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MEASURED ENERGY SAVINGS IN RETROFITTED MULTIFAMILY BUILDINGS

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ABSTRACT

Measured data on the energy savings and cost-effectiveness of conservation measures and practices installed in existing multifamily buildings are compiled and analyzed for over 100 buildings. Factors that explain the range in energy savings are analyzed including energy use before the retrofit, the level of investment, and choice of measures.

Energy savings achieved are typically 10 to 25 percent of pre-retrofit energy use although large variations are observed in energy savings and in costs per unit of energy saved. The median retrofit investment in multifamily buildings is approximately $530 per unit. Many conservation investments are attractive investments from a building owner's perspective: the median real rate of return for buildings in this study is 22 percent. Preliminary results also suggest that some envelope measures (e.g., "shell" packages and window measures) have longer payback periods than many of the heating system retrofit strategies.

KEYWORDS

Energy Conservation, Multifamily Buildings, Monitoring, Retrofits

INTRODUCTION

The multifamily sector, consisting of residential buildings with two or more units, comprises almost 27 percent of the U.S. housing stock (in terms of household units). Annual primary energy use in these buildings is approximately 2.8 quads (1 quad $= 10^{15}$Btu) and directly or indirectly costs U.S. households almost $20 billion. Multifamily buildings vary widely in complexity from single-family style of construction to large office-building type structures. Several studies have identified significant potential for cost-effective energy-efficiency improvements, although documented information on the results of retrofits is not widely available. A 1982 study by the Office of Technology Assessment estimated the conservation potential in the multifamily sector at 1.0 quad per year by the year 2000 (43% of the sector's current energy use), although likely savings are only 0.3 quad, because of the existence of complex technical, information, institutional, and economic barriers.[1] Surveys of multifamily building owners highlight some of these barriers:

1) an unwillingess to invest in costly measures without guaranteed savings
2) problems related to split in economic interest between landlords and tenants,
3) difficulty in obtaining financing for retrofits, and
4) conflicting information on the performance and costs of retrofits.[2]

This study seeks to address one information barrier, the lack of monitored building performance data, by compiling and systematically analyzing *measured* data on the energy savings and cost-effectiveness of conservation measures and practices installed in existing multifamily buildings.* We also examine the correlation between energy savings and initial pre-retrofit energy intensity, level of investment, and choice of measures and discuss limitations and gaps in the available data.

DATA SOURCES

Information on retrofit projects was obtained from city energy offices, research institutions and national laboratories, public housing authorities, utilities, and from non-profit and for-profit energy service companies. The data collected typically included metered energy consumption, installed retrofit measures and their cost, the price of the space heating fuel the winter after retrofit, and, in most cases, a brief description of the physical characteristics of the buildings (e.g., conditioned floor area, building and heating system type). In most cases, each data point represents one building, except for public housing projects which often have a number of buildings on a utility master meter.

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* The results are drawn from the Buildings Energy Use Compilation and Analysis (BECA) residential data base at the Lawrence Berkeley Laboratory.

BUILDING CHARACTERISTICS AND RETROFIT MEASURES

Approximately 70 percent of the 101 retrofit projects are low-rise buildings with four stories or less, although a majority of the 36 public housing projects included in this study are high-rise buildings (see Table 1). Almost all of the buildings have central heating systems and are master-metered. Approximately 60 percent of the retrofit projects use gas for the space heating fuel. Eighty-five percent of the buildings are renter-occupied. The sample of buildings in the database is somewhat skewed with respect to geographic location, with clusters of buildings in a few cities/regions. For example, 31 buildings are located in the Minneapolis-St. Paul area, 25 retrofit projects are in New York City, 11 projects are in San Francisco, and 13 projects are located in New Jersey. Floor area per dwelling unit ranges between 750 and 1000 ft^2 in over 50 percent of the buildings, while 20 percent of the buildings are between 500 and 750 ft^2. Most buildings in the data base are small to medium size multifamily buildings; 68 percent are less than 50 units while only 4 buildings have more than 150 units.

Retrofit activity in multifamily buildings lags far behind retrofits of single-family homes. Almost 50 percent of the available measured data comes from publicly-owned or publicly-subsidized multifamily housing. Another 30 buildings were retrofitted as part of the Minneapolis Energy Office's research/testing program.

At present, most residential retrofits are directed towards improving energy efficiency in the two largest energy consumption end-uses: space heating and domestic water heating. The most popular conservation strategies in our sample of multifamily buildings were various HVAC system retrofits: (Fig. 1a)

- heating system controls such as outdoor resets, high limit outdoor cutout, and aquastat,
- heating system equipment measures such as new burners, vent dampers and turbolators,
- boiler replacements, and
- altered operations and maintenance practices.

Various window retrofit measures, including storm windows and double-glazed thermal break aluminum windows, were also installed frequently. Typically, the cost per dwelling unit for these measures was high ($500 - 1200/unit), although building owners and tenants often cited additional benefits of these retrofits, including improved building appearance, security, and decreased maintenance expenses. In general, envelope measures were implemented far less frequently than heating and hot water system measures. Attic insulation was installed in 15 projects, caulking and weatherstripping was implemented in 11 buildings, and wall insulation in only one building. We suspect that the low implementation rate for shell measures is due in part to physical characteristics of many multifamily buildings (e.g., flat roofs and masonry walls) which make it difficult to insulate. Retrofit strategies designed to reduce hot water energy use include solar hot water systems (6 buildings), separate domestic hot water boilers, hot water temperature setback, low-flow showerheads, and insulation of water heater tanks and pipes.

The median cost of the retrofits is $534/unit for the buildings in this study. Retrofit costs were under $250/unit in 40 percent of the buildings, which suggests that many building owners confined their retrofit efforts to fairly low-cost measures (Fig. 1b).

METHODOLOGY

The approach used in this study includes three principal elements: (1) normalizing energy use for weather and occupant effects, (2) analysis of the level and range of energy savings, and (3) calculation of the economics of energy savings.

For most retrofit projects, LBL or the original analysts used the Princeton Scorekeeping Method (PRISM) to adjust for the effects of weather.[3] PRISM uses a regression equation to estimate weather-adjusted annual energy use, based on monthly fuel or electricity bills (depending on the space heat fuel) and daily heating degree-days (to different reference temperatures). The utility bills typically include heating energy usage along with other ("baseline") uses of the same fuel. The equation is:

$$E = a + b\ H_i(t) \qquad [1]$$

where

E is total gas or electricity use,

a is the base level use,

b is the heating slope, and

H_i is the number of heating degree-days to reference temperature, t.

The base level (a) and heating slope (b) are found by ordinary least squares regression for a range of base temperatures. The "best" base temperature is the one in which the mean-squared error is minimized. The normalized annual consumption (NAC) is then calculated for each period using the parameters a, b, and t:

$$NAC = 365a + bH_o(t) \qquad [2]$$

where

H_o is the normal-year heating degree days to the best-fit base temperature, t.

The NAC represents consumption which would occur in a year with typical weather conditions.

For some projects, only annual energy consumption data are available rather than monthly utility bills. In these cases, we correct for the varying severity of winter in different years by scaling annual estimated space heat energy use by the ratio of normal-to-actual year heating degree-days (base $65^{o}F$). Annual baseload energy use is calculated by scaling estimated summer fuel use to a full year. Summer fuel use is estimated by building owners or from regional and utility data for similar buildings.

For purposes of comparability, energy use at each project is expressed on a per dwelling unit basis. In multifamily buildings, particularly those that house low-income tenants, turnover is often high and occupancy rates vary greatly over time. Changes in energy use may be masked by increases or decreases in the number of occupied (and presumably heated) dwellings. Hence, we adjust for changing occupancy rates when vacancy data are available.

Retrofit costs are "standardized" based on the direct costs to the building owner of contractor-installed measures. An equivalent contractor cost is estimated in those few cases where only materials costs were known (materials cost multiplied by 2.7-3.0). Costs at the time of retrofit are converted to constant dollars (1985$). Two economic indicators are calculated: simple payback time (SPT) and internal rate of return (IRR). SPT is the period required for the undiscounted value of future energy savings (at today's energy prices) to equal the initial cost of the retrofit. The IRR is the rate of interest which, when used to discount the life-cycle costs and savings of an investment, will cause the two to be equal. In calculating the IRR, residential energy prices are assumed to escalate annually at a real rate of 4% (which was a typical assumption at the time most of these retrofits were installed). Conservation investments are amortized over the measures' expected physical lifetimes. Estimated annual operations and maintenance costs are included in addition to the initial investment.

RESULTS

Energy Savings

Median site energy savings per dwelling unit for the 101 retrofit projects are 11.7 MBtu (10^6 Btu) per year, or 16 percent of pre-retrofit energy use. Seventy percent of the retrofit projects had savings between 10 and 30 percent (see Fig. 2). Energy savings are correlated fairly strongly with pre-retrofit energy use (correlation = 0.68).

Energy savings are highly variable and vary by a factor of five at any particular investment level (Fig. 3). 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 fuel prices. Investment and energy savings patterns appear quite different for gas- and oil-heated buildings. This phenomenon can be explained in part due to relative differences in ownership structure and choice of retrofit strategy among gas- and oil-heated buildings in the data base. For example, 60 percent of oil-heated data points are retrofits in public housing projects while only 23 percent of the gas-heated data points are public housing complexes. Expensive retrofits (greater than $1000/unit), such as window measures and replacement of existing boilers, were installed much more frequently in oil-heated than gas-heated buildings. In most cases, investments in excess of $1500-2000 per unit are not saving enough energy to justify the additional cost.

Energy savings and cost-effectiveness are strongly influenced by the choice of retrofit strategies. We classified each building in the data base by retrofit strategy and then calculated median values for energy savings, total cost, simple payback time and internal rate of return for each strategy (Table 2). Several interesting trends emerge when the data are segmented in this fashion. Preliminary results suggest that, in multifamily buildings, some envelope measures (e.g., "shell" packages and window measures) have longer payback periods than many of the heating system retrofit strategies. It is worth noting that costs associated with HVAC system retrofit strategies span the entire cost spectrum (ranging from $50 to $2400 per unit), as high-cost HVAC system retrofits typically include replacement of the existing heating plant. The most cost-effective retrofit strategies are not always those that produce the highest energy savings. For example, median energy savings were relatively small in buildings that installed heating system controls, although these measures proved to be exceptional investments with a median payback time of just over one year.

Some caveats need to be emphasized with respect to two retrofit strategies, metering conversion and boiler replacement. Tenant metering is not strictly a technical efficiency measure; reduction in energy use is due to changes in occupant behavior. The economics of tenant metering systems appear quite attractive from the perspective of the building owner, based on a sample of 10 low-rise Minnesota buildings.[4] These buildings have hot water baseboard heating systems and individual zone control of the flow of hot water into each apartment. The metering system was used to divide the energy bill among individual apartments on the basis of use. Gas energy use decreased by 15-18 percent compared to pre-retrofit levels. However, if this retrofit is implemented without an ensuing rent reduction, the increase in the tenant's total costs can be quite significant, because space heating costs have been transferred to the tenant. Tenant metering systems raise several difficult institutional and technical issues that need to be considered, including:

1) significant weakening of building owner's incentive to continue efficiency improvements and
2) equitable allocation of energy costs on the basis of actual use (accurately measuring delivered heat, accounting and billing for non-space heating and standby losses, impact of apartment orientation and location on energy use).

In many older multifamily buildings, boiler replacement is done in conjunction with energy efficiency measures. In some cases, the new boilers were designed to be more energy-efficient and could account for a significant fraction of the energy savings, although the relative magnitude can not be determined because other measures are also installed. Median energy savings are large (21 to 28 MBtu/unit), however payback times are in excess of 10 years in many buildings because costs are high (over $2000/unit).

Cost-Effective Retrofit Strategies

Typical retrofit practice is to install a set of measures concurrently but we have compiled data for a subsample of buildings in which only one measure was implemented. Particularly cost-effective individual retrofit measures are shown in Table 3 and summarized in the following paragraphs.

Preliminary results suggest that high-efficiency, condensing pulse-combustion boilers are an extremely attractive boiler replacement option for certain large multifamily properties. Thirty-two modular, residential-size (150 kBtu/hour each), gas-fired boilers were installed at a New Jersey low-rise public housing project to supply space heat and domestic hot water.[5] Eight of the modular boilers supply hot water to a 500-gallon storage tank during the summer. Energy savings were approximately 50%, although the results are based on only 6 months of post-retrofit data. One possible drawback of this retrofit, which might limit its applicability to other buildings, is the very high noise level. At this project, the equipment is located in a separate boiler building, hence noise is not a major concern, although it might be a problem where boilers are located near living quarters.

Outdoor resets and cutout controls were installed in nine, apartment buildings with gas-fired hydronic boilers located in the Minneapolis-St. Paul area.[6] The master-metered buildings are all three-story walkups, and were constructed in the mid-1960's and early 1970's. They are of wood-frame construction with lightly insulated walls and roofs, double-glazed windows, and central heating and domestic hot water systems. Initial retrofit costs were quite low ($10-20/unit), space heat savings were significant (approximately 13 percent), and paybacks were very short (roughly one year). The results suggest that an outdoor reset is probably the most cost-effective retrofit for hydronically heated apartment buildings with cast-iron boilers.

Vent dampers were a particularly cost-effective retrofit strategy in four low-rise Minneapolis buildings, with simple payback times ranging from one to two years.[7] The heating systems were run alternatively with the vent dampers operating and then deactivated at two-week intervals throughout the 1984-85 heating season. Submetered space heat energy use data were collected by installing on-time meters to record the burner firing time, along with one-time measurements of the firing rate. Two of the buildings had large brick-set, site-built, gas-fired steam boilers with vents connected to brick masonry chimneys. Custom-made electronic vent dampers were installed in the boilers used for space heating. The other two buildings had gas-fired, atmospheric, hydronic boilers and vent dampers were also installed on the hot water heaters. All boilers used electronic ignition which allowed the vent dampers to be tightly closed. Space heat energy savings ranged between 10 and 16 percent in the four buildings.

Energy management control systems have also proved to be quite effective in large public housing projects in New Jersey and Minnesota.[8] A microcomputer-based boiler control system was installed at the New Jersey projects. The system consists of remote temperature sensors located in selected apartments on each floor of the building and at one outdoor location. The computer controls heating system pumps and boilers, based on periodic readings, to maintain comfortable temperatures (73°F) in each apartment. Space heat savings were higher at the project with hot water distribution system compared to a similar project with a steam-heated distribution system (44 versus 26 percent).

The New York City Housing Authority replaced incandescent hall and stairwell lights with 20-watt fluorescent fixtures in a 159-unit building.[9] This retrofit provided an impressive return on investment with a payback time of 1.4 years, although we have measured results from only one building.

DISCUSSION

It is also important to discuss limitations and gaps in the available measured data. It is difficult to accurately estimate space heat savings when energy data are limited to total billed consumption before and after a retrofit. Retrofit evaluations rarely submeter heating energy use or monitor inside temperatures. The use of secondary heating equipment or changes in occupant behavior might go undetected, masking the actual effect of the retrofit. It is also difficult to compare energy performance across buildings when key physical parameters are either missing, or not reported in a consistent fashion, as is the case for conditioned floor area. A detailed building description and operating profile, based on standardized energy audit procedures, and operating profile would be very useful, making it much easier to account for physical differences among buildings prior to retrofit.

It is worth noting that energy savings are based in most cases on only one year of energy use data after a retrofit. Measured data on the persistence of energy savings over multi-year periods are needed in order to validate engineering estimates of retrofit lifetimes, a factor that can be as crucial to cost-effectiveness as first-year savings. Long-term tracking of occupied buildings, however, magnifies the problem of accounting for changes in operating conditions, occupancy, or the effect of additional retrofits. Successful projects will almost surely require direct monitoring of major household end-uses and inside temperatures.

CONCLUSION

Data on energy consumption, retrofit cost, and physical descriptions of each building have been compiled on over 100 multi-family buildings. Energy savings achieved are typically 10 to 25 percent of pre-retrofit energy use although large variations are observed in energy savings and in costs per unit of energy saved. The median retrofit investment in multi-family buildings is approximately $530 per unit. Many conservation investments are attractive investments from a building owner's perspective: the median real rate of return for buildings in this study is 22 percent, which compares quite favorably with real rates of return from tax-free bonds (3-5%). Preliminary results also suggest that, in multifamily buildings, some envelope measures (e.g., "shell" packages and window measures) have longer payback periods than many of the heating system retrofit strategies. Finally, we are beginning to compile documented evidence on some particularly cost-effective retrofit strategies segmented by building and heating system type (e.g., outdoor resets for cold-climate buildings with hydronic, cast-iron boiler systems).

This study is part of an on-going project (BECA); data contributions from readers are welcomed.

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