MEASURED ENERGY SAVINGS AND COST-EFFECTIVENESS OF CONSERVATION RETROFITS IN COMMERCIAL BUILDINGS

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In this study, we examine the measured savings and cost-effectiveness of 447 commercial retrofit projects in the United States, Canada, and Europe, representing over 1700 buildings. For these projects, we examine savings and cost-effectiveness by building type and retrofit strategy, savings from individual measures, peak electric demand savings, comparisons of measured vs. predicted savings, and the persistence of savings in the years following a retrofit.

Median annual site energy savings amounted to 20 kBtu/ft^2, or 18% of whole-building usage; median retrofit cost was \$0.56/ft^2 (1988 \$), the median payback time was 3.1 years, and the median cost of conserved energy was \$3.10/site MBtu. When examined by retrofit strategy, we found that projects with only HVAC and/or lighting retrofits had median payback times of one to three years, while those affecting the building shell, either alone or in combination with other types of measures, had payback times of five or more years. Projects in which *only* maintenance practices were changed typically saved 12% of their pre-retrofit consumption, often using in-house labor.

Our research suggests that, despite significant savings and short payback times for the majority of projects, optimum savings are often not being achieved, due to limited owner willingness to invest in all cost-effective measures, as well as to improper retrofit installation and/or maintenance. A comprehensive understanding of energy management as a *process* is needed, including both inspection and commissioning of installed retrofits and ongoing tracking of energy consumption as an indicator of operating problems.

[1] *This study was carried out while all authors were at Lawrence Berkeley Laboratory.*

INTRODUCTION

In 1986, there were an estimated 4.2 million commercial buildings in the U.S., accounting for 2.65 quads of fuel consumption and 700 TWh of electricity usage, at an annual cost of \$61 billion (EIA 1989b).[2] Despite projected growth in commercial sector floorspace of 2.5 percent per year, about two-thirds of the commercial floorspace anticipated for the year 2000 is already in place, and is thus a prime target for energy efficiency improvements (DOE 1981). The technical potential for energy savings in the commercial sector has been estimated at about 40-50% (MacDonald et al. 1986).

As part of the ongoing "Buildings Energy Use Compilation and Analysis" (BECA) project, we have

[2] *1 quad = 10^{15} Btu; 1 TWh = 10^9 kWh.*

compiled and analyzed *measured* data on the energy performance and economics of 447 commercial buildings retrofitted with energy-saving features. These data provide needed feedback on the accuracy of savings predictions, improve the credibility of estimates of the technical potential for savings, and identify new issues that deserve more concentrated data collection and analysis. In addition to expanding the earlier data set by 50% (Gardiner et al. 1984), this update of the BECA compilation addresses the issues of savings and cost-effectiveness by building type and retrofit strategy, savings from individual measures, electric peak demand savings, predicted vs. actual savings, and persistence of savings in the years following a retrofit.

DATA SOURCES AND METHODOLOGY

The 447 projects contained in the BECA commercial retrofit data base represent 1779 U.S., Canadian, and European commercial buildings (typically, multiple buildings are on a single meter at one site). The majority of data came from utilities, research institutions, and state and local energy offices, primarily because these organizations had sufficient time and interest to compile the necessary information. For each retrofit project, we collected a brief description of the building(s), retrofit measures installed, retrofit costs (if available) and date, and metered pre- and post-retrofit energy consumption data. Energy use intensity (annual $kBtu/ft^2$) is calculated separately for both electricity and fuel, and then summed in terms of site energy (at 3413 Btu/kWh for electricity) and resource energy (at 11,500 Btu/kWh). Only "raw" (unadjusted) energy use data were entered in BECA, even though many of the data sources also included weather- or occupancy-normalized results.

Retrofit costs were reported for over two-thirds of the projects in this study; these data reflect the contractor-installed cost of each measure. Two economic indicators were calculated to characterize the cost-effectiveness of retrofit investments: simple payback time based on national average energy prices and the cost of conserved site energy. Because information on electricity rate structures was available for only a few projects, the electricity prices reflect *average* rates (total billed cost divided by total kWh consumption). In other words, the impact on payback time of changes in electricity peak demand was *not* taken into account (nor were other load-shape changes associated with some retrofits, such as a shift of energy use to off-peak periods). In calculating payback times, we used 1988 U.S. average fuel and electricity prices for the commercial sector ($4.23/MBtu and $0.07/kWh; EIA 1989a). A more detailed discussion of analysis methods, data quality, and other topics not covered here (e.g., results from submetered data, weather normalization, and effects of increased office equipment usage on discerning retrofit savings), as well as data tables, project descriptions, and references for projects mentioned here can be found in Greely et al. (1990).

BUILDING CHARACTERISTICS AND STOCK COMPARISON

Structural Characteristics

This study examines the results of 447 non-residential retrofit projects, ranging from prisons and post offices to warehouses and hotels (but excluding manufacturing and other industrial buildings). Table 1 compares the characteristics of projects in this study with those of the U.S. stock, both in terms of the percent of projects and the percent of floor area.[3] Ideally, we would like to compare BECA characteristics with those of the *retrofitted* stock, but such stock data, while collected as part of NBECS, are not currently available. Although BECA buildings are not deliberately chosen to represent the U.S. commercial stock, they are quite diverse in terms of type, size, location, and vintage.

As shown in Table 1, there is at least some BECA coverage for most major categories of commercial buildings. The BECA data base over-represents educational and health-care buildings, and under-represents assembly, food sales/service, and

[3] *Characteristics of the U.S. commercial building stock are taken from the Nonresidential Buildings Energy Consumption Survey (NBECS) (EIA 1988 and 1989b).*

Table 1. Building Characteristics of BECA Database vs. 1986 U.S. Stock

Building Type	*% of Buildings* BECA [a]	U.S. Stock [b]	*% of Floor Area* BECA [a]	U.S. Stock [b]
- Education	46	6	43	13
Elementary	28	-	15	-
Secondary	13	-	22	-
Colleges	5	-	6	-
- Health Care	7	1	14	4
Hospitals	4	-	4	-
Other	3	-	10	-
- Offices	17	15	15	16
Small (≤ 50,000 ft^2)	5	14	< 1	8
Large (> 50,000 ft^2)	12	1	14	8
- Retail (non-food)	22	31	22	22
Post Offices	21	-	22	-
- Food Sales/Service	< 1	8	< 1	3
- Other (assembly)	3	14	< 1	13
- Other (lodging)	2	3	1	5
- Other (warehouses)	< 1	13	<1	15
- Other (unspecified)	3	5	5	7
Size:				
- < 5000 ft^2	2	53	< 1	11
- 5-10,000 ft^2	4	22	1	12
- 10-25,000 ft^2	10	13	5	16
- 25-50,000 ft^2	15	6	13	15
- 50-100,000 ft^2	20	3	17	15
- 100-200,000 ft^2	25	1	25	12
- 200-500,000 ft^2	17	1	19	12
- > 500,000 ft^2	6	< 1	20	8
Region:				
- Northeastern U.S.	34	16	34	20
- Midwestern U.S.	25	26	34	28
- Southern U.S.	15	38	13	33
- Western U.S.	24	20	16	19
- Canada/Europe	2	-	3	-
Year Built: [c]				
- ≤ 1920	14	11	8	10
- 1921-45	24	15	35	15
- 1946-60	18	21	14	17
- 1961-73	35	24	36	27
- 1974-79	10	14	6	14
- ≥ 1980	< 1	15	< 1	17

[a] BECA data are for one or more buildings per retrofit "project" (typically, multiple buildings are on a single meter at one site). The BECA data include a small number of non-U.S. buildings (2%).

[b] Source: EIA, 1988. The NBECS stock data are for all U.S. buildings, not just retrofitted stock.

[c] Half of BECA projects did not report year built. Percentages are only for projects reporting year built.

warehouse buildings.[4] Although it appears that the proportion of offices and retail stores is about the same as in the stock, the BECA retail sample consists almost entirely of post offices. Very large buildings (over 100,000 ft^2) are over-represented in the BECA data base, compared with the U.S. stock, while very small ones (under 10,000 ft^2) are under-represented. Larger buildings are also over-represented within specific building-type categories. The over-representation of large buildings can be attributed to two factors: retrofits are more likely to be installed in larger buildings, and large-scale buildings are more likely to have a professional energy manager or other individual responsible for tracking energy performance and recording data suitable for BECA.[5] By region, more BECA projects are located in the northeastern U.S., and fewer in the South, than is true of the stock. The projects in this study tend to be older than the stock; almost none of the BECA buildings were constructed after 1980, compared to 15% of the buildings in the stock. Therefore, although BECA buildings are not representative of the stock, they do represent certain *segments* of the commercial stock very well.

Pre-Retrofit Energy Intensity

Before retrofit, almost all buildings in the data set were more energy-intensive than the median for the corresponding building type in the U.S. commercial stock (Figure 1). Some of the discrepancies may be caused by differences in the projects' location: commercial buildings in the Northeast (heavily represented in BECA) are typically more energy intensive than those in the South (under-represented in BECA). In addition, a lower percentage of BECA projects are all-electric than is true of the stock (12% vs. 23%). This may tend to make the energy intensities of BECA projects, expressed as site energy, relatively higher, since combustion equipment losses are counted at the building level rather than at the power plant. Pre-retrofit energy costs were reported for one-third of the BECA projects; the median cost per square foot, based on these site-specific energy costs, was about the same as for the stock ($1.05/$ft^2$ vs. $1.07/$ft^2$, in 1988 $).

RETROFIT MEASURES AND COSTS

HVAC system retrofits were by far the most popular conservation measures in all types of commercial buildings. Frequently implemented HVAC retrofits include improved maintenance, retrofits to the ventilation system, and HVAC controls such as energy management systems or time clocks. Some type of HVAC retrofit was done in 85% to 95% of the projects in each building category (education, health, office, retail, and other). Lighting retrofits were done in only 16% of the schools and 31% of the health care projects, but were installed in over half of the offices and retail projects. Changing the type of lighting system (e.g., from incandescent to fluorescent) was the most common lighting retrofit, while changes in lighting levels (delamping) and installation of lighting controls (e.g., occupancy or daylight sensors) were also popular lighting measures. Shell retrofits, most commonly roof insulation or window replacements, were installed in one-third of the schools but in only about one-fifth of the other building types.

Costs were reported for 70% of the retrofit packages in this study. The median retrofit cost was $0.56/$ft^2$, with one-quarter of the retrofits costing less than $0.25/$ft^2$. If examined by building type (see Table 2), retail buildings (mostly post offices) had the least expensive retrofits with a median of $0.36/$ft^2$, while hospitals typically had the most costly measures ($1.10/$ft^2$).

ENERGY SAVINGS AND COST-EFFECTIVENESS

Median annual site energy savings were 20 kBtu/ft^2 (1 kBtu=10^3), or about 18% of whole-building energy use prior to retrofit. Table 2 summarizes key indicators of energy savings and cost-effectiveness, by type of building and project sponsor. For all

[4] *Building types are taken from NBECS. "Other" assembly buildings include libraries, museums, and recreation centers; "other" health care buildings are medical clinics, development centers, and psychiatric centers; "small" offices are ≤ 50,000 ft^2 and "large" offices are > 50,000 ft^2.*

[5] *Only 5% of commercial buildings with less than 50,000 ft^2 have been retrofitted (following an energy audit), compared to 17% of those with greater than 50,000 ft^2 (EIA 1988).*

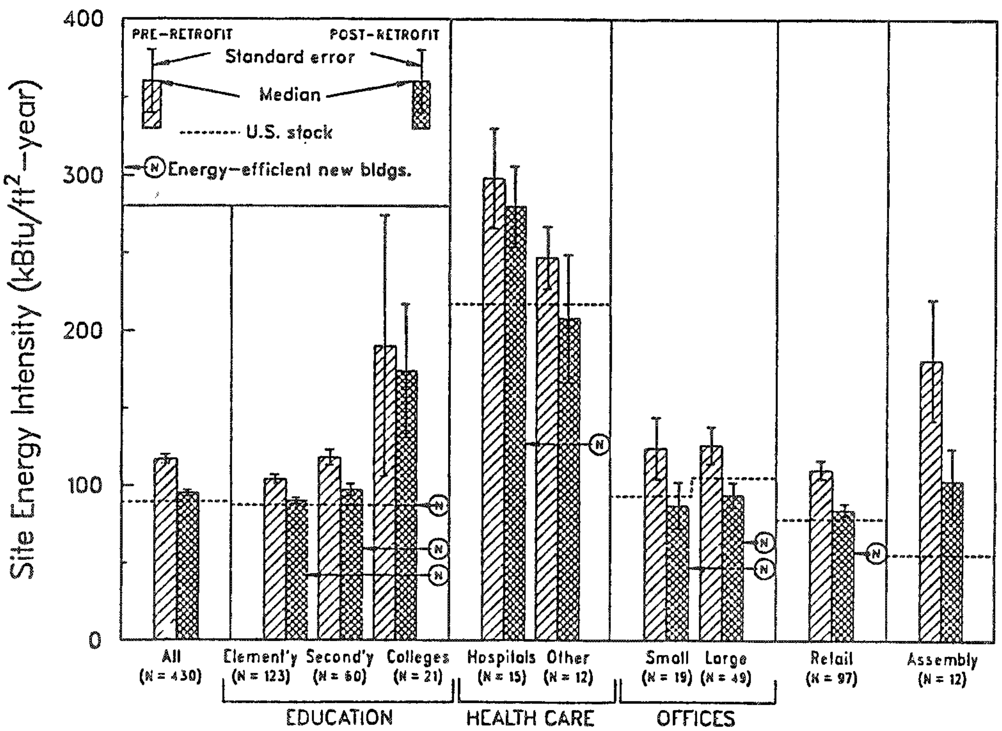


Figure 1. Pre- and Post-Retrofit Whole-Building Energy Intensity for Subsets of the BECA-CR Database. For definitions of building types, see section on "Building Characteristics and Stock Comparison" in text. "U.S. Stock" consumption represents average usage for the applicable building type as of 1986 (Source: EIA 1989b).

retrofitted buildings (both mixed fuel and electricity and all-electric), median fuel savings were 12 kBtu/ft^2 and median electricity savings were 0.66 kWh/ft^2. For the 54 projects in all-electric buildings, median electricity savings were 22% (4.59 kWh/ft^2). In about 10% of the retrofit projects we examined, energy intensity *increased* following the retrofit. Over 60% of these projects with "negative savings" were schools; in one-third of these cases, changes were made in maintenance practices only. The energy savings from improved maintenance may have been too small, compared with other factors related to pre-/post-retrofit differences in weather, occupancy, or added loads. Or, the new maintenance practices may not have been adequately followed throughout the post-retrofit period.

When examined by building type (Table 2), health care buildings had the highest absolute savings per square foot of floor area, and educational buildings the lowest. In percentage terms, however, savings in offices and retail stores were the highest. For schools and health care buildings, median electricity use stayed the same or increased following retrofit, while electricity savings in offices and retail stores were a significant component of total savings. Half of the retrofit packages saved between 10 and 30% of pre-retrofit use.

Following retrofit, Figure 1 shows that median energy intensity is still higher than that of the corresponding part of the U.S. stock, for all building types except offices and non-hospital health care buildings. Post-retrofit energy intensity for hospital, college, and assembly buildings is still significantly higher than intensity for the stock, while energy use in elementary and secondary schools and in retail stores was closer to the stock averages. For all building types, post-retrofit consumption of the BECA projects is still considerably higher than that of new commercial buildings designed to be energy-efficient, as reported in another BECA compilation (Piette and Riley, 1986). (The values for new hospitals and retail buildings are based on very

Table 2. Summary of Energy Savings and Economic Indicators[a]

	Number of Projects	Site Energy Savings[b] (kBtu/ft²-year)	(%)	Retrofit Cost (1988 $/ft²)	Payback[c] Time (years)	CCE Site[d] (1988 $/MBtu)
All Buildings	451	20 ± 2	18 ± 1	0.56 ± 0.05	3.1 ± 0.5	3.10 ± 0.40
Buildings with savings>0	406	23 ± 2	20 ± 1	0.57 ± 0.06	2.6 ± 0.3	2.80 ± 0.30
By Building Type:						
Education	207	16 ± 2	16 ± 2	0.61 ± 0.08	5.3 ± 1.2	3.10 ± 0.70
Health	29	37 ± 13	15 ± 4	1.10 ± 0.30	5.9 ± 4.5	4.20 ± 1.90
Office	74	22 ± 4	23 ± 3	0.81 ± 0.23	2.6 ± 1.5	5.10 ± 1.90
Retail	101	24 ± 2	21 ± 2	0.36 ± 0.04	1.0 ± 0.2	2.10 ± 0.50
Other	40	25 ± 7	15 ± 4	1.10 ± 0.50	7.1 ± 3.1	4.40 ± 7.30
By Project Sponsor:						
Owner-paid	282	20 ± 2	18 ± 1	0.45 ± 0.06	1.5 ± 0.3	2.60 ± 0.50
ICP-funded	96	14 ± 3	12 ± 2	0.56 ± 0.10	6.5 ± 14.2	4.10 ± 1.20
Other grants	49	39 ± 9	33 ± 4	1.09 ± 0.18	3.4 ± 1.4	2.70 ± 1.10
Demonstration projects	24	20 ± 8	23 ± 7	0.99 ± 0.28	6.8 ± 8.9	6.20 ± 2.40

[a] Values given are medians ± standard errors, unless the number of projects is less than or equal to 10, in which case averages are used.

[b] Electricity savings are converted to site energy using 3413 Btu = 1 kWh.

[c] Simple payback time is calculated using national average energy prices (see text).

[d] CCE: Cost of Conserved (site) Energy; electricity savings are converted to site energy using 3413 Btu = 1 kWh.

small samples.) While it may not be cost-effective, in retrofitting an existing building, to implement all measures that are feasible in new construction, these indicators still suggest a substantial remaining potential for retrofits and ongoing energy management in existing U.S. commercial buildings, as discussed below.

The median simple payback time for the BECA sample is 3.1 years, as shown in Table 2. This value is calculated using 1988 national average energy prices. This represents a significant increase over typical payback times from the previous BECA compilation of commercial retrofit data, which indicated median paybacks based on 1983 national average prices of about 1 year (Gardiner et al. 1984). A number of factors may have contributed to longer payback times, including a larger number of shell retrofits and more publicly funded measures in projects recently added to the data base.

For the retrofitted buildings, the median cost of conserved energy is $3.10/site MBtu, or $2.30/resource MBtu (1988 $) (cost of conserved resource energy not shown in Table 2). Retrofits in retail buildings (primarily post offices) were more cost-effective than those in other building types. Office conservation measures were the next most cost-effective, except when measured using the cost of conserved energy per site MBtu. In part, this is because offices had the highest fraction of all-electric buildings (40%). In addition, a relatively large number of short-lived measures, like some lighting and HVAC retrofits, were installed in offices. Education, health, and "other" buildings had longer median payback times (5 to 7 years) and higher costs of conserved resource energy.

Savings by Retrofit Strategy

Figure 2 summarizes energy savings and cost-effectiveness results grouped by retrofit strategy. Each retrofit project was assigned to the narrowest category which encompasses all conservation measures in that building. For example, a building in which high-efficiency fluorescent lights were installed would be assigned to the "Lights" category, but one where the retrofit included both high-efficiency lights and variable-speed fan drives would be placed in the "HVAC & Lights" group.[6] We found that projects with HVAC and/or lighting retrofits had median payback times of one to three years, while those affecting the building shell (changes to windows or insulation levels), either alone or in combination with other types of measures, typically had greater investments as well as longer paybacks: five years or more.

Changes in maintenance practices alone typically saved 12% of pre-retrofit consumption. Since it was common to use in-house labor for these projects, the costs associated with the maintenance changes were often not reported; where these costs were reported, they averaged about 20 cents/ft^2, leading to very short payback times (median = 1 year). Almost all of the projects involving maintenance changes were in fuel-heated buildings; four-fifths of the maintenance projects were in schools, with the remainder in offices and health care buildings.

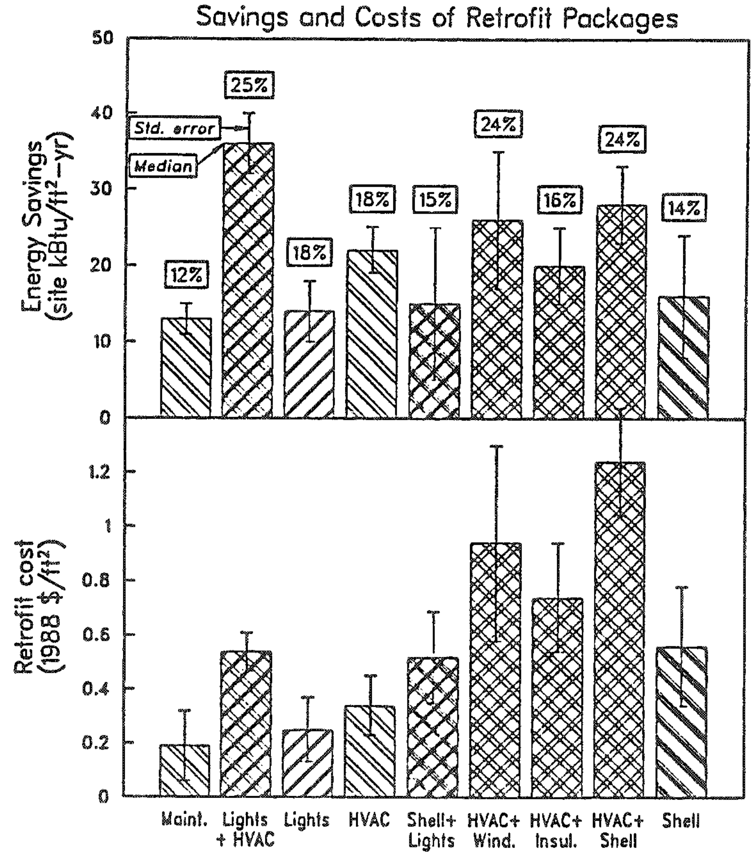
Savings from Individual Measures

Although most of the projects we studied involved several retrofit measures implemented at the same time, there were 33 projects in which single retrofits were installed, allowing us to isolate their effects. Savings and cost-effectiveness of these individual measures are presented in Table 3. Lighting controls, such as occupancy sensors, scheduling, or localized switching controls, were added to eight buildings, including five post offices and three office buildings. Average savings from the controls was 19% of whole-building usage (and thus a much larger fraction of lighting energy only); average payback times were about four years. Window modifications, including replacements, were installed in five groups of schools through the Minnesota, Utah, and Wisconsin Institutional Conservation (ICP) programs. Savings averaged 6% of pre-retrofit usage; the cost was typical of that for other shell retrofits. HVAC system controls were a very popular retrofit, installed in 35% of the projects we examined. Table 3 shows results for 20 projects involving only controls changes. We separated controls into two groups: (1) local HVAC controls, such as clock thermostats, boiler controls, and air conditioner controls, and (2) more comprehensive "energy management system" (EMS) retrofits, utilizing computerized control strategies. Both types of control systems were installed in a wide variety of building types, including schools, offices, post offices, hotels, and medical centers, though EMS were predominately used in large offices. All but one of the EMS were installed in buildings over 75,000 ft^2, whereas the local HVAC controls were more often used in smaller buildings. As shown in Table 3, the EMS resulted in higher savings, with costs per square foot of floor area slightly higher than those of local HVAC controls. However, the median payback time for the EMS retrofits was still over 10 years. The fact that many EMS systems perform functions other than energy management (maintenance scheduling, fire safety, security, etc.) may help explain the willingness to invest in measures with such long energy paybacks.

Demand Savings

Fifteen of the projects we examined were retrofitted with measures designed for load management. Energy management systems (EMS), either newly installed or enhancements of existing systems, provided control for the majority of these load management measures. In addition, one building was retrofitted with a specially designed "demand management system" being tested by a utility, and five post offices received "demand-limiting devices" of an unspecified type. Unfortunately, only four of these 15 buildings reported peak demand. Three of these buildings (two offices and a nursing home) reported peak demand savings of 21 to 27% (1.4 to 4.9 W/ft^2) following installation of EMS or demand management systems. The fourth building, in which

[6] *Minor lighting retrofits also took place in some of the buildings assigned to the "HVAC + Wind.," "HVAC + Insul.," and "HVAC + Shell" categories.*



	Maint.	Lights + HVAC	Lights	HVAC	Shell+ Lights	HVAC+ Wind.	HVAC+ Insul.	HVAC+ Shell	Shell
N =	88	101	31	115	10	25	33	30	18
Payback time (yrs)	1.1	1.4	2.0	2.9	4.7	5.7	6.2	6.7	8.6
CCE ($/site MBtu)	1.70	2.50	4.80	2.70	2.60	3.90	3.60	5.20	4.30
CCE ($/res. MBtu)	0.90	0.90	2.80	2.30	2.20	2.70	3.60	3.40	4.00

Figure 2. Energy Savings, Retrofit Cost, Median Payback Times (Using National Average Energy Prices), and Costs of Conserved Energy of Various Retrofit Strategies in Commercial Buildings. "Maint." retrofits are changes in maintenance practices only. "Shell" refers to window measures, improved insulation, and infiltration reduction.

an upgrade of the existing EMS was carried out, experienced slightly *increased* peak demand.

An additional 48 retrofit projects (mostly offices and some schools) reported peak demand, although the conservation measures were not specifically designed to affect demand. Three retrofit packages (HVAC system, lighting, and system and lighting combinations) were well-represented among the projects reporting changes in peak demand: HVAC system retrofits (20 projects) typically reduced peak demand by 0.15 W/ft^2, or 4%, lighting retrofits (9 projects) had a median demand savings of 0.06 W/ft^2,[7] and HVAC and lighting combinations (9 projects)

[7] *This seems low, in view of the large contribution of lighting to peak load in most commercial buildings. In these projects, percentage savings of peak load varies widely, from over 50% (of lighting use only) in one case, due to extensive delamping and replacement with efficient lamps, reflectors and ballasts, to a second case where the (whole-building) peak load* increased *by 22%--but the retrofit involved night lighting. In cases where lighting retrofits involved relamping with efficient (34-W) lamps, or ballast replacements, peak savings were about 0.1 to 0.5 W/ft^2.*

Table 3. Savings and Cost-Effectiveness of Individual Retrofit Measures[a]

Retrofit Measure	*# of Projects*	*Energy Savings* [b] *(kBtu/ft²-year)*	*(%)*	Retrofit *Cost (1988 $/ft²)*	Payback *Time* [c] *(years)*	*CCE (Site)* [d] *(1988 $/MBtu)*
Lighting Controls	8	18 ± 4	19 ± 3	0.55 ± 0.34	3.7 ± 2.7	4.60 ± 2.30
Window Modifications	5	6 ± 5	6 ± 5	0.49 ± 0.17	n/a [e]	n/a [e]
Local HVAC Controls	7	9 ± 7	8 ± 5	0.25 ± 0.17	n/a [e]	n/a [e]
Energy Mgmt. Systems	13	15 ± 9	13 ± 9	0.33 ± 0.08	11.2 [f]	7.80 [f]

[a] Values given are averages ± standard errors, except when the number of projects is greater than ten, in which case medians are listed.

[b] Electricity savings are converted to site energy using 3413 Btu = 1 kWh.

[c] Simple payback time is calculated using national average energy prices.

[d] CCE: Cost of Conserved Energy; electricity savings are in site energy using 3413 Btu = 1 kWh.

[e] For both of these retrofit measures, only four projects reported retrofit costs, and only two of these had positive energy cost savings and, therefore, payback times and CCEs.

[f] Three projects had negative energy savings; therefore the standard error of the cost-effectiveness indicators cannot be calculated.

typically saved 1.33 W/ft^2, or 22% of pre-retrofit peak demand. Six projects with energy management systems reported an average peak demand savings of 0.26 W/ft^2, or 7%. There was no marked difference in peak demand savings by building type. As noted earlier, the lack of data on electricity demand charges or savings precluded our including this component when calculating paybacks and other cost-effectiveness indicators.

Project Sponsorship: Owner-Paid, Institutional Conservation, and Other Grant and Demonstration Programs

To examine how retrofit cost-effectiveness varied by project sponsor, we divided the BECA data set into three groups: owner-paid retrofits (62%), those funded through the Institutional Conservation Program (ICP) (23%),[8] and those funded through other grants or as demonstration programs, typically utility grants or research projects (15%). Then, the types of retrofit measures and median savings and cost-effectiveness were examined for each group. With two exceptions, there was little variation, by type of sponsor, in the relative percentages of each major type of retrofit. One exception was that owner-paid retrofits were much less likely to include shell measures. A second exception was the tendency to include lighting measures in only 25% of the ICP retrofits, compared with 40-50% of the owner-paid and "other-sponsor" projects.[9]

As shown in Table 2, owner-paid retrofits and conservation measures funded through ICP had median costs of about $0.45 and $0.56/ft^2, respectively; retrofits paid for through other sources, mainly

[8] *One-quarter of the retrofit packages we examined were installed with funding from the Institutional Conservation Program, a $1.4 billion, multiyear program sponsored by the U.S. Department of Energy (Carroll et al. 1988). Since its inception in 1979, conservation measures in over 20,000 schools and hospitals have been subsidized through ICP. We obtained information on the statewide programs in Minnesota, Utah, and Wisconsin, and on individual buildings in California, Illinois, and Ohio.*

[9] *One explanation may be that schoolrooms, unlike many office, retail, and other nonresidential buildings, are often built with modest levels of fluorescent lighting, so there are fewer opportunities for savings. Another possibility, in the case of hospitals and other institutional buildings, is that lighting measures are easier for the owner to pay for incrementally and install with in-house personnel.*

utility or government demonstrations or grants, typically cost twice as much. Retrofits funded by ICP had the lowest median savings, in absolute and percentage terms, of the three groups examined. The projects financed by other grants and demonstrations had the highest median savings, possiblydue to their higher levels of retrofit investment. Both the ICP retrofits and the other grant and demonstration projects had payback times two to four times longer than measures paid for by the building owner.

These differences in cost-effectiveness narrowed when examined in terms of the cost of conserved energy (CCE): although the retrofits sponsored through ICP and other grant and demonstration programs remained less cost-effective than owner-paid measures, the gap was significantly narrower. This discrepancy between cost-effectiveness comparisons using payback time and using CCE is associated with the greater tendency to install longer-lived envelope retrofits under ICP and other grant and demonstration projects. However, for all groups except the demonstration projects, the median CCE is less than national average 1988 fuel price of $4.23/MBtu.

Measured vs. Predicted Savings

Of the projects in the data base, 30% included pre-retrofit predictions of energy savings, based on methods ranging from simple engineering estimates to sophisticated hourly computer models like DOE-2. Figure 3 shows actual, measured energy savings as a function of pre-retrofit predictions (normalized to floor area but *not* adjusted for post-retrofit changes in weather or operating hours). Symbols are used to show the source of data and method of prediction. For all the groups except the "Hourly [computer modeling]" category, predictions were made using engineering estimates, monthly models based on the ASHRAE temperature-bin method, or other unspecified "audit" methodologies. With the exception of the post office group, Figure 3 shows a fairly even split between underestimates and overestimates of savings. However, very few predictions (only 20 out of 128) came within 20% of the actual savings. The "hourly" predictions (made by Seattle City Light) both over- and underestimated savings, for a variety of reasons, mainly stemming from incorrectly specified pre-retrofit characteristics and/or operating schedules. Data reported by the Center for Neighborhood Technology (CNT) and the Washington State Energy Office (WSEO) also included both over- and underestimated savings. In the ICP projects with estimated savings (located primarily in California) and the post offices, savings were consistently underestimated, for unknown reasons. In the University of California at Berkeley (UCB) buildings, savings from lighting retrofits were overestimated; increasing use of computers during the post-retrofit period was probably at least one source of discrepancy. Many unforeseeable circumstances can contribute to *overestimates* of savings, such as poor retrofit installation, lack of maintenance, or increasing process loads which obscure savings. One possible generic explanation for *underestimated* savings was reported by one of our data contributors, a consulting engineer who said that he consistently underestimates savings so that his clients will get more than they expect.

Persistence of Savings

Energy savings are typically tracked for only one year after retrofit. However, intentional or unintentional changes in building operation or other factors can significantly degrade savings. Half of the projects we looked at collected energy use data for two to four years after retrofit (unadjusted for changes in weather or operating hours); these data are shown in Figure 4. (Note that each of the groups shown in Figure 4 is independent; the two-, three-, and four-year post-retrofit groups are *not* tracking the same buildings for different time periods, but rather showing results for *different* buildings for which post-retrofit periods of varying lengths were reported.) In 60% of the projects, energy use continued to decrease in the years following the retrofit.[10] Energy savings in two-thirds of the retail stores increased after the first post-retrofit year; for other building types, savings increased in about half the cases. Changes in savings did not seem to correlate with the type of retrofit.

10 *There may have been additional retrofits or changes in operation and maintenance that were not documented in the sources available to us.*

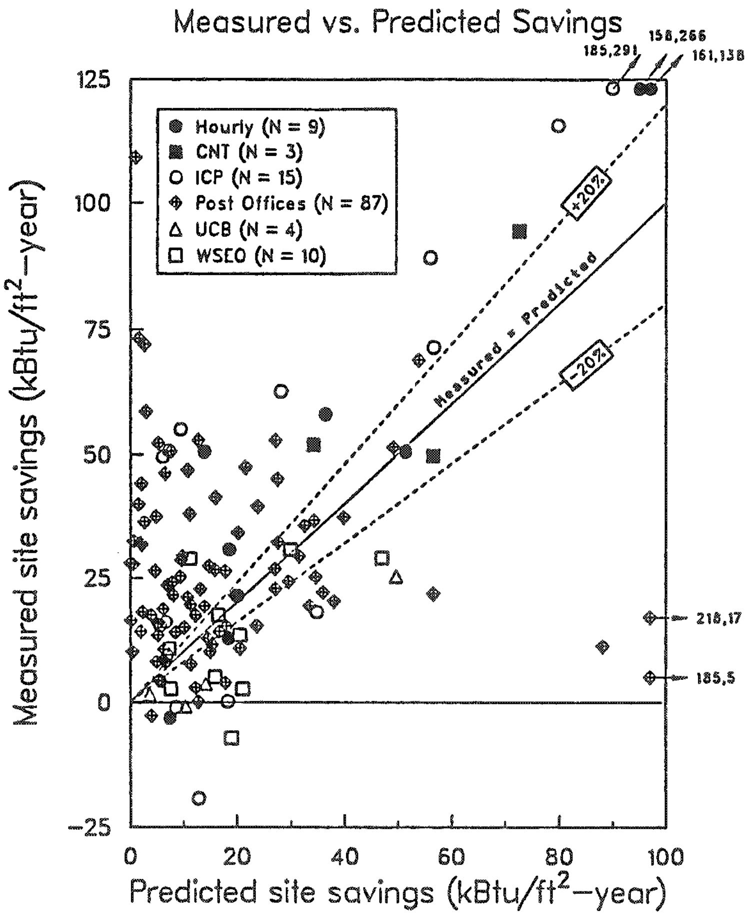


Figure 3. Measured vs. Predicted Savings for Commercial Building Retrofits. "Hourly" predictions were made using tools such as DOE-2. The other data sets, grouped by project sponsor, were based on less sophisticated methods such as engineering estimates, monthly models based on the ASHRAE bin method, or unspecified "audit" methodologies (see text for explanation of abbreviations).

For the projects with two and three years of post-retrofit data, energy intensity continues to decrease; however, energy use increased after the first year for the group of projects with four years of post-retrofit data. In all three cases, however, the changes in median energy intensity after the first post-retrofit year are smaller than the decrease in energy use associated with the conservation measure. For the projects which reported fuel and electricity use separately, it is interesting to note that median electricity use *increased* following the first post-retrofit year, for each of the subgroups. This is consistent with the view that growth in office equipment and other miscellaneous "plug" loads are responsible for at least part of the apparent "degradation" in energy savings over time.

EVOLVING PERSPECTIVES: FROM "RETROFIT" TO "ENERGY MANAGEMENT"

Energy conservation is often approached as a one-time alteration to a building. An energy auditor recommends the appropriate retrofits; once these are installed, the building is deemed to be "energy efficient." This view ignores the possibility of problems with retrofit installation or subsequent building operation--as well as future energy-saving opportunities that may accompany technological advances, building renovation, changes in tenancy, etc. The unfortunate result is that too many buildings fall well short of their energy conservation

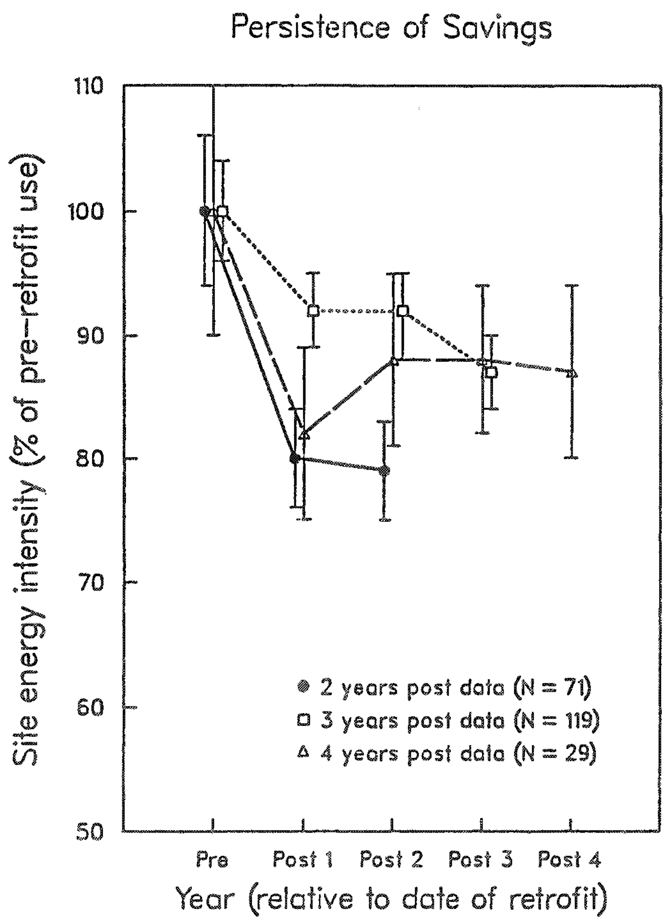


Figure 4. Persistence of Energy Savings for Several Years Following Retrofit Installation. Note that each of the subgroups is independent; the two-, three-, and four-year groups consist of different buildings.

retrofit potential, while the measures that are installed often fail to perform as they should.

A different approach was taken by the Washington State Energy Office (WSEO), which followed up on a number of buildings retrofitted under Bonneville Power Administration's Institutional Buildings Program. WSEO staff collected and analyzed post-retrofit consumption data, and visited each site to inspect the installation. They found a number of easily correctable problems, like time clocks which had defaulted to factory settings following a power outage, and energy management systems that were improperly set and operated. Such "retrofit commissioning," in which the installed retrofit is inspected and tested to ensure correct operation, would undoubtedly address part of the problem. However, even properly installed and calibrated measures can eventually be disabled through lack of maintenance, inappropriate usage, or other factors.

All this leads us to conclude that energy management must be viewed, not as an event but rather as a *process*--one that incorporates both an understanding of proper building operation on the part of the facility manager and the long-term tracking of energy performance and specific indicators of operating problems.

Two examples illustrate how such a process could be implemented. At a large corporate headquarters in Chicago, both conservation measures and maintenance activities have been carried out almost continuously since the building's construction in 1972. A skilled in-house maintenance crew, directed by a building manager with a good understanding of the building's behavior, have reduced the structure's consumption by over 40%, with a payback time of about six years. In another case, researchers examined two large Department of Energy office buildings and produced daily graphs of hourly demand to help the building staff identify operation problems. Solely through improved maintenance practices, energy consumption in both structures was reduced by 10%, despite increases in electricity use attributed to the proliferation of computer equipment. These examples point out the need for increased attention to building system operations and the usefulness of ongoing tracking of energy consumption to identify problem areas.

CONCLUSION

Overall results on the measured savings and cost-effectiveness of commercial sector retrofit measures, by building type and project sponsor, were summarized in Table 2. For the 447 retrofit projects now in the BECA data base, median energy savings were 18% of whole-building consumption, median retrofit investments $0.56/ft^2, and the median simple payback time 3.1 years. Retrofits focusing on HVAC and/or lighting systems had typical payback times of one to three years, while packages that included shell retrofits had median paybacks of 5-9 years. Post-retrofit energy intensity for buildings in the data base is higher than that of the stock average, and much higher than that of new commercial buildings designed to be energy-efficient. In addition, a number of studies indicate that optimum savings are not being achieved for every conservation dollar invested, due to improper retrofit installation and/or maintenance. A comprehensive understanding of energy management as a *process* is needed, including inspection of installed retrofits and ongoing tracking of energy consumption as an indicator of operation problems.

We have identified research needs in a number of areas related to retrofit selection, monitoring, and data analysis methods. Data on savings from individual retrofits are still sparse. More consistent reporting of the components of electricity costs, especially demand and time-of-use charges, would make it possible to incorporate load-shifting measures when calculating cost-effectiveness. Measured savings from conservation retrofits in retail stores and small buildings are severely lacking, as are data on long-term performance and operating costs of various measures, especially those affecting lighting, HVAC systems, and controls. Further work in these areas will allow us to develop more reliable, detailed estimates of the remaining conservation potential in U.S. commercial buildings. Such information will help policy makers to decide how much of our future energy needs can be supplied through improved energy efficiency, and what level of public and private resources should be devoted to mobilizing that conservation potential.

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