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Comparing Measured Savings and Cost-Effectiveness of Multifamily Retrofits in the U.S. and Europe

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ABSTRACT

In both the U.S. and Europe, multifamily buildings use a significant fraction of (non-transportation) oil and have increasingly been targeted by residential energy conservation and research programs. LBL and several European collaborators have compiled and analyzed measured data on retrofit savings and cost-effectiveness for 150 fuel-heated U.S. multifamily retrofit projects and 130 projects in Europe. Energy savings in the U.S., France, and Sweden were typically 14-18% of pre-retrofit energy use for space heat and hot water. Swiss buildings saved about 23%, but with much higher investments in conservation and greater emphasis on shell insulation rather than (lower-cost) heating system improvements. Median simple payback times for U.S. multifamily buildings were about 5 years; paybacks for the European retrofits were three to six times longer. In each country, heating system measures were generally more cost-effective than shell improvements, due to lower retrofit costs and comparable savings. Even after retrofit, the U.S. multifamily buildings used significantly more energy than the European buildings. This comparison, as well as the types of retrofits observed in the U.S. projects, suggest that many opportunities remain for improving efficiency in existing U.S. multifamily buildings.

Introduction

Energy efficiency in multifamily buildings merits special attention for several reasons. In most industrialized countries, multifamily buildings represent a large fraction of all housing units. This is especially true in Western Europe, with about 45 to 55% of the housing units in multifamily buildings (Aebischer, 1987; Ketoff, 1987). The U.S. is an exception among industrialized countries, with only about 16% of dwellings in multifamily buildings (EIA, 1986).[1] However, a disproportionate share of U.S. multifamily units are occupied by low-income households, who are especially burdened with high utility bills that result from inefficient building shells and heating systems.

Annual energy costs in U.S. multifamily buildings total $11 billion, or about $760/unit. Compared with U.S. single-family housing, these costs are 20% lower per dwelling unit, but nearly twice as high in terms of energy cost per heated floor area. In addition, nearly 10% of all multifamily units in the U.S. are operated by public housing authorities, which imposes annual energy costs of over $1 billion on the public treasury (Greely, *et al.*, 1988).

Finally, energy efficiency in multifamily buildings assumes a special importance to industrialized countries concerned with vulnerability of their oil imports, and with the linkage between oil use and global warming. Both oil heating systems and oil-saving opportunities are more common in multifamily buildings than in the single-family 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 heating plants that are oil- or gas-fired. This is especially true in the three European countries we studied, with 40-45% of their centrally heated multifamily buildings fueled by oil (Ketoff, 1987).

Early retrofit programs and research and demonstration projects in the U.S. concentrated on single-family houses (Hirst, *et al.*, 1985; Fels, 1986). In recent years, though, attention has been shifting to multifamily buildings. The opposite trend has occurred in most of Europe: retrofit programs initially emphasized multifamily buildings, with the focus shifting later to single-family homes. In France, for example, over 90% of the residential energy audits completed as of mid-1984 were in multifamily buildings (AFME, 1984-85).

This article is organized as follows. We first discuss data sources and analysis methods, and then examine characteristics of the multifamily buildings in our sample, including their pre-retrofit energy use and types of retrofit measures. Next, we present major results, in terms of both measured energy savings and cost-effectiveness, then discuss these findings and some policy implications. A concluding section summarizes work to date and future plans.

Data Sources and Analysis Methods

Overview of the BECA Data Base

The data we analyze in this report are drawn from the "BECA" (Buildings Energy-Use Compilation and Analysis) data base, maintained at Lawrence Berkeley Laboratory (LBL). BECA is an international reference source for policy-makers, practitioners, and researchers, containing over 2500 carefully screened records on the *measured* performance and cost-

[1] Defined as those with five or more units.

effectiveness of buildings designed (or retrofitted) to save energy and reduce peak electricity demand (Harris, 1985).[2] Part B of the BECA data base covers retrofits of single-family and multifamily residences. More detailed results, for multifamily buildings in the U.S. only, are presented in Goldman, *et al.* (1988).

The BECA compilation is based on available, well-documented, measured performance data rather than a statistically chosen sample, so the unweighted data do not necessarily represent trends in the entire building stock. We discuss, below, how the fuel-heated multifamily buildings we analyzed differ from the existing stock in each country. The buildings in BECA also differ from the *typical* retrofitted buildings in each country; however, little information exists on stock retrofit patterns, so this bias cannot readily be assessed. A first effort to extrapolate BECA results to stockwide estimates of energy savings potential in the U.S. is found in Meier, *et al.* (1988).

Multifamily Data Sources and Adjustments

Measured data for this study came from a number of sources. The U.S. data on fuel-heated buildings were provided mostly by local government agencies, public housing authorities, and research projects. The French data were from a series of retrofit demonstrations sponsored by the French Energy Agency (AFME) and the national association of social housing agencies (CNET-HLM, 1984b). Swiss data were from a variety of government and private sources, compiled by a research group at the University of Geneva (Berthoud, *et al.*, 1985). The Swedish data were from two research projects to test retrofits in large apartment blocks. Detailed data tables and narrative descriptions of each project are found in Goldman, *et al.* (1988).

The information available for each building or project[3] includes *measured* fuel use before and after retrofit (or, in some cases, post-retrofit data for both a treated and a control building), types of retrofit measures, retrofit costs, unit costs of energy, and selected building characteristics. Each data point is screened for completeness, internal consistency, and common definitions of key variables such as heat content of fuels, retrofit categories, and consistent measurement of floorspace. We then assign "data quality" ratings (A, B, C) to both energy and cost numbers, so that comparisons can be made among data points with roughly the same level of detail and accuracy of measurement. Energy use is normalized by heated floor area rather than interior volume, since data on ceiling heights were generally not available.[4] In many cases, space heat energy was not separately metered. Thus, the energy use data presented here reflect total fuel consumption for space heat, domestic hot water, and other fuel end-uses (mainly gas cooking, often present in U.S. multifamily buildings).[5] The energy used for space heating was also normalized

[2] The components of BECA include: New Residences (BECA-A), Residential Retrofits (BECA-B), New Commercial Buildings (BECA-CN), Commercial Retrofits (BECA-CR), Appliances and Equipment (BECA-D), Predicted vs. Measured Savings (BECA-V), and Load Management/Thermal Storage (BECA-LM).

[3] Data for U.S. public housing retrofits typically consist of fuel use for one central heating plant serving several buildings in a complex. Privately owned U.S. retrofitted buildings are most often metered building-by-building. The European data points include both individually metered buildings and complexes.

[4] Note that floor area, rather than number of dwelling units per building, is used to normalize energy use, since floor area is a better indicator of space heating requirements (the main end-use addressed by retrofits), and since floor area per dwelling differs significantly among and within the countries in our sample (see below).

[5] In cases where domestic hot water consumption was not included in space heat fuel use (nor metered separately) we added an estimated 155 MJ/m^2 to the measured space heat consumption of European buildings (Ketoff, 1987); consumption of U.S. buildings was adjusted using ratios of domestic hot water to total energy usage for different localities (Goldman, *et al.*, 1988).

to average-year weather in each location. Where measured data cover several monthly billing periods, energy use before and after retrofit was weather-normalized using the "Princeton Scorekeeping Method" (Fels, 1986).[6] Where the fuel use data were available only as a total for the entire heating season (as was true for most of the Swiss data), we normalize the estimated space heat fraction using the ratio of that year's heating degree-days to those for an average year. Data on vacancy rates before and after retrofit were available for about 20 % of U.S. multifamily buildings. Where vacancy rates changed, they were used as a scaling factor to adjust post-retrofit energy savings. Due to insufficient data, we do not (at present) adjust for differences in inside temperature, internal gains, window-opening practices, etc.—either among buildings or between the pre- and post-retrofit periods for a given building. These and other behavioral or demographic factors are more likely to affect comparisons *among* buildings than to change the estimate of retrofit savings for a given building. Thus, comparisons of percentage savings in energy are relatively unaffected by these occupant-related variables, for which few reliable data were available.

Energy costs and retrofit costs (including labor and materials) are both expressed as constant (1987) U.S. dollars. For U.S. projects, the GNP deflator is used to convert costs to 1987 dollars. For other countries, original energy and retrofit costs are translated to 1981 local currency using that country's GDP cost deflator, converted to U.S. dollars using 1981 exchange rates, and then expressed as constant 1987 U.S. dollars using the U.S. deflator.[7] Energy costs reflect actual local prices paid at the time of retrofit (or, as a default, national average residential energy prices for that year). These procedures allow a more consistent comparison of retrofit economics in the different countries. (Note that both the calculation of payback times and the retrofit "investment index," defined below, are independent of currency exchange rates.)

Building and Retrofit Characteristics

Multifamily Building Characteristics

Table 1 summarizes, by country, selected characteristics of the 280 multifamily retrofit projects in the data base.

Size. The median building size in Sweden (38 units) was significantly larger than in the other countries; the median Swiss building had only 11 units, but with the largest median dwelling size (85 m^2).[8] The 21 French retrofit projects, exclusively in large social housing complexes, had the lowest median floor areas (70 m^2/unit), about equal to the French stock average (CNET-HLM, 1984a; Ketoff, 1987). Median dwelling size was about the same in the U.S. and Swedish buildings (75-76 m^2). However, compared with their respective national stocks, the U.S. multifamily buildings in our sample had units about 10 m^2 smaller than average, while those in the Swedish buildings were 10 m^2 above average (Ketoff, 1987). Due to these variations in dwelling size, we present energy use data normalized by floor area, rather than per dwelling.

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[6] PRISM estimates energy use in an average-weather year by regressing monthly energy use against heating degree-days based on daily outdoor average temperatures.

[7] 1981 exchange rates are considered fairly typical of long-term trends, and reduce the effect of fluctuating rates in more recent years.

[8] Floor area per dwelling, as calculated here, includes pro-rated floor area for conditioned common areas, such as hallways, entrance foyers, laundry, etc.

Year of construction. The U.S. multifamily buildings in our data set are significantly older than those in the three European countries; more than half were built before World War 2, compared with postwar construction typical of the European retrofit sample. This difference in vintage may help explain the higher energy intensity of U.S. buildings, both before and after retrofit, as discussed below.

Heating fuel. Nearly all of the retrofitted buildings in our sample were centrally heated with oil or gas.[9] As noted, fuel heat is more typical of the older multifamily stock now being retrofitted; many recent buildings are all-electric or have apartment-level gas heating. Electric heating had penetrated 19-23% of the total multifamily stock in the U.S., France, and Sweden as of the mid-1980s, but retrofits of all-electric buildings are still relatively rare.[10] For the U.S., the gas-heated multifamily buildings in the data base represent only the central-heated stock, although about 20% of the pre-1980 gas-heated buildings had individual heaters in each apartment (EIA, 1986). For France, there is only one gas-heated building in the data base *vs.* 25-30% gas heat in the centrally heated stock (AFME, 1986-87; Ketoff, 1987). Nearly all the French and Swiss buildings in our sample were heated by oil, along with one-fourth of the U.S. buildings but none of the Swedish ones. By comparison, oil heating was present in about 20% of the U.S. multifamily building stock as of 1984, and nearly 40% of the stock in France and Sweden (Ketoff, 1987).

Construction. Wood frame wall construction was used in nearly two-thirds of the U.S. multifamily buildings we analyzed; the remaining third, plus all of the European buildings, had masonry walls. A typical wood-frame building that is not insulated during construction has an empty wall cavity (typically 10 cm.) available to retrofit blown-in insulation. Even after repairing access holes and repainting the exterior walls, such internal cavity insulation is usually cheaper than attaching rigid insulation to a masonry wall and re-cladding the exterior (or in some cases, the interior) wall surfaces.

The number of window glazing layers was not reported for all buildings, and tends to vary regionally within both France and the U.S. We believe that most of the French (social housing) projects in our sample were single-glazed, as were about one-third of the U.S. buildings. About two-thirds of the U.S. buildings, located mostly in the colder states of the upper Midwest, were double-glazed prior to retrofit. From general observation, most Swiss buildings and nearly all the Swedish ones have at least double-glazing.

Climate. Average outdoor temperatures during the heating season are roughly comparable in the U.S. and France, while winter temperatures in Switzerland are somewhat colder—and in Sweden significantly colder. The U.S. buildings in our sample, however, were not regionally representative of the U.S. stock, but were disproportionately found in colder climates, as shown by the distribution of heating degree-days in Table 1.

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[9] Exceptions were the Swedish buildings, served by district heat, and a few public housing retrofits in San Francisco with individual gas heat in each apartment.

[10] This is in part because they tend to be newer than the fuel-heated stock, were initially better insulated, and (in the case of individually controlled apartment- or room-level resistance heat) have relatively few heating system retrofits which are practical or cost-effective. One important exception to the lack of retrofit examples in electric-heated multifamily buildings is a series of demonstrations sponsored by electric utilities in the northwest region of the U.S.

Energy use before retrofit. In the U.S. multifamily buildings we studied, median pre-retrofit energy intensities for space and water heating (1340 MJ/m^2) were significantly higher than those in the three European countries: 20% higher than the French buildings and 56% and 77% higher than the medians in Switzerland and Sweden, respectively (Table 1). These comparisons reflect similar patterns in the multifamily stock, with lower energy intensities in Europe than in the U.S. (after adjustment for climate differences). This is due not only to differences in building shell and heating system efficiency, but to less appliance energy use in much of Europe and lower levels of heating comfort (lower average indoor temperatures and fewer buildings with central heat; Ketoff, 1987).

Pre-retrofit energy use for our building sample should also be compared with estimated average values for the stock in each country. Prior to retrofit, the U.S. buildings in our data base used about 40% more energy per dwelling than the stock average, even though unit floor area was smaller (EIA, 1986). In contrast, the French buildings prior to retrofit were about average for the multifamily stock—but used about 25% more energy than the typical social housing project (CNET-HLM, 1984a). Pre-retrofit energy intensity for the Swiss buildings was about 10% above the stock average; for the Swedish buildings pre-retrofit usage appeared to be typical of the stock, or slightly lower (Aebischer, 1987; Ketoff, 1987).

Retrofit Measures and Levels of Investment

Figure 1 shows the frequency, by country, of each major type of retrofit. Envelope insulation (typically on the exterior of masonry wall buildings) is much more common as a retrofit in the European buildings (45-85% of the cases) than in the U.S. buildings in our sample (20%). Heating equipment changes occurred in 50-75% of the buildings in each country. Heating system control changes, water heating retrofits, and other system measures were most common in the U.S. and Switzerland. Without better data on retrofit trends in the multifamily stock, it is difficult to determine whether the 250 cases in our data base are typical for each country. However, a French survey of multifamily retrofits showed about the same rate of heating equipment retrofits as in our sample, and greater emphasis on system maintenance—but significantly lower frequencies of system control retrofits, window measures, and insulation in walls/floors and roof/attics (AFME, 1983). One technical report on Swiss retrofits suggested that shell measures are about 50% more common than system retrofits in multifamily buildings; this is roughly consistent with retrofit patterns in our sample of 104 Swiss buildings (OFQC, 1985).

Median levels of retrofit investment differed dramatically by country. Median retrofit costs for the U.S. buildings, at about \$6/m^2, were less than one-third of the retrofit investment levels in the French and Swiss buildings, and under 20% of investments in the Swiss buildings (Table 1). This same relationship is shown by a second indicator: the "investment index," or ratio of retrofit costs to (pre-retrofit) annual energy expenses. The U.S. buildings show a median investment index equal to only six months of energy costs, compared with 1.6 to 4.4 years of energy costs for the buildings in the three European countries. However, as noted above, the European retrofits emphasized more costly shell insulation measures; some of these higher retrofit costs could be attributed to building preservation and restoration, rather than to energy savings alone.

Results

Energy Savings

U.S. buildings tended to save the most energy per dwelling, but also had much higher pre-retrofit energy intensities (Table 1). This resulted in median percentage savings that were similar for the U.S., French, and Swedish buildings (14-18%), but higher for the Swiss buildings (23%).

Figure 2 presents the same results in graphic form, showing (weather-normalized) annual energy savings *vs* pre-retrofit annual consumption. Despite the scatter in these data, several general trends are evident:

- Pre-retrofit energy use, as noted, is highest in the U.S. buildings and lowest in Swedish buildings.
- The French buildings (all from social housing projects of about the same age) showed relatively little variation in pre-retrofit use; U.S. buildings showed the most variation, ranging from 500 to over 2500 MJ/m^2.
- As a group, the Swiss retrofits had the highest percentage savings, despite relatively low energy intensities before retrofit.
- Although a number of U.S. buildings achieved similarly high percentage savings (20-40%), these tended to be very energy-intensive to begin with—often due to poorly controlled boilers and distribution systems. Thus, achieving substantial savings in these buildings was in large part simply a matter of operating the systems efficiently, rather than undertaking costly modifications. This helps explain why retrofit projects were often very cost-effective in many of the U.S. buildings—but also indicates that the retrofits already in place probably do not exhaust the opportunities for further efficiency improvements.
- Figure 2 also shows a small number of projects with "negative savings" (i.e., increased energy use after retrofit). These may indicate a performance failure of the retrofit measure, due to poor product quality, installation, or operation. However, other factors may also contribute to an increase in whole-building energy use, such as changes in occupancy patterns, indoor comfort settings, or energy use by other building systems (not covered by the retrofit). The weather-correction techniques we used, while appropriate for the type of energy data available, may not be ideal in the case of multifamily buildings with complex heating distribution and control systems, or those located in milder regions of the U.S. Finally, Figure 3 shows that many of the retrofits with negative savings also involved modest levels of investment. Expected savings were correspondingly small, compared with total energy use. Thus, the "signal" of retrofit savings is more easily masked by other factors, when whole-building data are used. This suggests, in turn, the need for more detailed monitored data, both pre- and post-retrofit.

Cost-Effectiveness

Table 1 shows the dramatic differences by country in median simple payback times. Paybacks for the European retrofits were three to six times longer than for their U.S. counterparts, partly due to their emphasis on costlier shell improvements, and also because many of the European retrofits were undertaken as government-sponsored demonstrations. **Figure 3** shows percentage energy savings as a function of the investment intensity index for each project. Beyond the initial impression of large scatter in the data, we see that the Swiss buildings stand out as a group, showing the highest investment levels (relative to pre-retrofit annual energy costs) and also saving the most energy—but not saving enough to avoid very long payback times. A number of the very low-cost U.S. retrofits (with paybacks well under five years) involved the addition of controls to large, poorly controlled central heating systems. However, to look beyond the general relationships between energy savings and investment shown in Figure 2, we need to disaggregate the data further, by type of retrofit as well as by country.

In **Figure 4**, the projects in each country are grouped under three general retrofit categories: heating system measures only, shell measures only, and combined shell and system measures. For each country, the combined system and shell measures were the most "intensive" in several respects: (1) they tended to be installed in buildings with the highest pre-retrofit energy use, (2) saved the most energy (in absolute and percentage terms), and (3) resulted in the lowest post-retrofit energy use (with the exception of the small sample of Swedish buildings). The combined shell and system retrofits were associated with the highest levels of retrofit investment (except in the U.S., where shell/system and shell-only retrofit costs were about equal). However, cost-effectiveness for these combined retrofits, as measured by simple payback, was intermediate between the shell-only measures and system-only measures.

The conventional way to look at retrofit results is to consider energy savings and the cost to achieve them. But an equally important question is the *performance level achieved* after retrofit. **Figure 5** takes this other perspective, showing post-retrofit energy intensities compared with median energy intensities before retrofit, for each country. The right side of this Figure is a histogram of energy intensities (space heat and hot water), by country; the left side provides further disaggregation according to the heating degree-days for each project. The histogram clearly shows that, after retrofit, the U.S. multifamily buildings were still significantly more energy-intensive than their European counterparts; the majority of the U.S. buildings used more energy after retrofit than the median energy use *prior* to retrofit in the three European countries. Moreover, this difference is not readily attributable to colder climates, as shown in the heating degree-day scatterplot on the left side of the figure.[11] Nor are the differences in median energy intensity explained by the fact that U.S. retrofitted buildings in our sample tended to be older, as noted above. The observation that U.S. multifamily buildings tend to use more energy after retrofit than the median European building before retrofit also holds if we look separately at the pre-war and post-war subsamples.[12] We commented earlier that, to some extent, the gap in post-retrofit energy intensity may reflect different comfort demands and appliance saturations in the U.S. and Europe. But, in part, this difference also highlights the remaining potential for energy efficiency improvements in the U.S. stock.

Discussion

While the small, non-random samples available in the BECA-B multifamily data base may not be fully representative of retrofit practices and results in these four countries, a comparison of results is at least suggestive on two points. First, U.S. multifamily buildings, because of their higher post-retrofit energy use and modest levels of retrofit investment to date, may still offer significant opportunities for energy savings.[13] Second, owners of multifamily buildings in Europe appear to be more willing than those in the U.S. to make major investments to preserve

[11] U.S. buildings with higher post-retrofit energy use (above 1100 MJ/m^2) were distributed across all the climate zones; with more of them in the cluster around 2700 HDD than in the group near 4500 HDD.

[12] Pre-war multifamily buildings in the U.S. did use about 20 % more energy before retrofit than the post-war buildings, and about 10 % more after retrofit.

[13] In addition, even the low-cost heating system retrofits documented in the BECA data base have not yet been implemented in much of the multifamily stock (Goldman, *et al.*, 1988; Meier, *et al.*, 1988).

and improve the existing stock.

We have already noted that the median U.S. building used more energy after retrofit than the median European building, before retrofit. In addition, median post-retrofit energy use in our U.S. sample (1122 MJ/m^2) was only slightly below the estimate for all fuel-heated U.S. multifamily buildings built prior to 1980 (1146 MJ/m^2), and still one-third more energy-intensive than the post-1980 stock (823 MJ/m^2; EIA, 1986).[14] Achieving these added savings, however, may require higher investments and longer payback times than most U.S. building owners, public or private, have been willing to consider up to now. Payback times of 15-30+ years, common in our sample of European shell retrofits, would require a major shift in economic perspective for building owners in the U.S.

Note that many of the European buildings, both social housing and privately owned, were retrofitted as part of government-sponsored demonstration programs, which partly accounts for the owners' willingness to accept longer paybacks. However, median paybacks still differ by more than two to one, when we compare Switzerland and the U.S. in terms of two separate subsets: non-subsidized retrofits (privately owned buildings) and subsidized demonstration programs. The European perspective on retrofits often includes an awareness of non-energy benefits, such as extending the useful life of the building stock and enhancing its value. Thus, when European building owners invest in shell retrofit measures, the associated renovation of the building exterior may be an important motivation. A third factor explaining longer paybacks may be that the European retrofits were undertaken at a time when many building owners in these countries—even more than those in the U.S.—expected to see large, continuing increases in oil and gas prices, a trend which has been slowed or reversed, for the time being.

One clear policy implication is for the U.S. to begin pricing fossil fuels at a level more reflective of their long-term societal value, as do the European countries, through significantly higher fuel excise taxes. In the long term, different price signals can help redirect the market toward more efficient fuel use. However, other policies may be needed to complement market forces, especially at a time of growing concern for the global climate effects of CO_2 from fuel combustion. The multifamily stock consists disproportionately of rental units, where there are only weak links, at best, between higher heating prices and economic incentives to invest in efficiency. The same applies to that fraction of the stock occupied by low-income households. This has been a major justification for government and utility incentives for low-income weatherization programs in the U.S. Unfortunately, these programs are only now beginning to focus on the multifamily stock, from their historical emphasis on single-family retrofits. Retrofit programs sponsored by gas utilities have been scaled back in many areas, in the face of momentarily ample supplies, moderate price increases, and concerns over loss of large customers to bulk purchase or to all-electric technologies. Finally, the public housing sector in the U.S. remains a source of hundreds of millions of dollars of untapped energy savings each year, while federal spending constraints slow the process of investing in improved energy efficiency (Greely, et al., 1988).

The disappearance of most government retrofit incentive programs raises another important policy question: to what extent can further energy and cost savings be achieved through

[14] These comparisons should be adjusted slightly for climate differences. Median heating degree-days for pre-1980 stock were about 15% below HDD for our sample, while HDD for the post-1980 stock were only about 5% less.

strategies that require little capital investment? One promising approach, still largely untried in the multifamily sector, is to achieve and maintain effective building operation through better maintenance practices, increasingly assisted by remote telemetry or by computerized, on-site control systems. Even with improved monitoring, these operation and maintenance efforts require little new capital investment. However, new monitoring and control "hardware" is only part of the answer; equally important are efforts to recruit and train competent operating personnel, and to equip them with the responsibility, data, and proper incentive structures to keep the hardware systems working well.

Conclusion

Prior to retrofit, typical energy use and costs in European multifamily buildings were lower than those in the U.S., due to better equipment maintenance and operation and to building shells that were initially tighter and better insulated. The median percentage savings in energy were reasonably close (14-18%) in the U.S., France, and Sweden, but higher in Switzerland (23%). The European retrofits in the BECA data base were generally more expensive than those in the U.S., largely due to the higher incidence of shell (or combined shell and system) measures. Median payback times for the U.S. retrofits were 5 years, compared with 15-30 years in the three European countries. Shell retrofits in multifamily buildings, while less cost-effective strictly in terms of energy, may offer other benefits in improved appearance, comfort, and structural preservation. Comparisons of U.S. and European multifamily retrofits are interesting because the latter may represent a "second-generation" effort, providing U.S. policy-makers and technical experts with a look into the future at the retrofit options (and costs) that could continue to improve the energy efficiency of U.S. multifamily buildings.

Under the BECA project, we continue to compile and review measured data on building energy performance, retrofits, and operating practices among different countries. Reader comments and information on additional data sources are always welcome.

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

	U.S.	France	Switzerland	Sweden
Number of Projects[a]	149	17	104	13
Building Type:				
High-rise	35	8	22	9
Low-rise (≤ 4 floors)	110	6	62	1
Combination/Unknown	4	3	20	3
Number of Dwellings/Building (median)	21	24	11	38
Floor Area/Dwelling (median, m^2)	76	70	85	75
Year of Construction (median)	1942	1961	1961	1957
Heating System Type:				
Central	146	17	104	13
Individual	3	0	0	0
Heating Fuel Type:[b]				
Natural Gas	106	1	3	0
Oil	36	16	101	0
Mixed Fuel[c]	2	0	0	0
District Heating	0	0	0	13
Climate Zone ($HDD_{18° C}$)				
< 2000 HDD	12	2	0	0
2000 - 3000 HDD	52	15	3	0
3000 - 4000 HDD	20	0	99	9
> 4000 HDD	65	0	2	4
Energy Intensity (median, MJ/m^2):[d]				
Pre-retrofit	1340	1118	857	756
Post-retrofit	1122	812	648	598
Absolute Savings	216	146	184	101
Percent Savings	16	18	23	14
Frequency of Retrofit Measures (%):[e]				
Insulation	20	65	45	85
Windows	24	29	14	39
Heating Equipment	53	53	57	85
Heating Controls	56	35	30	85
Domestic Hot Water	26	6	9	69
Other	26	53	44[f]	69
Median Retrofit Investment:				
$US (1987)/$m^2$	6	21	33	17
Investment Index[g]	0.5	1.6	4.4	2.3
Median Simple Payback Time (years)[h]	5	15	24	29

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

[b] Some of the U.S. retrofits did not affect the space heat fuel consumption; therefore, the heating fuel type for those buildings does not appear here.

[c] "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.

[d] Fuel used for space and water heating; sometimes cooking use is also included. Domestic hot water use was estimated for some buildings; see text for details.

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

[f] One-quarter of the buildings received unspecified envelope retrofits, which are included in this category.

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

[h] To facilitate comparisons among the countries, the payback calculations *exclude* any increase—or decrease—in real energy prices after the date of retrofit.

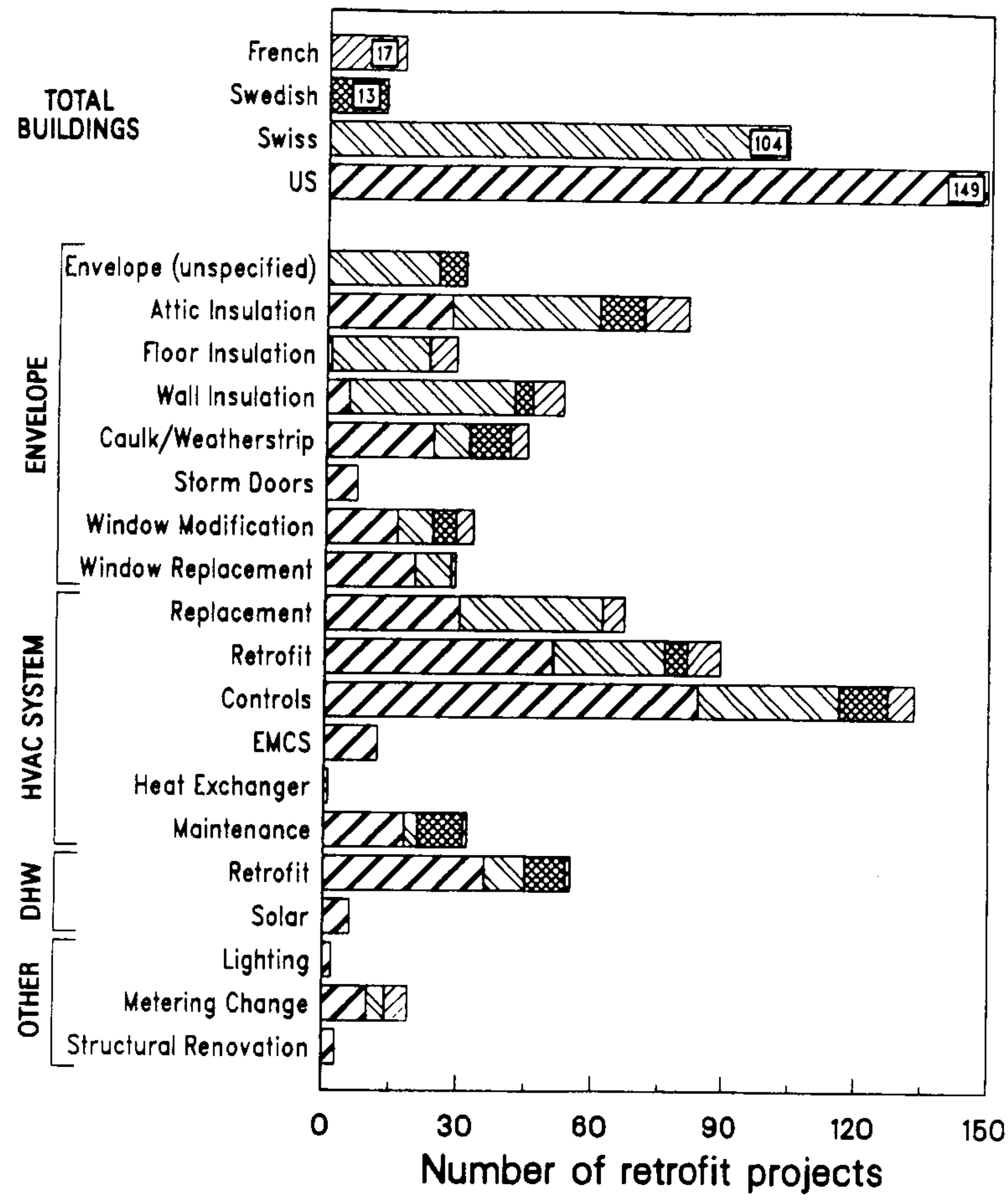

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Figure 1. Relative frequency with which retrofit measures were installed in U.S. and European fuel-heat multifamily buildings. Total number of buildings is shown at top; note that the cumulative total of measures is much greater than the total number of buildings, because more than one measure is often installed in an individual building.

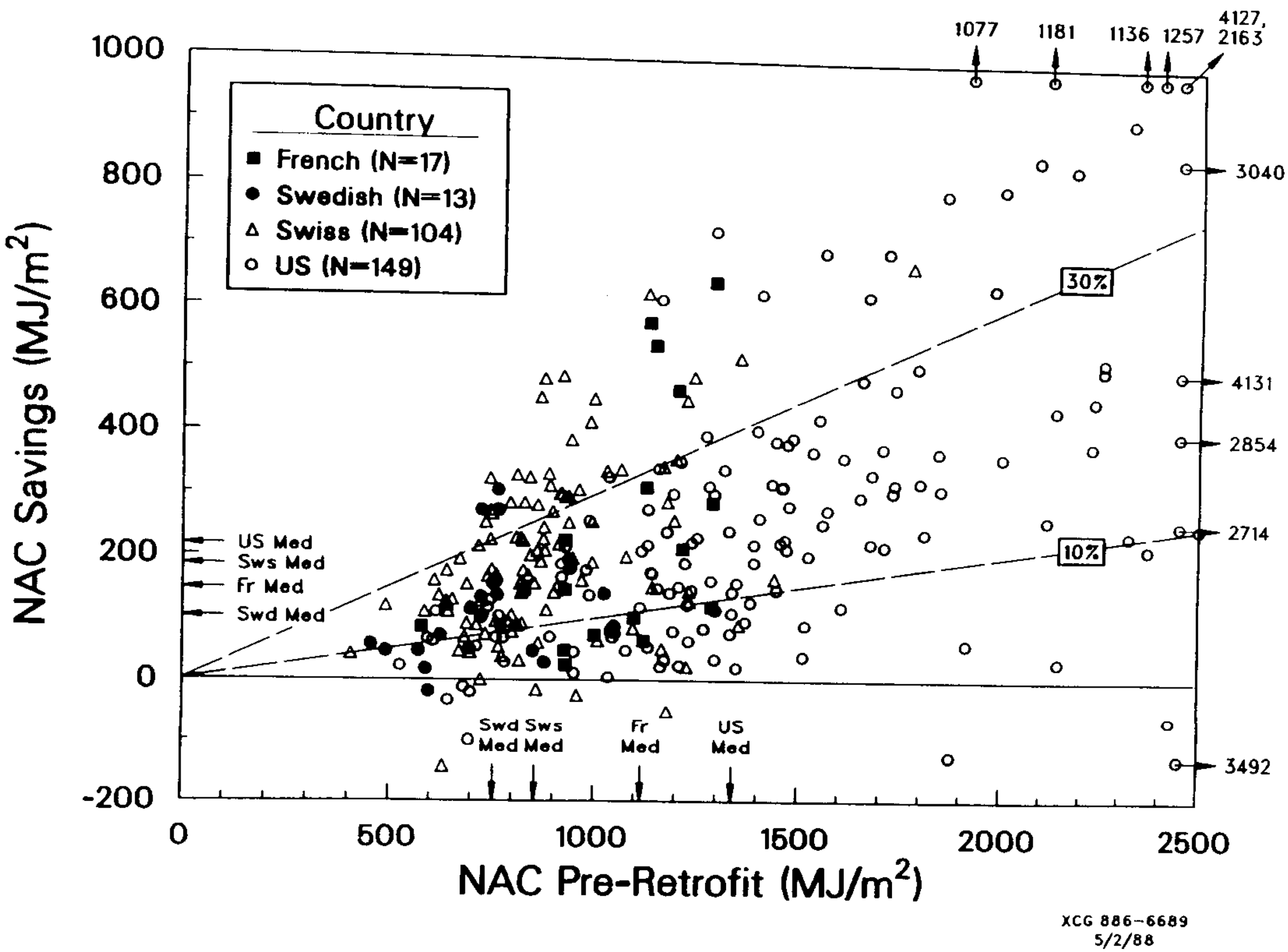

Figure 2. Multifamily energy savings as a function of pre-retrofit energy use, for fuel-heat buildings in the U.S. and three European countries. Energy consumption includes space heating and domestic hot water. In cases where metered data on hot water energy use were not available, an estimated value for hot water energy was added to space heat energy, to allow comparisons across buildings; see text for details.

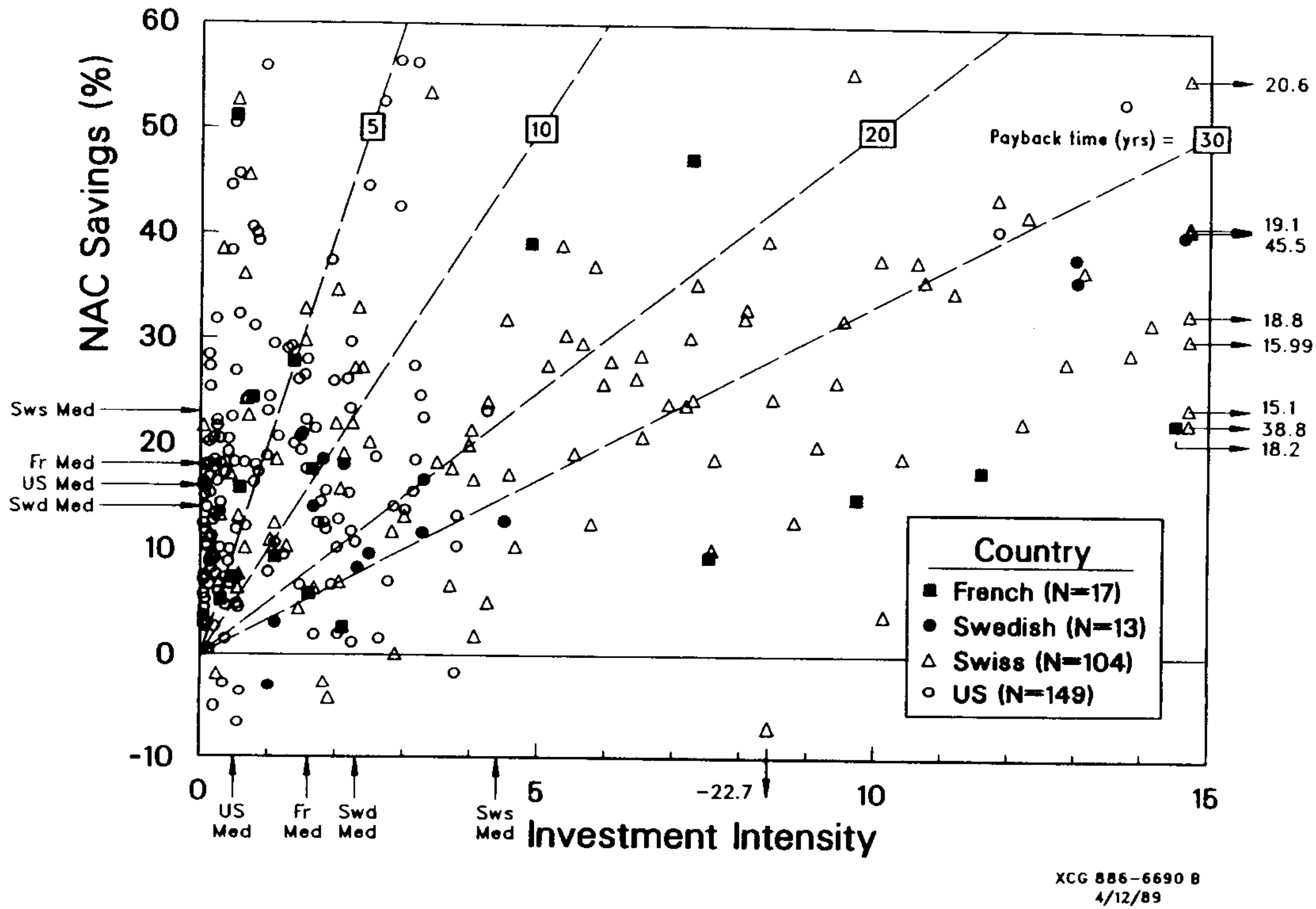

Figure 3. Percentage energy savings as a function of retrofit investment for fuel-heat buildings in the U.S. and three European countries. "Investment intensity" is defined as the retrofit cost divided by annual energy costs, prior to retrofit. This index can be interpreted as the number of years of energy expenses invested in a retrofit. Lines radiating from the origin indicate simple payback times of five to thirty years. U.S. multifamily buildings show significantly lower levels of retrofit investment (and shorter paybacks) than their European counterparts; not shown in this Figure is the higher pre-retrofit energy use of the U.S. buildings (see Fig. 2).

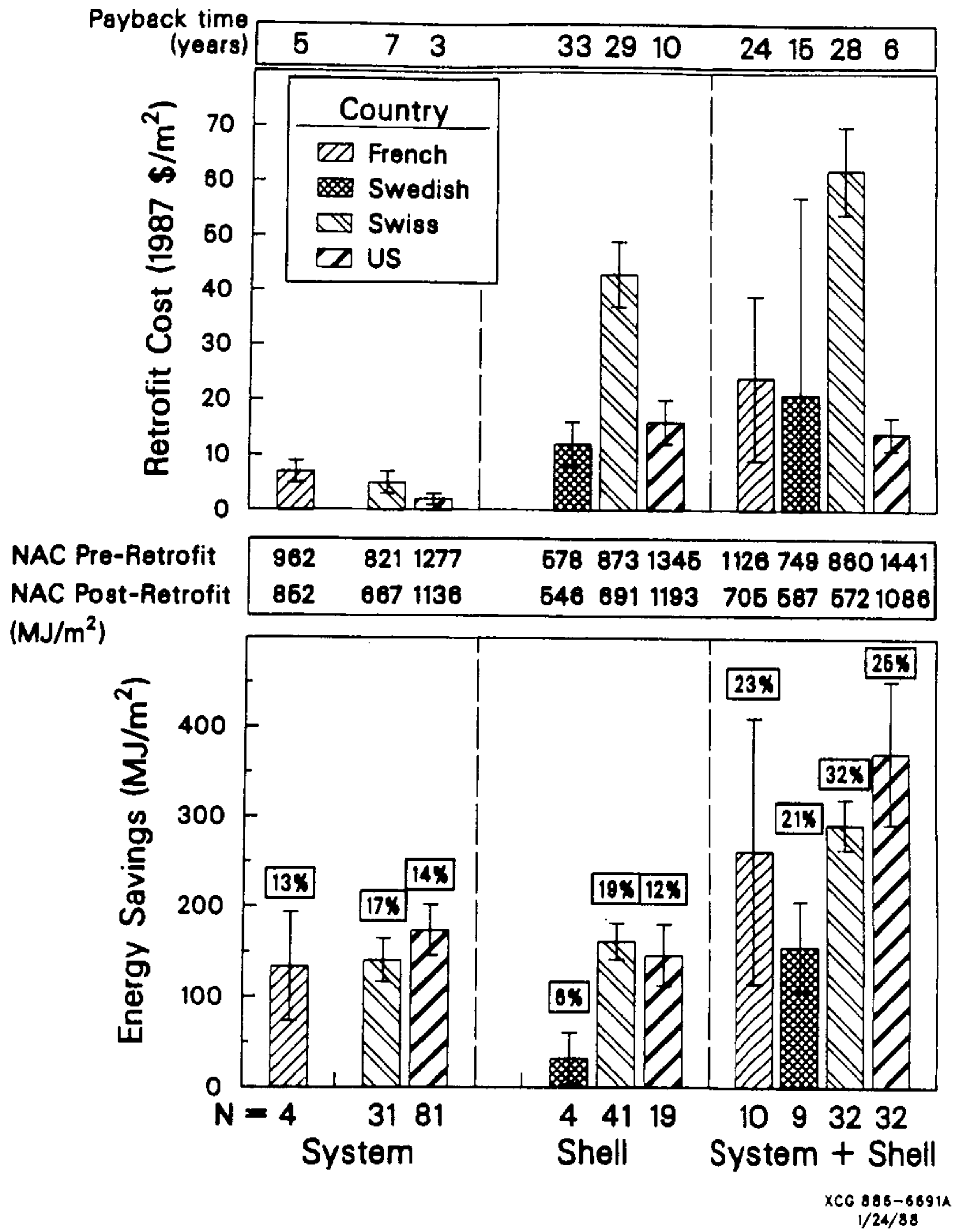

Figure 4. Median energy savings, pre- and post-retrofit energy intensity, retrofit cost, and payback time by general retrofit strategy (system, envelope, and combinations), for U.S. and European fuel-heat multifamily buildings. *System* retrofits are measures that affect the heating or hot water systems. Envelope (or *shell*) retrofits include measures such as insulation, caulking, window replacements, and storm windows. The *System and Shell* category includes buildings where both types of measures were installed. The I-shaped "whiskers" on each bar show the 25th and 75th percentiles. "N" is the number of projects in each category.

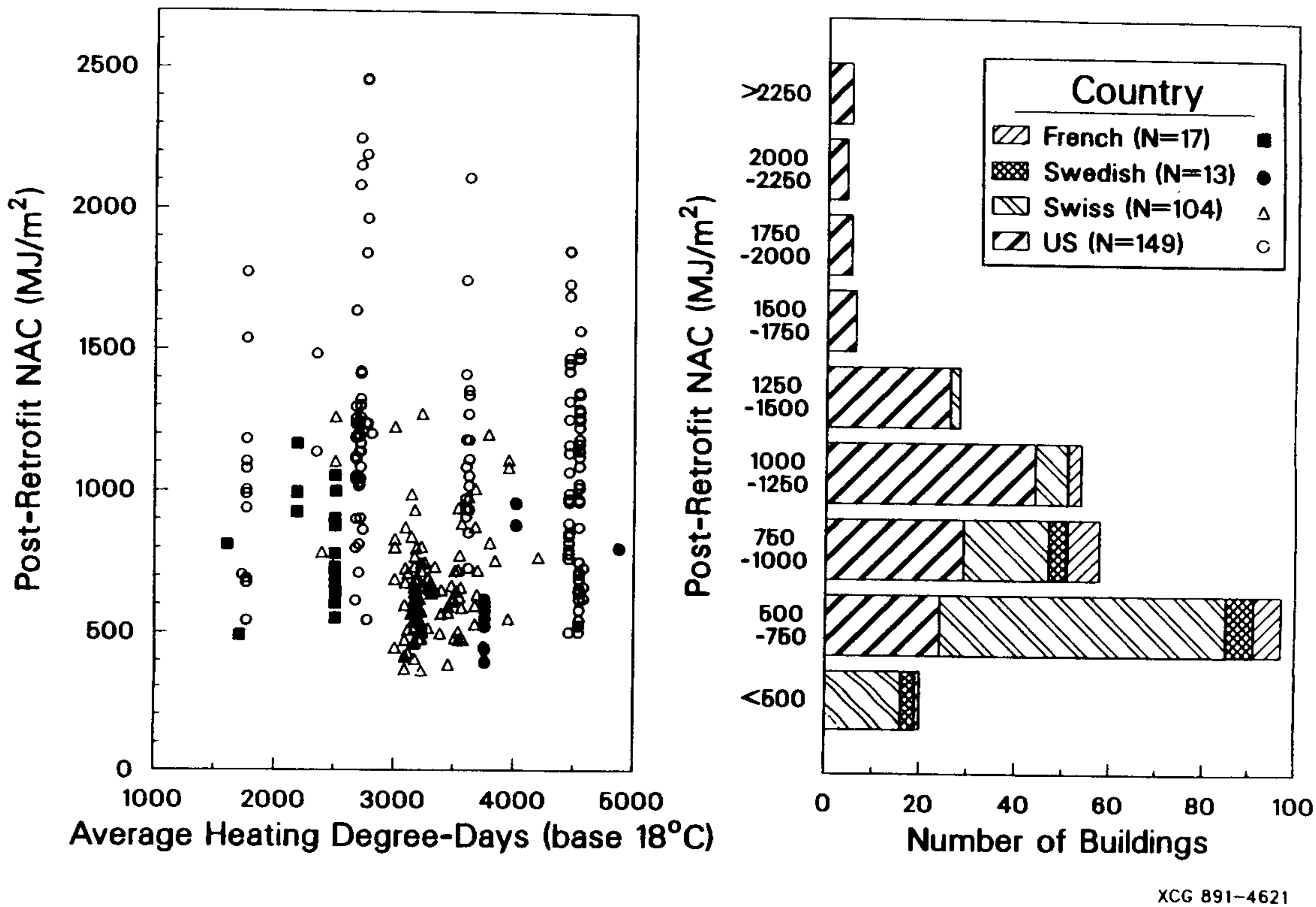

Figure 5. Energy intensity after retrofit, for U.S. and European fuel-heated multifamily buildings. The right half of the Figure shows a frequency distribution by country; the left half plots post-retrofit energy intensity (space heat, hot water, and in some cases cooking energy) as a function of heating degree-days.