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Author
Meier, A.K.

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Alan K. Meier

Building Energy Data Group
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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Alan K. Meier
The Buildings Energy Data Group*
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

ABSTRACT

We present results of several compilations of monitored energy performance of buildings and equipment. We compare the performance of over one hundred monitored low-energy homes. Measured results from residential and commercial building retrofits are summarized.

KEY WORDS

active solar, database, commercial buildings, computer simulation, cost-effectiveness, monitored performance, passive solar, retrofits, superinsulated, validation.

INTRODUCTION

It is surprisingly difficult to find good data on the energy savings that have actually occurred in buildings and the cost of achieving them. Most data have been collected for specific, short-term purposes, and the lack of consistency in definitions, data collection procedures, and reporting formats often makes it arduous to compare results. There has been little long-term tracking of building energy performance to determine the persistence of savings over several years, nor-until now-any established mechanism to share or exchange energy performance data, or to independently review new data for technical accuracy.

The Buildings Energy Data (BED) Group compiles, analyzes, updates, and publishes data bases on the measured performance, cost-effectiveness, and further potential of energy-saving technologies in new and retrofitted residential and non-residential buildings. We report here on four related compilations of measured energy performance for residential and commercial buildings.

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* Many members of the Buildings Energy Data group have worked on the BECA (Building Energy Compilation and Analysis) projects. Our current research staff includes: J.P. Harris, B.L. Gardiner, C.A. Goldman, V. Magnus, A.K. Meier, B.C. O'Regan, M.A. Piette, A.H. Rosenfeld, A. Usibelli, B.S. Wagner, and L.W. Wall.

NEW RESIDENCES

We have collected data on the heating performance and economics of new passive solar, active solar, and superinsulated homes throughout North America and have evaluated submetered data for 276 of these homes (mostly single-family), of which 207 have adequate cost data to assess cost-effectiveness as well as performance.

In many of these houses, space heating energy use has been economically reduced to about one-fifth the level required in the average existing house, or about one-third the level estimated for typical new homes. Heating loads for the best superinsulated and passive solar homes in our sample were about 1.5 Btu/(ft^2-^{o}F-day) [30 kJ/(m^2-^{o}C-day)] per year. The average for 37 homes with the most complete data was 2.5 Btu/(ft^2-^{o}F-day) [50], compared with the average of 8.9 [180] for the U.S. housing stock and about 5.0 [100] for all new single-family homes surveyed by the National Association of Home Builders (NAHB). In other words, it is not unusual to find low-energy homes, even in the coldest U.S. climates, where energy use for space heating is roughly the same as that required for heating water or operating domestic appliances.

Figure 1 plots energy performance vs. heating degree-days for the 37 best-documented homes in the data base. The low-energy homes are compared with heating usage under the proposed federal energy performance guidelines (labeled BEPG), with current building practice, and with the existing stock (all normalized for floor area).

To make valid comparisons among low-energy homes, the metered space-heating energy data must be corrected for variations in inside thermostat settings and internal gains from appliances and occupants, as well as for local weather. Internal gains alone can account for half or more of the total space heating load. We made corrections for standard inside temperatures and internal gains for each house shown in Fig. 1.

New homes must be compared on the basis of cost-effectiveness and performance. We obtained data on the incremental costs of energy-saving features for about two thirds of the entries. The added cost of energy-saving features ranges from \$2 to \$6/ft^2 in most cases. The exceptions tend to be homes with active-solar heating or extensive south glazing areas, which cost more.

RESIDENTIAL RETROFITS

A second data base addresses the technical performance and economics of energy-saving retrofits in existing homes. The compilation includes more than 65 retrofit projects, with sample sizes ranging from 1 to 33,000 homes. Most of the retrofits involve insulation or other shell improvements to reduce space heating consumption. Most of the data include the combined effects of several retrofit measures; it is still difficult to determine the relative contribution of individual measures.

Figure 2 shows space heating energy savings (as a percent of pre-retrofit usage), plotted as a function of retrofit costs. For the overall sample, median space heating energy savings are 24% (28 MBtu/year), achieved at a median cost of about \$1100 per home.

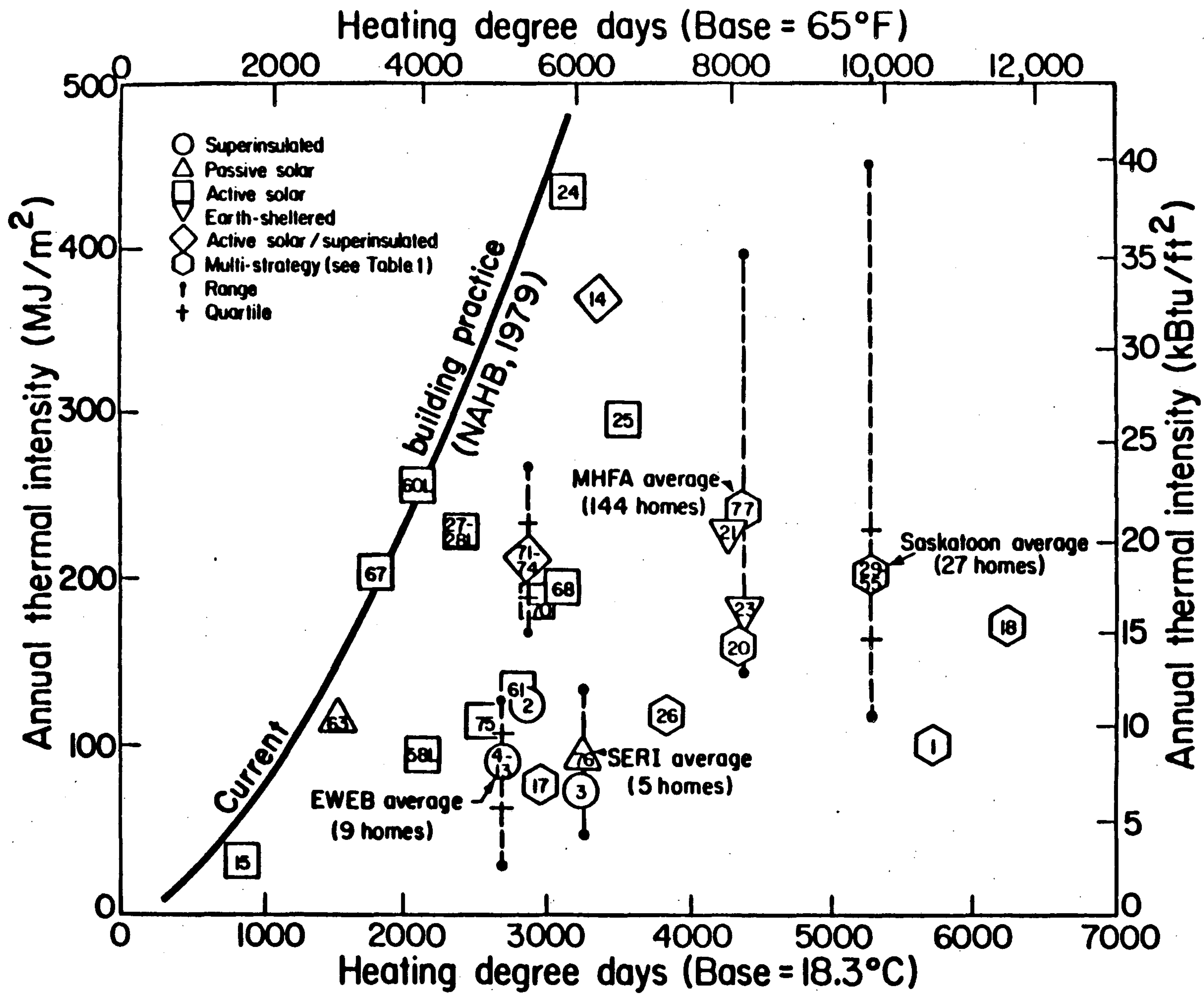

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Figure 1. Scatter plot of annual heating loads versus climate for 27 points representing 276 submetered energy-efficient, new homes. The solid curve represents the simulated performance of houses built by respondents to the NAHB's 1979 survey of U.S. building practice.

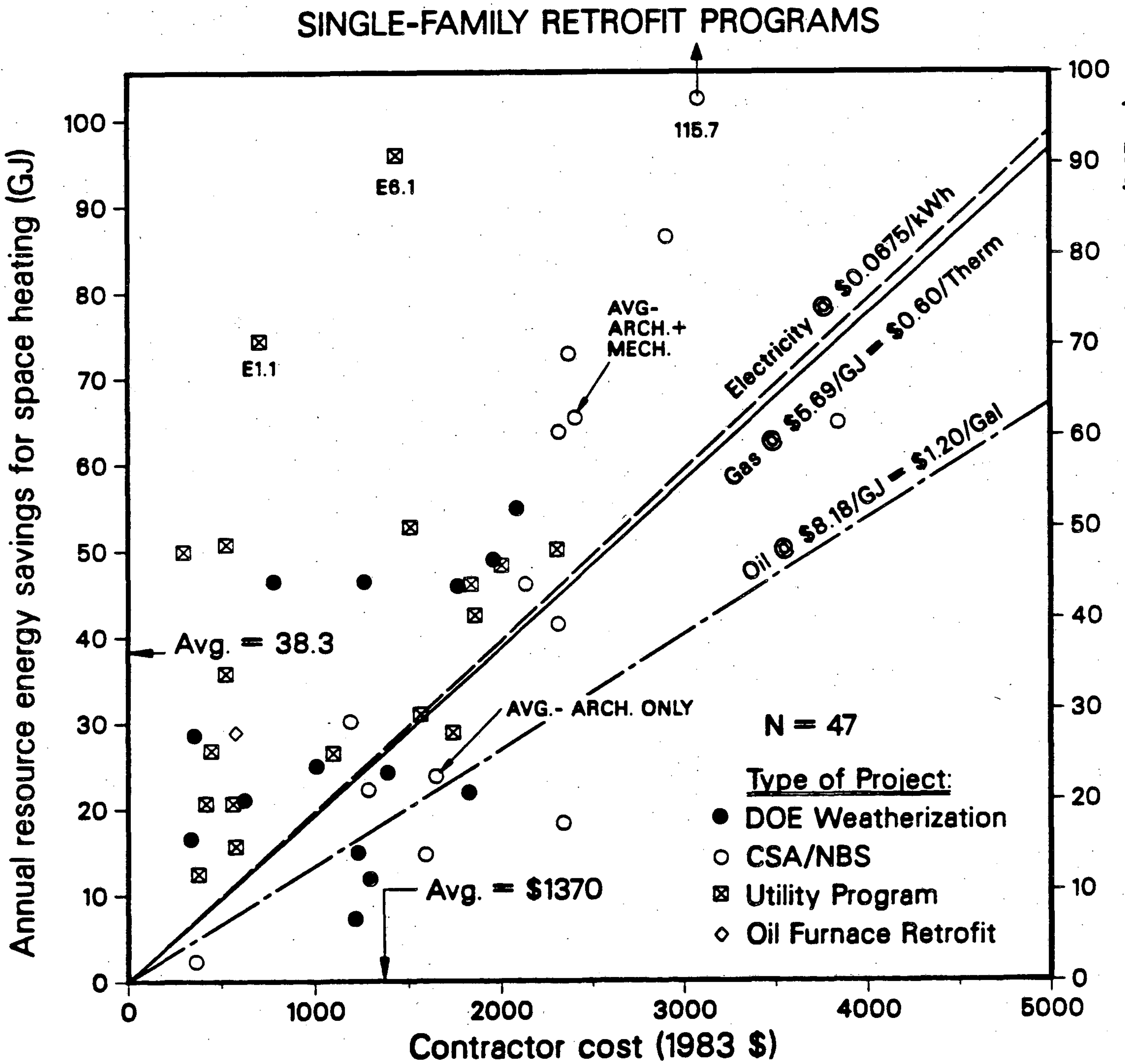

Figure 2. Annual space heat energy savings versus first-cost of the retrofit investment for utility-sponsored or low-income weatherization programs. Average savings are 36.3 MBtu. The 49 data points represent results from over 50,000 homes. The sloping reference lines show the minimum energy savings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

For the fuel-heated homes in our sample, the median cost of conserved energy was \$3.86/MBtu, substantially less than average 1981 residential-sector prices for natural gas (\$4.50/MBtu) and fuel oil (\$8.70/MBtu). The 11 data points for electrically-heated homes had a median cost of conserved energy of 3.1 cents/kWh, compared to average residential electricity prices of 6.2 cents/kWh.

In spite of the scatter in Fig. 2, it appears that investing more than \$2000 in residential (envelope) retrofits rarely yields significant returns.

COMMERCIAL BUILDINGS

The commercial building data base currently includes energy savings for 223 retrofitted commercial buildings, mainly schools and hospitals located in the eastern United States. Adequate data on both retrofit costs and energy savings are available for only one-fourth of the sample.

Figure 3, which summarizes our results, shows a wide range of both absolute and percentage energy savings. Median fuel savings were 21% of pre-retrofit consumption, while electricity savings were 7%-a lower ratio of electricity to fuel savings than estimated in other studies of commercial-sector retrofits.

Most of the retrofits were low-cost operation and maintenance improvements. This emphasis was reflected in the low level of retrofit investments (the median was about \$0.56/ft^2, compared to typical annual energy costs of about \$1.50/ft^2) and in short payback times (the median was less than 2 years).

VALIDATION OF BUILDING ENERGY PERFORMANCE MODELS

We have also collected comparisons of predicted and measured building energy performance-ranging from the output of complex computer simulation models to simplified calculations used for energy audits or building efficiency ratings.

The 12 validation studies examined to date include 63 data points, representing 202 buildings. These studies compared computer model predictions with utility-metered or site-measured energy consumption, both for individual homes and commercial buildings, and for groups of up to 75 buildings.

On the whole, the complex computer models (DOE-2, BLAST, NBSLD, REAP) were accurate to within 10%, both for total energy use and for space conditioning-provided that correct (i.e., measured or instrumented) input data were used. Simplified calculation procedures, or any program used to analyze a non-submetered building, were accurate to within $\pm$15%.

The Buildings Energy Data Group (BED) was created in 1982 at the Lawrence Berkeley Laboratory to collect data on the measured energy performance of buildings and equipment. In addition, we provide assistance in the design and analysis of conservation programs. We invite persons having performance data, or those planning to monitor buildings, to contact us at Building 90H, Lawrence Berkeley Laboratory.

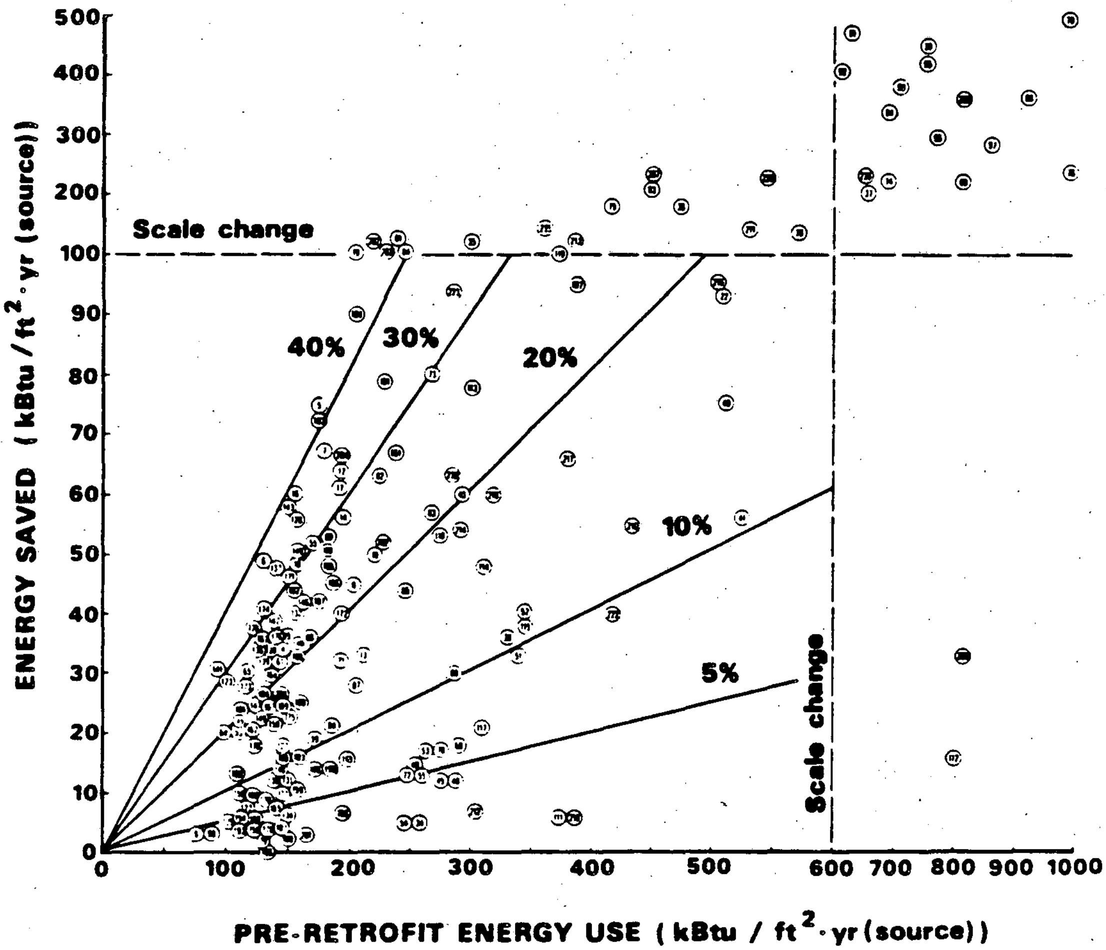

Figure 3. Energy savings versus pre-retrofit energy use for 223 commercial buildings in the BECA-C data base. While one might expect a general trend toward increased savings with larger pre-retrofit consumption, no simple correlations emerge from the current sample. We have plotted lines that bin the data points by percent of energy saved. Note the scale change on both axes, an indicator of wide variance among data points. The axes can be converted to SI units by using the factor 1 $kBtu/ft^2/year = 11.36\ MJ/m^2/year$.

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