# A COMPARISON OF MULTIFAMILY RETROFITS IN THE U.S. AND EUROPE: MEASURED RESULTS AND POLICY IMPLICATIONS

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## Overview of the BECA Data Base

The Buildings Energy-Use Compilation and Analysis ("BECA") data base is an international reference source for policy-makers, practitioners, and researchers on the *measured* performance and cost-effectiveness of buildings designed—or retrofitted—to save energy and reduce peak electricity demand (1). The data base is maintained at Lawrence Berkeley Laboratory (LBL), with the help of other research centers within and outside the U.S. who contribute data or staff assistance. BECA contains carefully screened records on over 2200 energy-efficient residential and non-residential buildings, mostly in the U.S., Canada, and Western Europe. Part B of the data base covers retrofits of single-family and multifamily residences. The present paper focuses on multifamily retrofit results, including over 100 recently added data points that allow an initial comparison of retrofit experience in the U.S. and in three European countries. Results summarized here are presented elsewhere in more detail (2) and will be included in a forthcoming LBL report updating BECA-B.

Early retrofit programs in the U.S. concentrated on single-family houses, with attention shifting, in recent years, to multifamily buildings. The opposite trend has occurred in most of Europe: the initial retrofit emphasis was often on multifamily buildings, with a later focus on single-family homes (3).* Energy efficiency in the multifamily sector merits special attention for several reasons. In most developed countries, multifamily buildings represent a large fraction of all housing units. This is especially true in Western Europe, with about 45 to 55%

* For example, in France over 90% of the residential energy audits completed as of mid-1984 were in multifamily buildings.

multifamily units,* but less so in the U.S. with 24% multifamily (4,5,6). Oil use and oil-saving opportunities are found to a greater extent in multifamily buildings than elsewhere in the stock. Although most newer French and U.S. multifamily buildings are electrically heated (or furnished with individual gas space and water heaters for each apartment), the less-efficient older stock tends to have central oil or gas-fired heating plants. Annual energy costs in U.S. multifamily buildings (with 5+ dwelling units) total $ 11 billion, or $830/unit. Per dwelling unit, this is 20% lower than for U.S. single-family housing, but nearly twice as high in terms of energy cost per heated floor area (6). Also, compared with the single-family stock, energy costs in multifamily buildings are more often paid by households with below-average incomes, or else—in the case of social (public) housing—from tax revenues. In Western Europe, energy use and costs in multifamily dwellings are generally lower than in the U.S., reflecting both lower appliance energy use and somewhat *higher* degree-days in most of Europe.

A comparison of U.S. and European multifamily retrofits is interesting because the latter appear to represent a "second-generation" effort. The European retrofits in the BECA data base were generally more expensive than those in the U.S., and achieved similar percentage savings—but on a lower pre-retrofit base. Lower pre-retrofit consumption of these European buildings may be due to better equipment maintenance and operation, and to building shells that were initially tighter and better insulated. The European buildings emphasized shell rather than system improvements. Most shell retrofits in multifamily buildings, while less cost-effective in energy terms, may offer other benefits in improved appearance, comfort, and structural preservation. We discuss data sources, methods, and results in the next sections.

## Data Sources and Analysis Methods

BECA-B data sources include local government energy offices, public housing authorities, private and non-profit building owners and managers, research organizations, and utility companies. The data vary in completeness and level of detail; at a minimum they include *measured* energy use for periods before and after retrofit (or post-retrofit data for a treated and a control building), retrofit costs and type of measures, and selected building characteristics. Each data point is screened for completeness, internal consistency, and common definitions of key terms such as fuel heating value, retrofit type, and floorspace measurement. Energy use of the space heat fuel is normalized either for floor area or number of dwelling units.** Where there are measured data for several periods, energy use is weather-normalized using a statistical fit (7). Where only seasonal energy data are available, we normalize using the ratio of that year's heating degree-days (base 18°C) to HDD for an average year. Due to insufficient data, we do not at present adjust for differences—either among buildings or between the pre- and post-retrofit periods—in inside temperature, internal gains, window-opening

* Within Europe there is considerable variation; the U.K. has fewer than 20% multifamily residences, Switzerland about 80%.

** Where space heat energy is not separately metered, we use summer consumption or typical "space-heat fractions" to separate it from water heating and other end-uses.



practices, etc.

Energy costs and retrofit costs (including labor and materials) are both expressed as constant (1985) U.S. dollars. Energy costs reflect actual local prices paid at the time of retrofit (or, as a default, national average residential energy prices). For U.S. projects, the GNP deflator is used to convert costs to 1985 dollars. For other countries, original energy and retrofit costs are translated to 1981 local currency using that country's GDP cost deflator, converted to US dollars using 1981 exchange rates, and then expressed as constant 1985 US dollars using the U.S. deflator.* This procedure allows a more consistent comparison of retrofit economics in the different countries, without affecting payback calculations or other indices, such as the retrofit "investment index" (ratio of investment to annual pre-retrofit energy expenses).

## Building Characteristics

We summarize characteristics of the 250 multifamily retrofit projects in the data base, by country, in Table 1. Average dwelling size is largest in the Swiss buildings (8). The 21 French retrofit projects, exclusively in social housing, included the largest buildings (both in number of units and total floorspace) but had the smallest average unit size: slightly below the French stock average (9,10). With few exceptions, all the retrofitted buildings were centrally heated with oil or gas; as noted, this is more typical of older multifamily stock than of recent construction. For the U.S., retrofits in gas-heated buildings are overrepresented compared to the stock. The opposite is true for France, with only one gas-heated building in the data base, *vs.* 30% gas heat in the centrally heated stock (11).

Average pre-retrofit energy intensities for space and water heating are significantly greater in the U.S. buildings than for the three European countries: 40% higher than the French buildings and twice as high as the Swedish cases. U.S. buildings in the data base used about 40% more energy prior to retrofit than the overall multifamily stock average (12). Prior to retrofit, the French buildings, as a group, were about average for the multifamily stock—but used about 25% more energy than the typical social housing project (9). Pre-retrofit energy intensity for the Swiss buildings was about 10% above the stock average; for the Swedish buildings pre-retrofit usage appears typical of the stock, or slightly lower (4,5).

## Types of Retrofit Measures and Levels of Investment

Table 1 also shows the frequency of each main type of retrofit measure, by country. Shell insulation (typically exterior insulation on masonry buildings) is much more common in the European retrofit cases than in the U.S. examples. Heating equipment changes occurred in one-half to three-quarters of the cases for each country in the data base. Heating control changes, water heating retrofits, and other measures were most common in the U.S. and Switzerland. Without

* 1981 rates are considered more typical of long-term trends, given the fluctuating rates of recent years.

Table 1. Multifamily Building Features, Retrofits, Energy Savings and Cost-Effectiveness.

| | U.S. | France | Switzerland | Sweden |
|---|---|---|---|---|
| **Number of Projects**[a] | 147 | 21 | 64 | 18 |
| **Building Type:** | | | | |
| High-rise | 36 | 7 | 15 | 15 |
| Low-rise (≤ 4 floors) | 107 | 9 | 47 | 0 |
| Combination/Unknown | 4 | 5 | 2 | 3 |
| **No. dwellings/building** * | 40 [22] | 60 [45] | 17 [12] | 38 [37] |
| **Floor area/dwelling ($m^2$)** * | 77 [73] | 64 [58] | 99 [91] | 74 [75] |
| **Heating System Type:** | | | | |
| Central | 134 | 21 | 64 | 18 |
| Individual | 8 | 0 | 0 | 0 |
| **Heating Fuel Type:** | | | | |
| Natural Gas | 100 | 1 | 1 | 0 |
| Oil | 38 | 16 | 63 | 0 |
| Electricity | 5 | 0 | 0 | 0 |
| Mixed Fuel[b] | 5 | 3 | 0 | 3 |
| District Heating | 0 | 0 | 0 | 15 |
| **Climate Zone ($HDD_{18°C}$)** | | | | |
| < 2000 HDD | 12 | 8 | 0 | 0 |
| 2000 - 3000 HDD | 57 | 13 | 0 | 0 |
| 3000 - 4000 HDD | 13 | 0 | 64 | 15 |
| > 4000 HDD | 65 | 0 | 0 | 3 |
| **Energy Intensity ($MJ/m^2$):** *,c | | | | |
| Pre-retrofit | 1453 [1347] | 1038 [1038] | 849 [839] | 726 [720] |
| Post-retrofit | 1183 [1123] | 885 [871] | 628 [624] | 605 [583] |
| **Percent Savings** | 17 [16] | 15 [15] | 27 [26] | 16 [14] |
| **Frequency of Retrofit Measures (%):**[d] | | | | |
| Insulation | 15 | 76 | 67 | 72 |
| Windows | 25 | 24 | 20 | 22 |
| Heating Equipment | 48 | 81 | 70 | 56 |
| Heating Controls | 61 | 24 | 44 | 56 |
| Domestic Hot Water | 23 | 5 | 9 | 50 |
| Other | 26 | 33 | 30 | 50 |
| **Retrofit Investment:** * | | | | |
| \$US (1985)/$m^2$ | 11 [5] | 31 [20] | 46 [38] | 38 [16] |
| Investment Index[e] | 1.3 [0.6] | 4.7 [3.0] | 6.6 [5.5] | 4.5 [2.3] |
| **Simple Payback Time (years)** * | 11 [4] | 41 [20] | 52 [23] | 24 [27] |

* Values are given as mean [median].

[a] A project may include one or more retrofitted buildings at one site, which are treated as a unit for this analysis.

[b] "Mixed Fuel" means that either two fuels are used for space heating (typically gas and oil, depending on availability), or that fuel switching occurred after the retrofit.

[c] Energy used for space and water heating; water heating energy is estimated in some cases, using a default value of 0.15 $kWh/m^2$-day.

[d] As a percent of all projects from that country in the database. Totals reflect multiple measures per site.

[e] Ratio of retrofit investment to pre-retrofit annual energy expenses.



better data on retrofitting patterns in the multifamily stock, it is difficult to determine how typical are the 250 cases in the data base. However, in France, a 1982 survey of multifamily retrofits produced results that can be compared with our 21 social housing examples. The survey shows about the same rate of heating equipment retrofits (27%); greater emphasis on system maintenance (23%), controls (17%), and window measures (13%); and lower frequency of insulation in walls/floors (17%) and roof/attics (12%) (13). One guide to Swiss retrofits suggests that shell measures are about 50% more common than system retrofits in multifamily buildings (14).

Average levels of retrofit investment also differ dramatically by country, as shown in Table 1. Average retrofit costs for the U.S. buildings were less than one-third the costs in the European buildings in the data base (under 25%, compared with the Swiss buildings). This holds true for both indicators: retrofit cost per unit floor area, and retrofit cost indexed to (pre-retrofit) annual energy expenses. As noted earlier, however, to the extent that the European retrofits emphasized shell insulation, some of the retrofit cost could reasonably be attributed to building preservation and restoration, not to energy savings alone.

## Energy Savings and Cost-Effectiveness

Table 1 shows that, on average, the U.S. buildings saved the most energy per dwelling, but also had much higher pre-retrofit energy intensities. Average percentage savings were similar in the U.S., French, and Swedish examples (15-17%), and higher in the Swiss buildings (27%). Most dramatically, average simple payback periods for the European retrofits were between two and four times longer than for the U.S. buildings. * Payback periods this long would be unacceptable to most public or private sector building owners in the U.S. However, many of the European buildings were retrofitted earlier than their U.S. counterparts, often as part of demonstration programs that were subsidized by the government, which partially accounts for the higher cost of the European projects.

Figures 1 and 2 present the same energy savings and cost-effectiveness results in graphic form. Figure 1 shows annual energy savings *vs* pre-retrofit annual consumption.** By country, the U.S. buildings tended to have the highest pre-retrofit energy use, and the Swedish buildings the lowest. French buildings showed little variation in pre-retrofit use. In terms of percentage savings, the Swiss retrofits, as a group, performed best. U.S. buildings with similarly high percentage savings tended to be those which were very energy-intensive to begin with—often due to poorly-controlled boilers and distribution systems.

Figure 2 shows percentage savings as a function of the investment intensity index for each project. As in the first figure, a primary impression is of large scatter in the data. A number of the very low-cost U.S. projects involved adding

* Note, however, that to facilitate comparisons, the payback values in Table 1 do *not* include any increase—or decrease— in real energy prices after the date of retrofit.)

**Consumption includes energy used for space heating, domestic hot water, and, for many U.S. buildings, cooking. (In cases where hot water consumption was not available, estimated domestic hot water consumption of 190 MJ/sq.m. has been added to space heat use.)

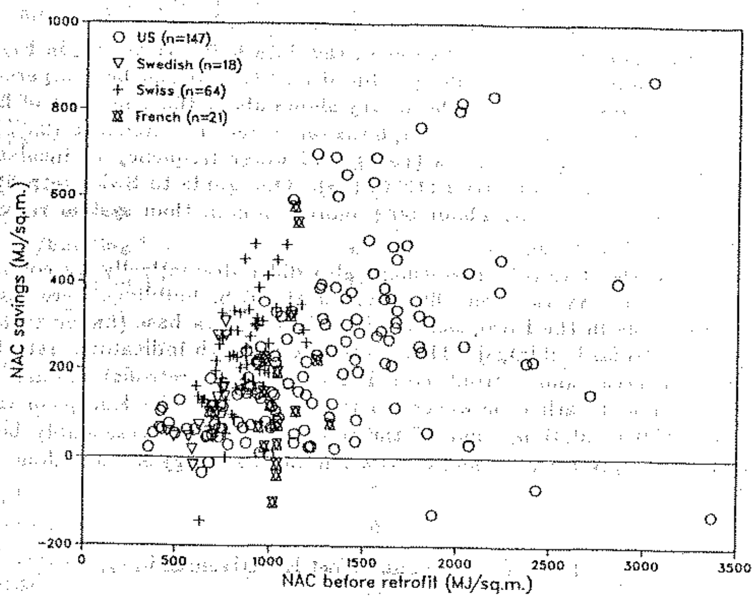


Fig. 1. Energy savings vs. pre-retrofit energy use, for U.S. and European multifamily buildings.

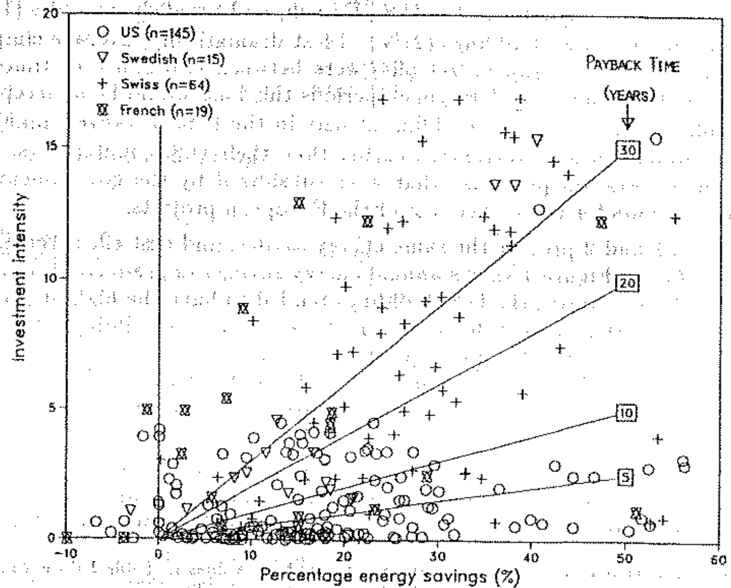


Fig. 2. Retrofit investment intensity vs. percentage savings. "Investment intensity" equals retrofit cost divided by annual pre-retrofit energy costs. A few U.S., French, and Swiss buildings lie outside the boundaries of this plot. Constant payback lines are illustrated for five through thirty year payback times.



controls to large central heating systems. The Swiss buildings, as a group, showed the highest levels of investment and also saved the most—but not enough to avoid very long payback periods.

## Conclusions and Plans for Future Research

While the small, non-random samples presently in the BECA-B multifamily data base may not be typical of general retrofit practices and results in any of the four countries, a comparison of the results is at least suggestive on two points: (a) U.S. multifamily buildings, because of their higher initial energy use, may offer more obvious opportunities for low-cost savings, and (b) owners of existing multifamily buildings in Europe appear to be more willing than those in the U.S. to make major investments in preserving and improving the existing stock—based on very long time-horizons (or alternatively, low discount rates). A third factor may have been that the European retrofits were undertaken at a time when many building owners expected continuing major increases in oil and gas prices, a trend which has been temporarily slowed or reversed. In this sense, these European multifamily retrofit results may offer a preview of future retrofit possibilities in U.S. buildings, as well as an indication of what might be done in the remaining un-retrofitted buildings in each European country.

Under the BECA project, we continue to compile and review data from buildings in both the U.S. and Europe; suggestions and further leads from readers are welcome. Future work will include improved methods for weather- and occupancy-normalization, more detailed comparison of retrofitted buildings in the data base with typical stock, submetered end-use energy data, and increased efforts to document the *long-term* performance and reliability of retrofits—beyond the first one or two years. Detailed (submetered) retrofit monitoring projects now underway in the U.S. and Europe are trying to explain the scatter observed in energy savings: How much is due to differences in building operation, occupant behavior, retrofit product or installation quality, or other factors? These data will be included in BECA as they become available. We will also look in more detail more at how individual, well-documented retrofit projects compare with general practice affecting the multifamily stock in each country. We plan to develop and test more refined methods to compare building energy performance, retrofits, and operating practices among different countries.

At the policy level, an important issue is the extent to which further energy and cost savings can be achieved, despite the end of most government retrofit subsidies, through low-capital-investment strategies or "alternative" (third-party) financing. Perhaps the largest remaining opportunities for energy management in existing buildings lie in the continued, effective management and maintenance of existing facilities, increasingly assisted by remote telemetry or by computerized, on-site, control systems. New "hardware" technologies should not be overlooked, but neither should the training and encouragement of competent personnel with the responsibility and knowledge to keep them working well.

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# THE ISPRA "BENCHMARK" EXPERIMENT TO COMPARE EXISTING BUILDING ENERGY AUDITING SCHEMES.

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## 1. Introduction

The space heating of buildings accounts for over 25% of total energy consumption within the European Community. With a building renewal rate of about 2% p.a. it is clear that an appreciable reduction in this consumption can only be obtained by improving existing buildings.

Selection of the most appropriate energy saving measures for a particular building requires careful analysis of the energy flows within it, using what are known as Energy Auditing (E.A.) techniques. If the E.A. and the recommended Energy Conserving Opportunities (E.C.O.) are, jointly, to be cost-effective, it is essential that the cost of the E.A. alone be low by comparison with the value of the probable energy savings.

The E.A. schemes currently used in Europe (1), range very widely in their degree of complexity and cost, so that the question arises for the consumer as to whether cheap audits can be relied upon or conversely whether more expensive audits can be justified by greater accuracy. The Ispra "Benchmark Experiment" was devised by the Joint Research Centre (J.R.C.) in an attempt to answer this question. Four companies were commissioned to carry out separate E.A.s of the same set of buildings. Their reports were then compared not only with each other but with a much more thorough study (the benchmark) carried out by the JRC's own staff. Preliminary results have already been presented (2).

The buildings selected, all publicly owned, and in the Ispra area, were:
a) six, 5-floor apartment buildings connected to one heating plant by a small district heating network. Built in 1965;
b) a primary school, built in the early 70s;
c) a single-family, mid-terrace house, built in the early 80s.

The auditing companies came from three different countries and each employed a different level of auditing. The audits were as follws:

Company n.1: most detailed audit: infra-red (Thermovision) study of envelope with computer processing of images; dynamic thermal simulation model for larger buildings, static for the terrace house.

Company n.2: detailed audit but somewhat simpler than above: hand-held infra-red viewer to inspect envelope, static thermal simulation model.

Company n.3: audit concentrated on the performance of the heating plants ; a small data logger used to obtain the "Building Energy Signature". This, together with reference values, used to calculate the annual energy