs to see how better data sources and feedback mechanisms can be built into them. For example, arrangements for financing energy conservation projects on the basis of "shared savings," or under "energy services" contracts (discussed elsewhere at this conference) offer the added advantage of automatically generating information on actual energy savings, compared with retrofit costs.

More generally, any conservation incentive that is based on payments for energy saved, rather than money or effort spent, has two important benefits. The expenditures and other operating records from such an incentive program will automatically provide at least some data on the energy savings being achieved. At this point, all that can be said about the $57 M in public funds spent per year on the California conservation tax credits is that $57 M has been spent. More important, a savings-based incentive is likely to be more efficient and equitable; it avoids bias towards one set of technologies (such as solar systems receiving a greater tax credit than conservation), and also avoids rewarding expensive solutions where a cheap one will do. Administratively, of course, it may be easier to pay consumers for the money they spend than for the energy they save, but France seems to have found solutions to these administrative problems that policy-makers in California might consider. So far, only a few utility-sponsored conservation programs in California have experimented with a savings-based incentive; utilities in other states (Texas, the Southeast U.S.) have gone much further.

Another approach to structuring feedback and data collection into conservation programs is to set aside, by law, a small fraction of the total funds (perhaps 0.5 to 2 %) for monitoring, data-collection, and evaluation. So far, neither the Federal government nor California has done this on a consistent basis. Faced with budget pressures, such "overhead" activities are the first to be cut, even if a reduction of 1 % to gather better data might improve program effectiveness or reduce program costs by many times this amount. The few cases where resources have been set aside for data and evaluation are worth looking at carefully, as examples. This is another area where we from California would like to hear about the French experience.

What else can be learned from the measured energy conservation data now available? The wide range of conservation results identified in the BECA data base emphasizes the need for more detailed data, in the hope of explaining why savings and costs vary. The variance in results also argues for increased efforts in quality assurance (inspections, warranties, etc.) in the manufacturing and installation of products and systems. California has often been ahead of other states in this area, but without an adequate data base on actual energy savings, as well as long-term performance, there is no way to tell if conservation quality assurance programs to date have been sufficient--or perhaps excessive.

Similarly, the discrepancies between predicted and measured savings point to the need for better means of feedback to energy auditors, building designers, and engineers on the analytical methods and data they are using. Utilities and professional organizations should take the major responsibility for providing this feedback to practitioners on the actual outcome--both successes and failures--of their energy conservation recommendations.

The data on measured energy savings also suggest strongly that most efforts to date have fallen well short of the identified technical potential. Retrofit investments are limited to very short-payback and relatively low-cost items; new buildings seem to perform more poorly--especially in their first one or two years of operation--than design studies predicted; and there is a considerable range in efficiencies among appliance models now on the market, even among those that meet the California standards.

There are many other technical areas that remain to be explored, with well-designed experiments or instrumented demonstration sites. For example, it would be valuable to have the state and utilities jointly sponsor a program of intensive retrofits of a few existing buildings, to test (alone and in combination) the more advanced products, equipment, and control technologies now being developed or introduced to the market. Also, even with implementation of the new Title 24 state building standards, there are a number of complementary strategies that could be encouraged through building energy labels, revised utility "new home awards," or builder financial incentive programs. Examples include energy-efficient site design and landscape treatment, measures to reduce peak electricity demand, and builder installation of high-efficiency appliances and equipment.

All of these represent new areas of opportunity for future conservation policy and research. In pursuing them, it will be important to monitor--more closely than in the past--the actual energy savings achieved, cost-effectivness of each additional dollar, and side-effects on occupant health, safety, and comfort. As we move beyond many of the easier, obvious, and least expensive conservation measures (the "cream-skimming" that should take place first), each additional energy-saving measure will be more costly, more subtle in its effects, and more specific to a sub-set of the building stock. This does not mean that additional conservation is impossible; far from it. It does mean that we must pursue future energy savings in a less simplistic, more scientific, and better-documented fashion.

Notes

1. References for this section include two California Energy Commission (CEC) publications, "California Energy Demand, 1982 - 2000: Forecast for Consideration for Biennial Report IV," Vol. 2, 6/82, Report #P105-82-002 (Appen. C and D); and "1983 Electricity Report," 1/83, Report #P104-83-001, Appendix B. French data are from two publications by l'Agence pour les Economies d'Energie, "Les Consommations et les Economies d'Energie du Secteur

Residentiel et Tertiaire," 9/81; and "Receuil de Donnees sur L'Energie," 11/81.

2. These numbers are extrapolated from several different sources.

Public sector: C. Danforth of the Calif. Public Utilities Commission staff, estimates that for the regulated investor-owned utilities, 1983 planned expenditures for conservation and load management programs are $430 M. To this we add $20 M for municipal utilities, and assume (conservatively) that 2/3, or $300 M, applies to buildings. State expenditures for the conservation and solar tax credits were $55 M in 1981, based on a 3/9/83 report from the State Franchise Tax Board. Additional government expenditures include an estimated $50 M through programs such as the State Conservation Plan grant, Solar/Conservation Bank, Low-Income Weatherization Program, Institutional Buildings grants and loans, and "oil overcharge" funds.

Private sector. J. Wilson of the Energy Commission staff estimates, based on 1981 tax credit data, that total private expenditures for which tax credits were claimed amounted to $195 M for households and $14 M for businesses (of which $53 M and $4 M, respectively, were paid by the state). According to Wilson, a survey from the Residential Conservation Service suggests that household conservation expenditures for which claims were not submitted may add another $500-600 M to this. This seems high; to be conservative we will add only $200 M for residential investments made without tax credits claimed. Other private spending on conservation is estimated as $50 M/year for efficient appliances (2 M units sold/year, @ $25 additional cost); $60 M for new residential buildings (120 K homes/year, @ $500); $110 M for new commercial buildings (55 M ft^2/year added, @ $2/$ft^2$); and $130 M for improving existing commercial buildings (assuming that, beyond tax-credit-eligible measures, each year customers representing 10% of the sector's usage, or $430 M, invest in 1-2 year payback measures that save an average of 20% of energy use).

3. Extrapolated from the 1980 total, in California Energy Commission, "California Energy Demand, 1982 - 2000, Volume I: Technical Report," 6/82, p. 118.

4. California Energy Commission, Securing California's Energy Future, 1983 Biennial Report, Draft, 11/82. Figures 2-14 and 2-16 show estimated site energy use by fuel type for residential and commercial buildings in 1981, totaling 1135 TBtu (1197 PJ, site energy). Average 1981 electricity and gas prices to residential and commercial customers are shown, by utility area, in the Energy Commission's "1983 Electricity Report," Appendix B. The calculated Statewide weighted average prices are shown in Table 1, supra. We assume that the 14% of commercial building energy supplied by oil is priced at about the same level as gas. Multiplying unit energy prices by annual usage yields the estimated $9.2 billion/year energy expenditures for 1981.

5. California Energy Commission, "1983 Electricity Report," 1/83, Report #P104-83-001, pp. 2-15 to -17, and Appendix D.

6. Utility billing records for residential customers served by the "Residential Conservation Services" (RCS) program will soon be evaluated under an Energy Commission contract, but there has been no comparable study of actual energy savings from other home retrofit projects, including those undertaken with utility loans, tax credits, or through the Low-Income Weatherization Program. Utility company reports of energy saved from commercial audit programs are based mainly on auditors' estimates, rather than changes in billed energy use. Data on institutional buildings retrofitted

with federal grants or state loans are only now beginning to be collected by the Energy Commission.

7. Chapter 1, "Buildings," co-authored by A.H. Rosenfeld and Lawrence Berkeley Laboratory staff, in Solar Energy Research Institute (SERI), A New Prosperity: Building a Sustainable Energy Future, Brick House Publishing, 1981.

8. J. Wright, et al, "Saving Energy Through Greater Efficiency: The Potential for Conservation in California's Residential Sector," 1/81, LBL Report #10738. Also to appear in book form, published by the University of California Press.

9. L.B. King, et al, Moving California Toward a Renewable Energy Future: An Alternative Scenario for the Next Fifteen Years," Natural Resources Defense Council (NRDC), 1980.

10. These reports, all prepared by the consulting firm of A.D. Little, are: Southern California Edison Co., "SCE Estimates of Electricity Conservation Potential, 1982-2000" (6/82) and "SCE Projections of Conservation Goals, 1983-1987" (12/82); Southern California Gas Co., "Estimate of Conservation Potential for the Southern California Gas Co. Service Area, 1981-2000" (7/81); and Pacific Gas and Electric Co., "PG&E Estimates of Energy Conservation Potential, 1980-2000" (6/80) and "PG&E Assessment of Achieving Energy Conservation Potential, 1980-2000" (9/80). Reports for the San Diego Gas and Electric Co. have not yet been released.

11. Securing California's Energy Future, op cit, Chapter 9.

12. Commissariat General du Plan, "Une Perspective de la Consommation d'Energie a Long Terme," 6/80, pp. 9-15.

13. Securing California's Energy Future, op cit, p. 7-4.

14. Summary Table prepared by C. Danforth, staff, Energy Conservation Branch, California Public Utilities Commission.

15. L. Wall, et al, "Building Energy Compilation and Analysis (BECA) Part B: Existing North American Residential Buildings," to be published in Energy and Buildings; Lawrence Berkeley Laboratory Report LBL-13385, 1982.

16. H. Ross and S. Whalen, "Building Energy Use Compilation and Analysis (BECA) Part C: Conservation Progress in Retrofitted Commercial Buildings," to be published in Energy and Buildings; Lawrence Berkeley Laboratory Report LBL-14827, July 1982 (rev.).

17. California Energy Commission, "Energy Efficiency in California's Commercial, Industrial, and Agricultural Sectors: Progress and Prospects," Report #P103-82-001, Nov. 4, 1981. The 20 % savings goal was established by legislation directing the Commission to prepare this report.

18. J. Ribot, et al, "Monitored Low-Energy Houses in North America and Europe: A Compilation and Economic Analysis," forthcoming in 1983 in What Works: Documenting Energy Conservation in Buildings, Selected Proceedings of the 1982 ACEEE Summer Study on Energy-Efficient Buildings, Santa Cruz, Calirornia; Lawrence Berkeley Laboratory Report LBL-14788, 1982.

19. L. Wall and A.H. Rosenfeld, "The Assessment of Progress in Energy-Efficient Buildings," Submitted to the Proceedings of th Second International Congress on Building Energy Management, Ames, Iowa, May 3-June 3, 1983; Lawrence Berkeley Laboratory Report LBL-15412 (rev).

20. The formula is maximum kWh/year = 460 + 65 x V, where V is the combined volume, in ft^3, of refrigerator and freezer space.

21. Association of Home Appliance Manufacturers (AHAM), "1982 Directory of Certified Refrigerators and Freezers," Ed. 2, 6/82. This value is estimated by taking the average of implied kWh usage in the high-electricity-cost and low-electricity-cost cases.

22. *Securing California's Energy Future*, *op cit*, p. 7-14, citing an article by D. Goldstein of the Natural Resources Defense Council.

23. Based on an assumption of 530,000 units sold per year in California, or 10 % of the annual U.S. refrigerator sales reported by AHAM, *op cit*.

24. AHAM, "1982 Directory of Certified Room Air Conditioners," Ed. 2, 10/82. The Energy-Efficiency Ratio, or EER, is the ratio of Btu removed to kWh input, or 3.413 x co-efficient of performance.

25. B. Wagner and A.H. Rosenfeld, "A Summary Report of Building Energy Compilation and Analysis (BECA) Part V: Validation of Energy Analysis Computer Programs," presented at the 1982 Summer Study on Energy-Efficient Buildings, Santa Cruz, California; Lawrence Berkeley Laboratory Report LBL-14838, 1982.

Table 1

Average Energy Prices for Residential and Commercial Buildings

	Original Units	Resource Energy[6] ($1/GJ)
California, 1981[1]		
Residential Sector		
o Electricity	5.71 ¢/kWh	$5.28
o Gas	$3.23/MBtu	$3.06
Commercial Sector		
o Electricity	6.15 ¢/kWh	$5.69
o Gas (+ Oil)	$3.60/MBtu	$3.41
France, 1980[2]		
Residential Sector		
o Electricity	40.1 c/kWh	$4.95
o Gas	10.46 c/kWh_{gas}	$3.87
o Fuel Oil[3]	14.58 $F/10^2$ ℓ	$5.39
Commercial Sector		
o Electricity[4]	30.7 c/kWh	$3.79
o Gas	6.5 c/kWh_{gas}	$2.41
o Fuel Oil[5]	8.06 - 14.19 c/thermie	$2.57 - 4.52

NOTES

1 Statewide weighted average prices by sector calculated from 1981 estimates for each utility area, in CEC, "1983 Electricity Report," 1/83, Appendix B.

2 From Agence pour les Economies d 'Energie, "Recueil de Donnees sur L' Energie," 11/81. Assumed exchange rate is 7.5 F/$; prices do not include tax.

3 As of 2/81, excluding 22.7% tax

4 Weighted average of high + medium voltage (50%) at 21.4 c/kWh and low voltage (50%) at 40.1 c/kWh.

5 Range shown is for distillate (14.19 c/thermie) and residual oil (8.06 c/thermie. 1 thermie = 10^6 cal = 10^{-4} tonne equivalent pétrole [tep]).

6 Electricity is converted to resource energy at 1 kWh = 10, 239 Btu = 10.8 MJ, which is the factor used in calculations for California's building standards.

Table 2

Estimated Natural Gas Savings from Six Residential Conservation Retrofit Measures[1]

Location	Annual Savings Per Household Therms/yr.	GJ/year	Percent[2]
PG&E (Fresno)			
o Energy Commission (1981)[3]	368 Th.	39 GJ	24%
o Energy Commission (1983)[4]	389	41	---
o Utility[5]	351	37	---
SoCal Gas (Los Angeles)			
o Energy Commission (1981)[3]	---	---	---
o Energy Commission (1983)[4]	284	30	---
o Utility[5]	217	23	---
SDG&E (San Diego)			
o Energy Commission (1981)[3]	276	29	30
o Energy Commission (1983)[4]	247	26	---
o Utility[5]	156	16	---
Statewide Average			
o Energy Commission (1983)[6]	340	36	30

NOTES

1 Measures include attic, duct, and water heater tank insulation; weatherstripping; caulking; and low-flow showerheads installed in single-family, gas-heated homes averaging 159-161 $m.^2$

2 Percentage of pre-retrofit space heating and water heating energy.

3 J.A. Walker, Commissioner, "Mandatory Retrofit," Testimony before the Assembly Committee on Energy, Low Angeles, Dec. 10, 1981.

4 J. Ainsworth, "RCS Follow-up Survey Analysis," CEC staff draft report, 3/83.

5 C. Danforth, "Report on the Quantitative Measurement of the Pacific Gas and Electric Company's Conservation Programs, Test Year 1982," Testimony on general rate case Application No. 60153, 6/81 (rev.). Table 5-2 summarizes each utility's estimated savings.

6 Securing California's Energy Future, 1983 Biennial Report (11/82 draft), p. 7-9.

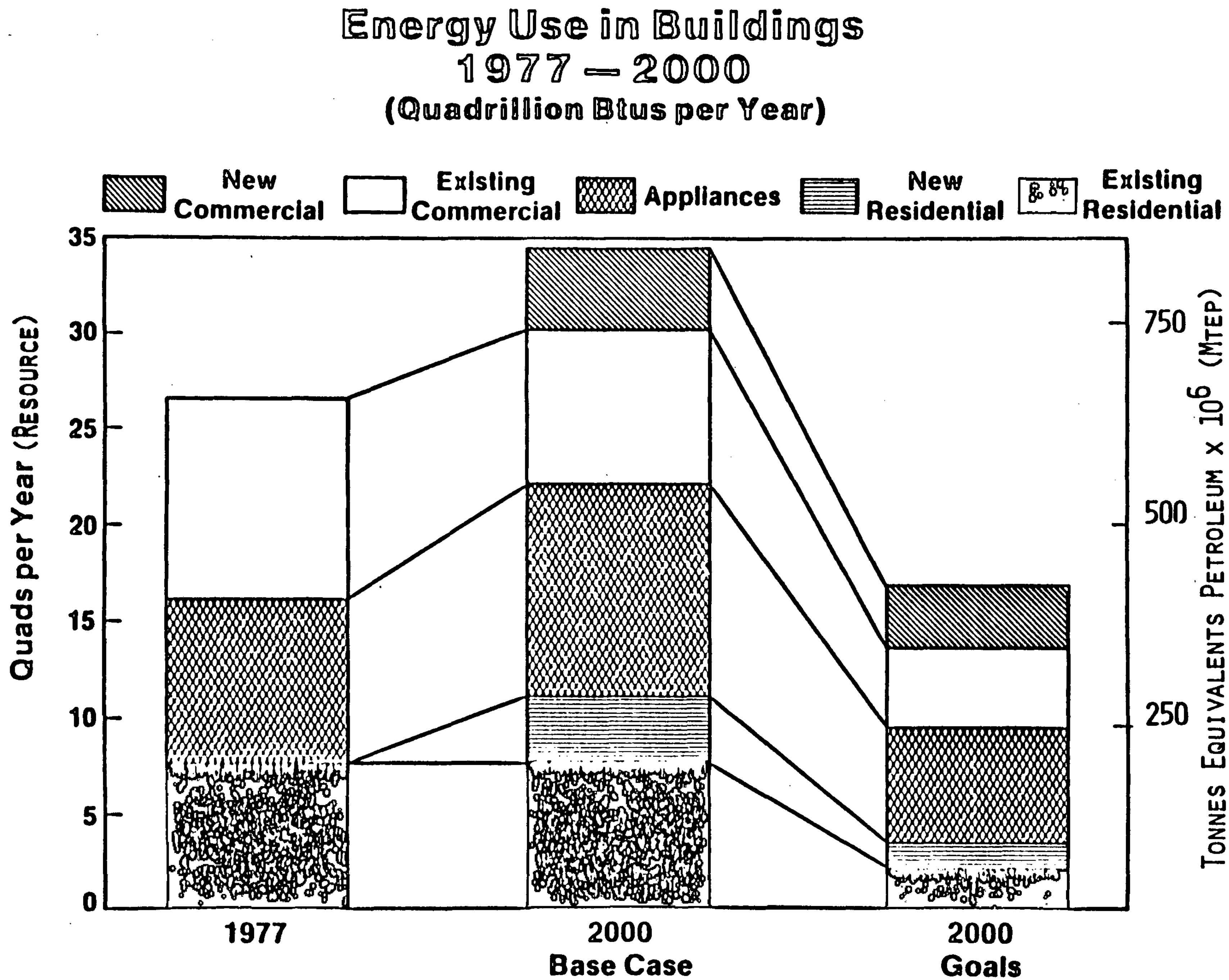


Fig. 1. A New Prosperity: Building a Sustainable Energy Future 1981, Brick House Pub. Ch. I, Buildings. (by LBL)

Source: SERI/LBL (1981)

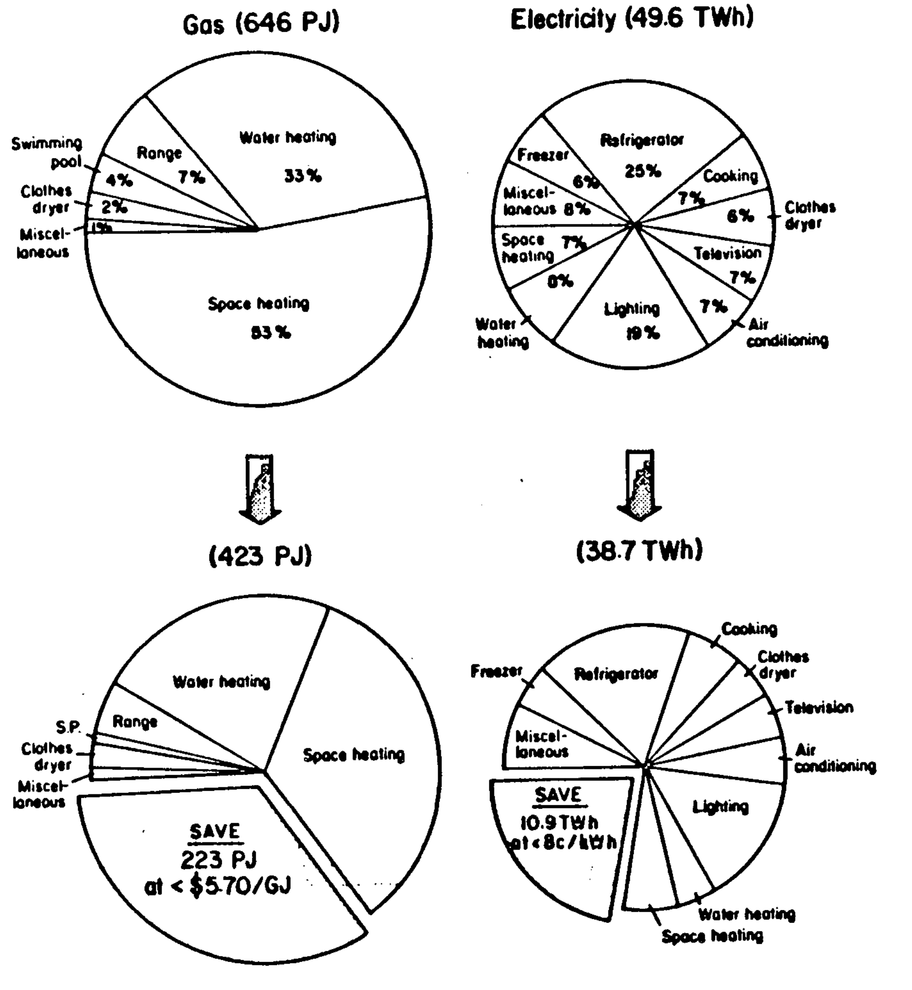
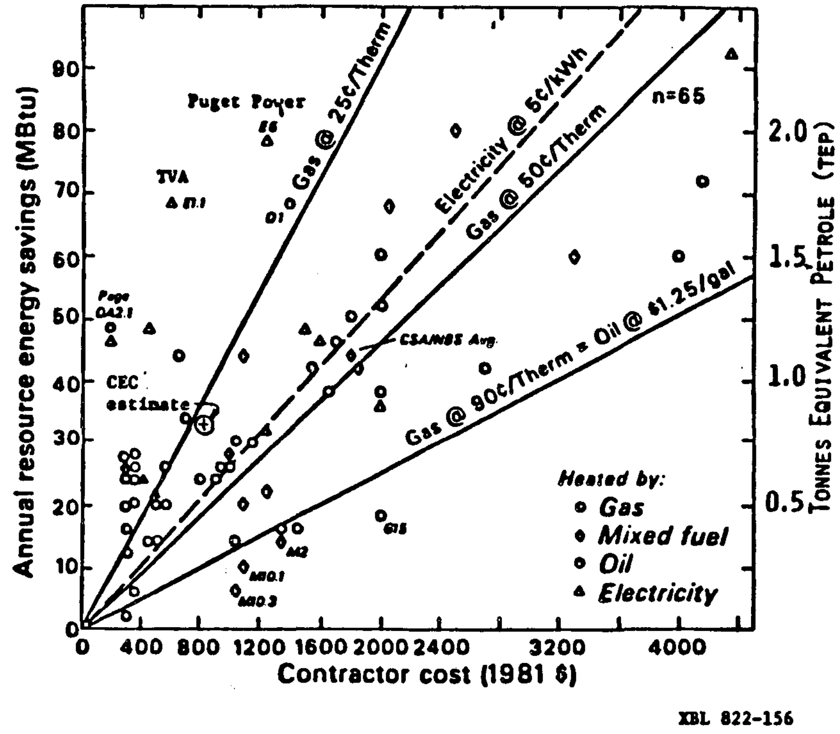


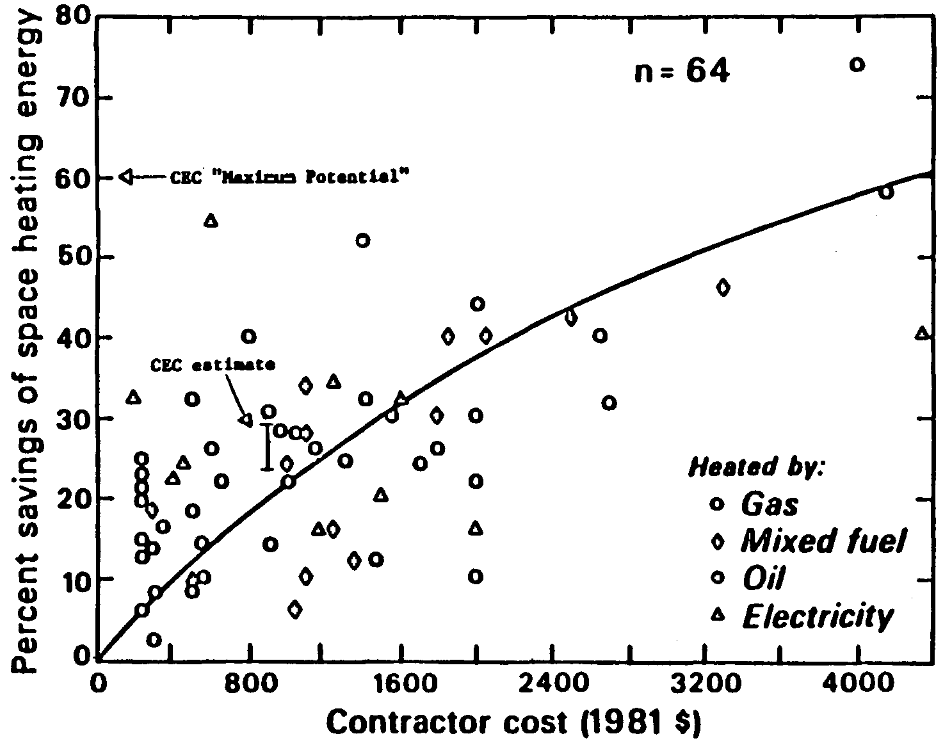
Fig. 2. Energy conservation potential in existing California Residences. Residential energy consumption by end use in 1978 (above) and after ten years (below) assuming all economic conservation measures are implemented. The shaded area represents the potential savings. The areas of the pie graphs are proportional to the energy in primary (or resource) energy. Electricity was converted to primary energy assuming a 33% efficiency, 10,300 Btu/kWh.
Source: Wright, et al. (1981)



XBL 822-156

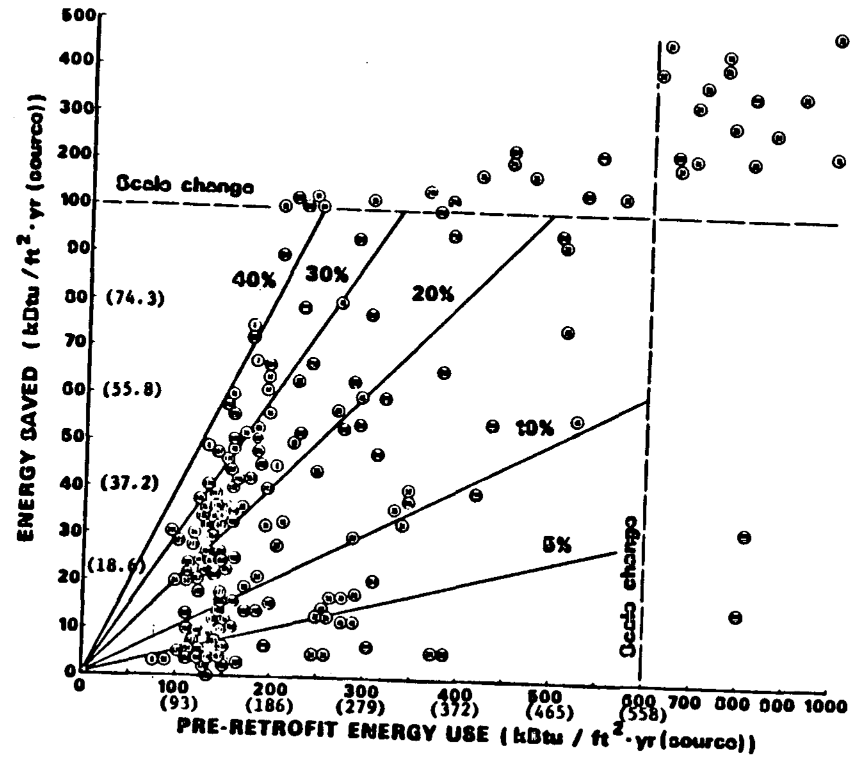
Fig. 3. Annual resource energy saving vs. contractor cost for 65 residential retrofit projects. Annual savings, in resource energy, after retrofit are plotted against the contractor cost of retrofits. The sloping reference lines represent the boundary of cost-effectiveness for typical residential energy prices. Since conservation investments are typically "one-time," the future stream of energy purchases for 15 years is converted to a single present value, assuming a 7% real discount rate. The conservation retrofit is cost-effective if the data point lies above the purchased energy line for that fuel. Electricity is measured in resource units of 11,500 Btu per kWh sold.

Source: Wall, et al. (1982)



XBL 822-161

Fig. 4. Percent savings of space heating energy vs. contractor cost for 64 residential retrofit projects. The curved line represents a (very poor) fit of the data to the equation $y=a(1-e^{-bx})$.
Source: Wall, et al. (1982)



XBL 826-782

Fig. 5. Energy savings vs. pre-retrofit energy use for 223 retrofitted commercial buildings in the BECA-C data base. While one might expect a general trend toward increased savings with larger pre-retrofit consumption, no simple correlations emerge from the current sample. We have plotted lines that bin the data points by percent of energy saved. Note the scale change on both axes, a indicator of wide variance among data points. The axes can be converted to SI units by using the factor: 1 kBtu/ft^2/year = 11.36 MJ/m^2/year. Numbers shown in parentheses are in tonnes équivalent pétrole (tep) per 100m^2.
Source: Ross and Whalen (1982)

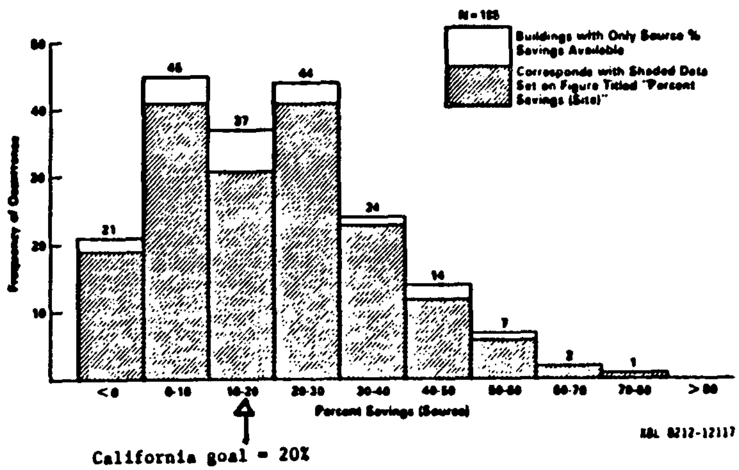


Fig. 6. Distribution of resource energy savings, as a percent of pre-retrofit energy use, for 195 commercial buildings in the BECA data base. Not included are 20 buildings which used more energy after retrofit than before.

Source: Ross and Whalen (1982)

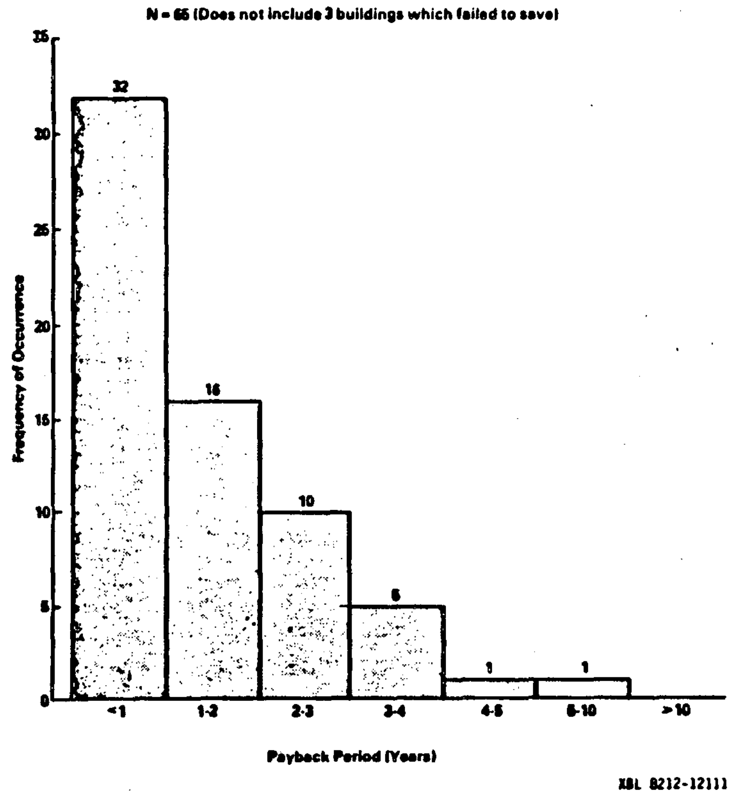


Fig. 7. Distribution of simple payback periods for a sub-sample of the retrofitted commercial buildings in the BECA data base. The median payback time was only 1.2 years, suggesting that building owners are reluctant to invest in measures representing the full range of technical potential that is cost-effective at current energy prices.

Source: Ross and Whalen (1982)

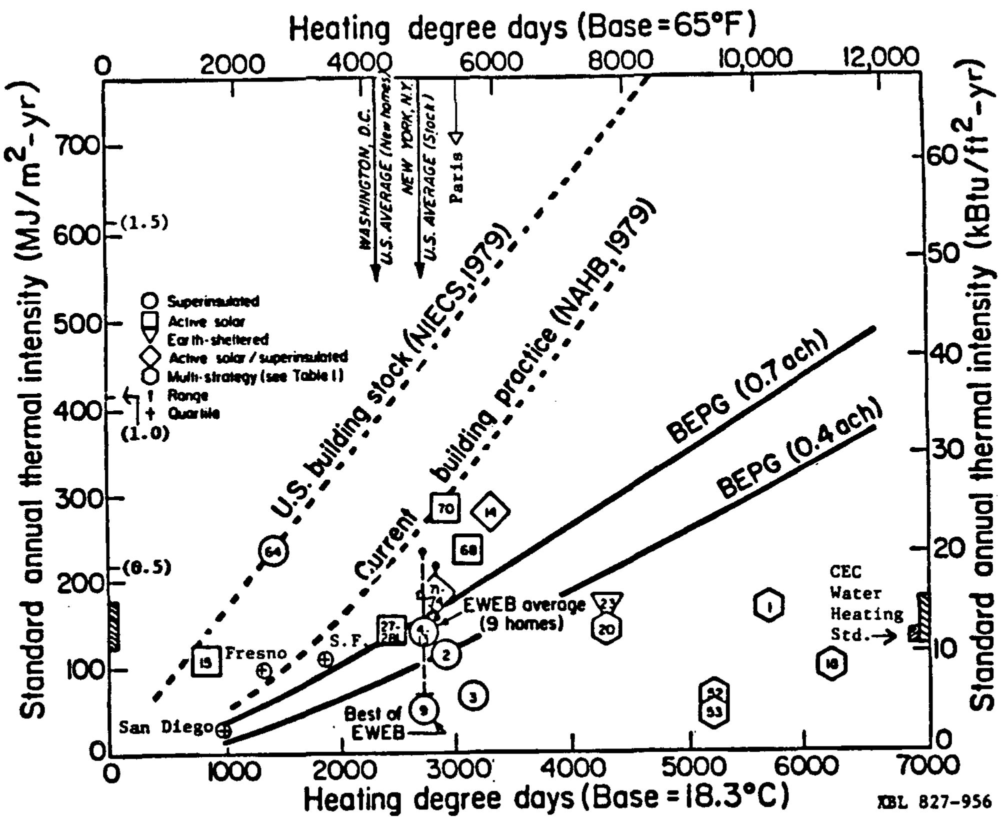


Fig. 8. Thirty-seven home scatter plot of "standardized" thermal intensity vs. climate for low-energy new homes. The various comparison curves are defined in the text. The average thermal intensity per degree-day for our 37 homes is 50 kJ/m²-°C-day), or half of the current building practice (labeled "NAHB") and about one-third of the space heating energy used in existing homes (labeled "NIECS"). Units shown in parentheses on the left axis are tonnes équivalent pétrole (tep) per 100 m². Shaded bars represent typical water heating loads--comparable to space-heating in the low-energy homes shown. The labeled California points are design budgets for space heating energy under the latest Title 24 building standards.

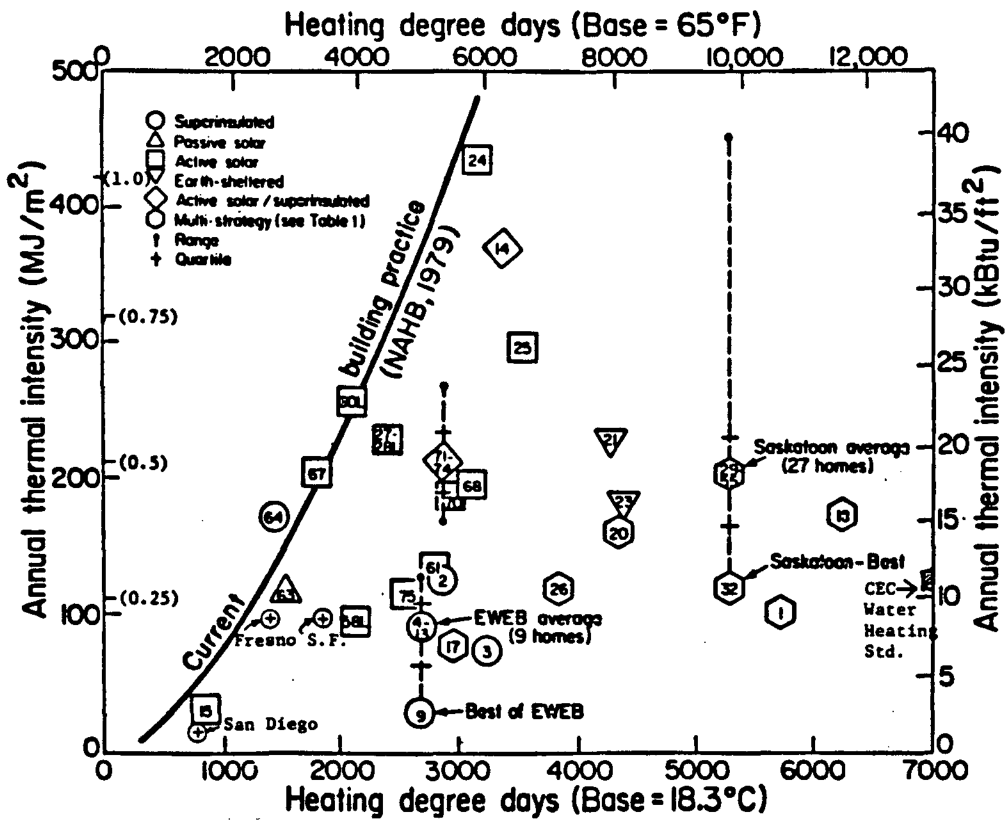


Fig. 9. Scatter plot of annual heating load/m² vs. climate for 28 points representing 128 submetered energy-efficient new homes. The solid curve represents 1979 U.S. building practice. Units shown in parentheses on the left axis are tonnes équivalent pétrole (tep) per 100 m². The labeled California points are design budgets for space heating energy under the latest Title 24 building codes. Source: Ribot, et al. (1982)

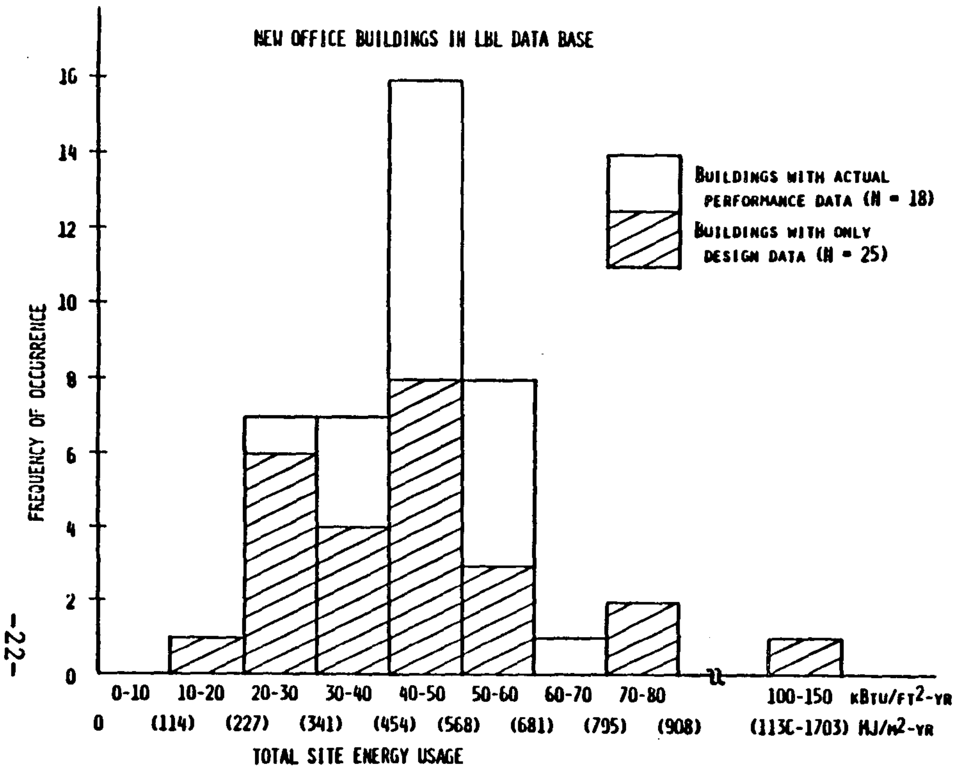


Fig. 10. Distribution of energy intensities for a subsample of new, efficient office buildings in the BECA data base, showing those with actual/measured energy use (open bars) and with design data only, to this date (shaded bars).

Source: Wall and Rosenfeld (1983)

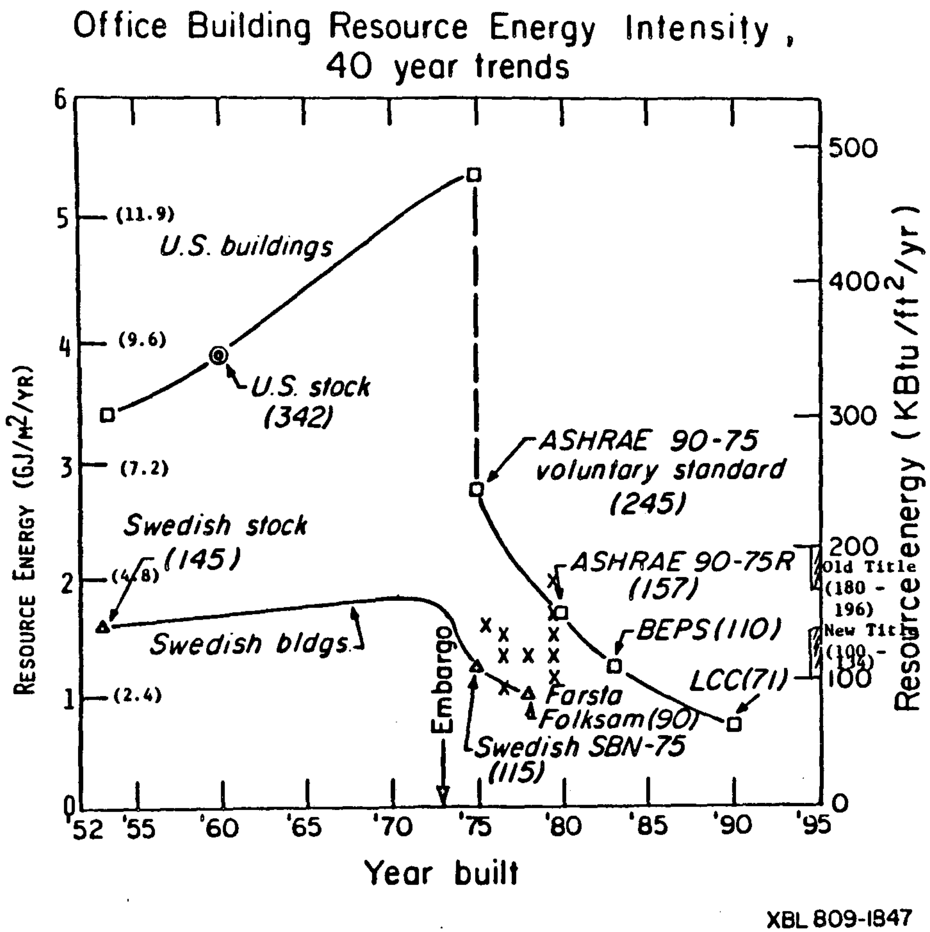


Fig. 11. Measured site energy intensities for a subsample of 10 new, energy-efficient office buildings in the BECA data base. For comparison, the plot also shows trends in new U.S. and Swedish offices, and (shaded bars at right) the old and proposed new Title 24 Standards for new, low-rise offices in California. Numbers in parentheses on the left axis are in tonnes équivalent pétrole (tep) per 100 m^2.

Source: Wall and Rosenfeld 1983

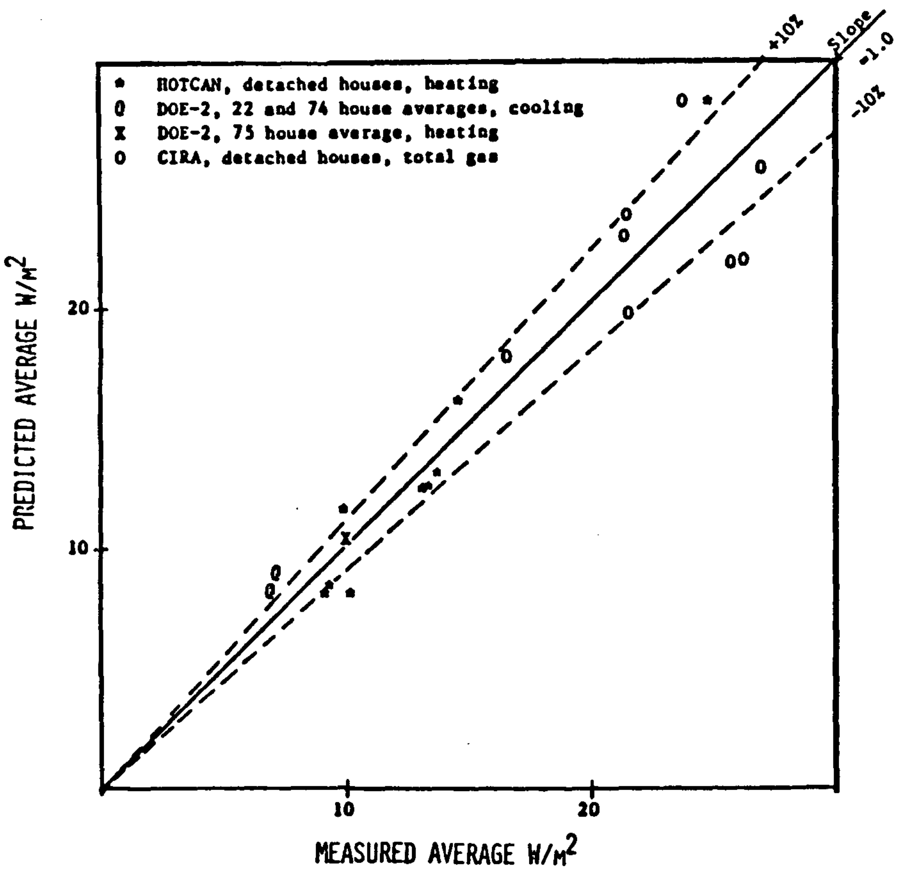


Fig. 12. Energy consumption as predicted by 3 computer models, vs. actual measured consumption, for individual residences and groups of residences with good quality building data, but no sub-metering or site-measured data.

Source: Wagner and Rosenfeld (1982)

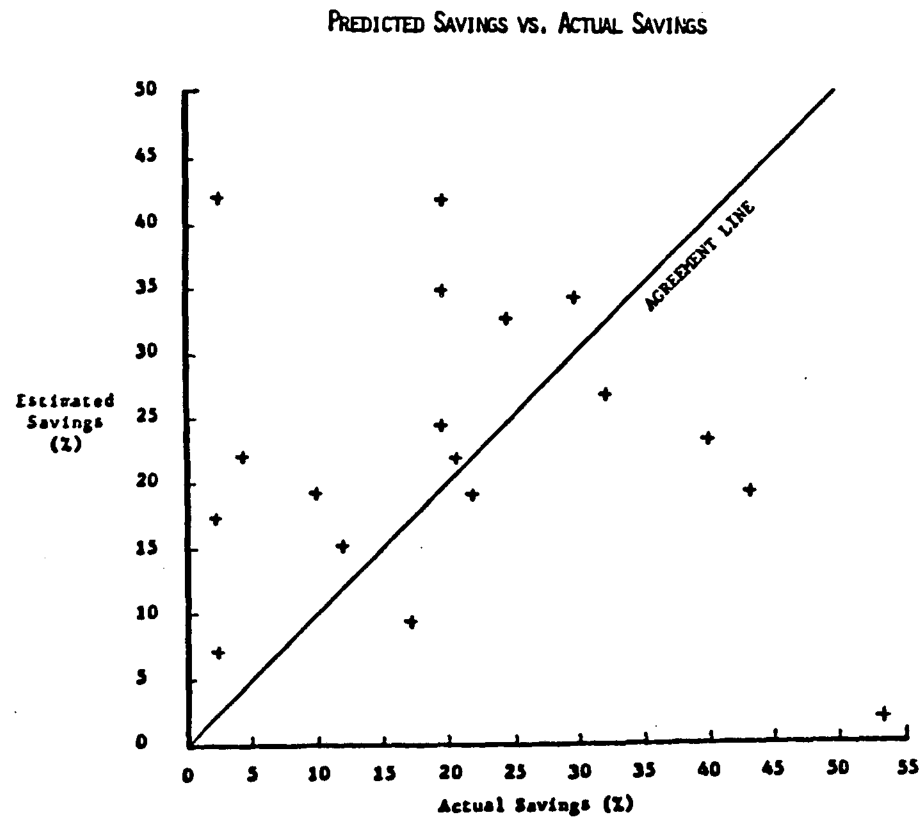


Fig. 13. Energy savings predicted by an energy auditor vs. actual energy savings achieved (percent) for 18 well-documented commercial building retrofit projects, showing no significant correlation between predictions and measured results.

Source: Ross and Whalen (1982)

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LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720