THE EVALUATION OF RETROFIT MEASURES IN A TALL RESIDENTIAL BUILDING

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ABSTRACT

As part of a joint demonstration effort involving the U.S. Department of Energy (DOE), the U.S. Department of Housing and Urban Development (HUD), a Massachusetts utility company, and a division of a national laboratory participated in the evaluation of energy and demand saving retrofits for a tall residential building located in Boston, Massachusetts. The 13-story all-electric building underwent window, lighting, and control renovations in December 1992. Annual energy consumption was reduced by 15% and peak demand fell by 17%. Hourly whole-building consumption data were available for the comparison of pre- and post-conditions and for calibration of a DOE-2.1D simulation model. The analysis found the window retrofit accounted for 90% of total energy savings and 95% of average demand savings, due to reductions in both conduction and infiltration. Benefits from lighting retrofits were low in cooling months and negligible in winter months due to the increase in demand for electric-resistance heating, which was proportional to the reduction in lighting capacity. Finally, the simulation model verified that heating system controls had not been used as intended and the utility rate structure would not allow cost savings from the original control strategy. These results and other interesting lessons learned are presented.

INTRODUCTION

Energy retrofit measures are often installed with little or no accounting for possible interactions with the building and/or other measures. Additionally, the effects of utility rate structure are not always adequately considered. As a result, expected energy and cost savings can be disappointing. As part of a joint demonstration with the U.S. Department of Housing and Urban Development (HUD), a Massachusetts utility company, a national laboratory, and the U.S. Department of Energy (DOE) participated in the computer modeling and subsequent evaluation of retrofits installed in a residential apartment building located in Chelsea, Massachusetts. By calibrating the computer models with the pre- and post-retrofit hourly and monthly whole-building data, the effectiveness of each retrofit measure is easily quantified. The computer model also provides interesting insight into energy-intensive components of the building, thus establishing a basis for future conservation efforts. The concepts, methods, and results presented here are easily transferable to other building types.

APPROACH

The impacts of retrofits in lighting, window, and energy management control in the apartment building are analyzed. The study looks at the effectiveness of retrofits individually and combined to understand interactions that occur between the building and other retrofits. At the basis of this analysis is a computer model, using the DOE-2.1D simulation code, which is calibrated to the pre- and post-retrofit conditions of the building using corresponding weather data for the neighboring Boston airport. Pre- and post-retrofit energy use is supplied via hourly and monthly whole-building data.

Both the whole-building data and the results of the computer simulation provide interesting insight into the behavior of the building and the effectiveness of the retrofit measures. Pre- and post-retrofit utility data confirm actual savings of energy and corresponding costs. Hourly utility data are used to determine the present effectiveness of the new energy-management control system (EMCS) and to predict effectiveness based on potential reprogramming. Results from simulations determine the impacts on energy and cost savings of different retrofit scenarios. The simulation results also provide direction for additional efforts.

BACKGROUND

Building Description

The apartment building, built in 1974 and located in Chelsea, Massachusetts, is served by a local utility company. The building is an all-electric, 13-story, 150-unit residential tower. Lighting, window, and control retrofits occurred in December 1992. Pre-retrofit annual

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energy consumption and peak demand were 2,174 MWh (7,418 MBtu) and 594 kW (2,027 kBtu/h), respectively, with corresponding utility costs of $190,000.

The first story of the building contains carports for 11 automobiles and a main lobby with postal boxes. The remaining 12 floors comprise 142 one-bedroom units and 8 two-bedroom units, with a laundry room and an activity area on the thirteenth floor. In addition to the bedroom(s), each apartment contains a kitchen, living room, full bathroom, and dining area. Apartments are heated via electric-resistance baseboard heaters. Several tenants have installed small air conditioners, but the majority must cool via natural ventilation through open windows.

Approximately 160 tenants occupy this low-income apartment building. The majority of the tenants are elderly and a small percentage are handicapped. The building exhibits occupancy-dependent residential profiles during warmer months, with peaks in consumption occurring at 9:00 a.m. and 5:00 p.m. Consumption profiles during colder months reflect a building dominated by heating energy. This variation in behavior is due to the minimal amount of mechanical cooling. During the respective seasons, these profiles rarely vary on weekends and holidays.

The building envelope has walls with 4-in. (101.6-mm) bricks on 6-in. (152.4-mm) concrete blocks with 2 in. (50.8 mm) of rigid insulation and interior gypsum sheets for a total conductivity of 0.094 Btu/h·ft^2·°F (0.534 W/m^2·°C). The roof is built-up roofing with air space and the equivalent of R-25 insulation for a total U-factor of 0.036 Btu/h·ft^2·°F (0.203 W/m^2·°C). The worn pre-retrofit double-pane windows and sliding glass doors, including aluminum framing, had conductivities of 0.88 Btu/h·ft^2·°F (5.0 W/m^2·°C) and 0.92 Btu/h·ft^2·°F (5.2 W/m^2·°C), respectively, and comprised approximately 15% of the exterior wall area.

Prior to retrofit, the building was plagued with ventilation and infiltration problems. Tenants often complained about draftiness, odors, and uncomfortable temperatures in the building. Neither the supply-air system (designed to provide 7,000 cfm [3,304 L/s] of air to the main corridors) nor the exhaust fans (designed to remove kitchen and bathroom odors) were functional due to filtering and motor failures. Blower-door infiltration diagnostics performed on a sample of apartments found that 75% of air leakage occurred through exterior walls, which included the windows and sliding glass doors. Additionally, elevator shafts and stairwells were found to be sources for high amounts of infiltration.[1]

[1]Ventilation and infiltration study performed by a national laboratory. Contact Rick Diamond at (510) 486-4459 for further information.

Retrofit Measures

Conservation retrofits in lighting, window, and EMCS were installed in the building following the technical assessment of several retrofit scenarios.[2] Hourly and monthly utility data may be used to evaluate the overall effectiveness of the retrofits; however, energy and demand responses may vary from year to year with changes in weather patterns. To normalize these weather effects, "typical meteorological year" (TMY) weather data (NOAA 1993) may be used with DOE-2.1D. The simulation model also provides a means for determining the impacts of each retrofit by comparing the pre-retrofit consumption model to models with individual and total installed retrofits (Crown et al. 1993).

As designed, the building contained an abundance of inefficient lighting fixtures and several opportunities existed for interior and exterior retrofits. The incandescent lighting in each apartment, with a power level of 0.8 W/ft^2 (8.61 W/m^2), was replaced with energy-efficient compact fluorescents, which reduced the power level to 0.46 W/ft^2 (4.95 W/m^2). Mercury-vapor fixtures, located in carports, were replaced with high-pressure sodium fixtures for a reduction in power level from 0.4 W/ft^2 (4.30 W/m^2) to 0.15 W/ft^2 (1.60 W/m^2).

A window retrofit was installed to reduce apartment conduction losses and infiltration levels. Original apartment sliding windows and doors were double-paned and had conductivities (including aluminum framing) of 0.88 Btu/h·ft^2·°F (5.00 W/m^2·°C) and 0.92 Btu/h·ft^2·°F (5.22 W/m^2·°C), respectively. Stairwell windows were also double-pane sliders with an estimated total conductivity of 0.88 Btu/h·ft^2·°F (5.00 W/m^2·°C). All of the sliding windows were replaced with double-pane, argon-filled windows, for a new total conductivity of 0.60 Btu/h·ft^2·°F (3.41 W/m^2·°C). Sliding glass doors were retrofitted with double-pane, argon-filled sliding doors for a new conductivity of 0.49 Btu/h·ft^2·°F (2.77 W/m^2·°C). Tenants have commented that problems with draftiness have nearly disappeared after replacement of the failed windows.

The apartment building is heated with electric-resistance baseboards controlled by tenant-adjustable thermostats. Due to infiltration from strong northwest winds, a polarity in temperatures existed between northwest- and southeast-facing apartments. Existing apartment thermostats were replaced with new thermostats connected to an EMCS that allowed programmable temperature settings. The new EMCS was installed with intentions of limiting daytime setpoints and implementing nighttime setbacks. However, due to tenant dissatisfaction, nighttime setbacks have been disengaged.

[2]Assessment performed by Citizens Conservation Corp. (now EUA Citizens). Contact the authors or EUA Citizens (William Bartovics) at (508) 656-3502 for further information.

Energy Model Calibration

To evaluate the performance of the installed retrofits, a computer model of the apartment building was developed. The model was built using detailed information gathered from architectural drawings, site-audit reports, building diagnostics, and photographs. This included information on building layout and construction, installed appliance and indoor/outdoor lighting capacities, infiltration and ventilation conditions, and general building use. The simulations were run using actual hourly weather data, collected at a nearby airport, and results were compared to monthly utility data prior to detailed calibration.

After the basic building characteristics were incorporated into the simulation model, a calibration process was executed. Significant consumption parameters and their usage profiles were adjusted iteratively using audit information, existing background data on residential consumption behavior (ACEEE 1986; PG&E 1987), and engineering insight, until the hourly output of the model reasonably matched the actual whole-building consumption profile. The pre-retrofit calibration process was divided into two components: one for the cooling season and one for the heating season.

The cooling season calibration was performed first. Because the building lacked a significant amount of cooling equipment and the ventilation system was inoperable, the overall calibration process was simplified. Summer consumption was considered to be composed of purely occupant-driven loads, such as lighting and appliances. During these months, the building exhibits a typical residential dual-peak daily consumption profile. Using the summer hourly profile, a model of the base consumption of the building was developed. Figure 1a shows the hourly consumption comparison of actual and simulated pre-retrofit data for a week in July 1992.

In a somewhat more complicated effort, the heating season model was developed using the summer model as the base-consumption component for the apartment building. According to site visit reports, infiltration was a major problem in the building. While baseboard heating capacities taken from mechanical drawings were considered to be accurate, the infiltration loads on this system were difficult to estimate. DOE-2.1D offers three options for modeling infiltration in a large building: the crack method (wind-dependent), the wind-dependent air-change method, and the constant air-change method, none of which is accurate for a building of this type. After several comparisons of the three methods with actual building consumption data, it was determined

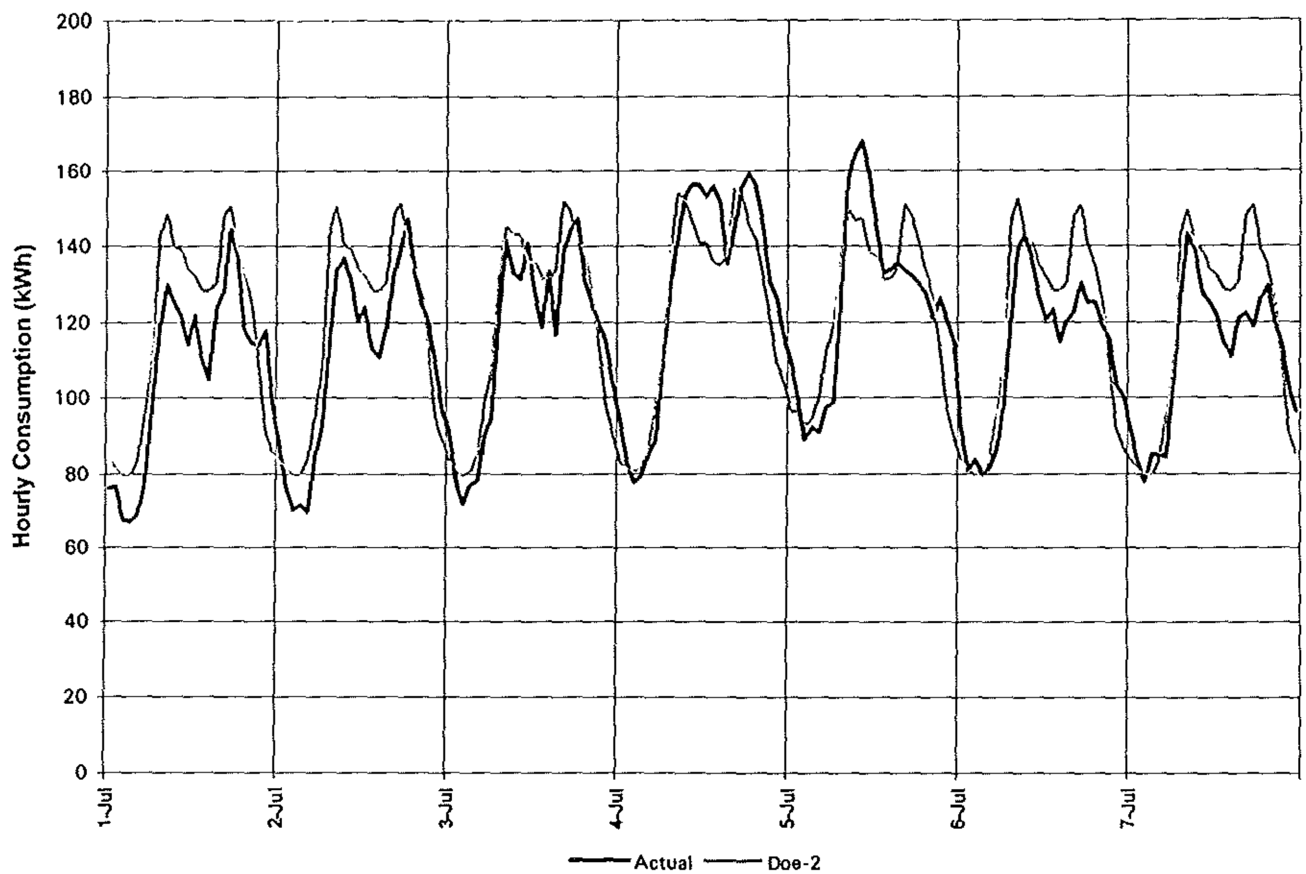

Figure 1a *Pre-retrofit comparison of DOE-2.1D and whole-building hourly data, July 1992.*

that the building was not as sensitive to the recorded wind velocity as the wind-dependent infiltration models had predicted. For this reason, the constant air-change method was selected. The pre-retrofit model shown in Figure 1b, for a week in January 1992, illustrates the comparison between actual building behavior, the erratic wind-dependent air-change model, and the constant air-change model.

The post-retrofit model did not require the detailed fine-tuning used in the pre-retrofit model. Lighting, window replacement, and EMCS retrofits were quantified and implemented in the pre-retrofit model to simulate post-retrofit. During the development of the post-retrofit model, it became evident that the newly installed EMCS was not functioning according to specifications. The EMCS originally was programmed to drop the nighttime setpoint temperatures by 4°F (2.2°C) during the hours of 11 p.m. to 6 a.m. As shown in Figure 1c, when compared to the calibrated DOE-2.1D simulation with setbacks, the actual building profile does not exhibit setback behavior such as increased morning peaks and evening valleys. The DOE-2.1D post-retrofit model without setbacks more closely follows the profile of the actual building. Apparently, tenants had complained about the setbacks and were overriding the EMCS. To prevent system damage, the setback program was disabled. The annual impact of the intended operation of the EMCS will be discussed later in detail.

The results of the hourly pre- and post-retrofit simulations were used to calculate electrical energy costs. Due to the complexity of the utility company's rate structure, DOE-2.1D was not capable of properly determining the energy costs for the apartment building. Instead, an external routine incorporating the exact utility billing charges and rate schedules was developed and used to properly calculate the building's energy costs. Actual pre- and post-retrofit billing data were used to validate the billing model.

RESULTS

Monthly Utility Profiles

Figure 2 shows the actual consumption and peak demand profiles for the building, pre- and post-retrofit, according to monthly utility data (BECo 1993). Under the utility company's rate structure, peak hours occur in June through September from 9 a.m. to 6 p.m., and in October through May from 8 a.m. to 9 p.m. During the first nine months after retrofit (December 1992 through August 1993), the maximum peak demand was reduced by 41 kW (140 kBtu/h), and a total consumption savings of 317 MWh (1,082 MBtu) occurred when compared to the same months in 1992. While there is a definite

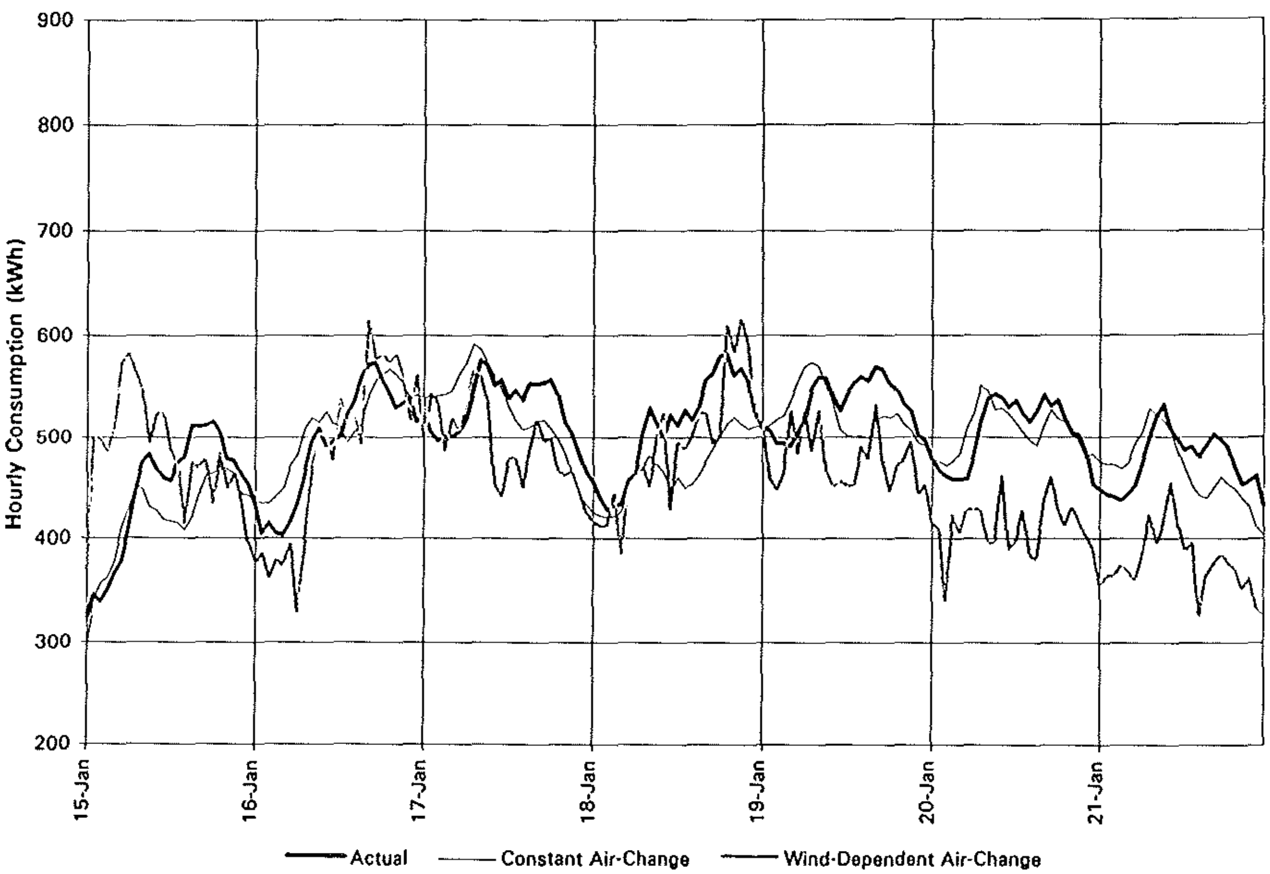

Figure 1b *Comparison of air-change method hourly consumption models with actual data, January 1992.*

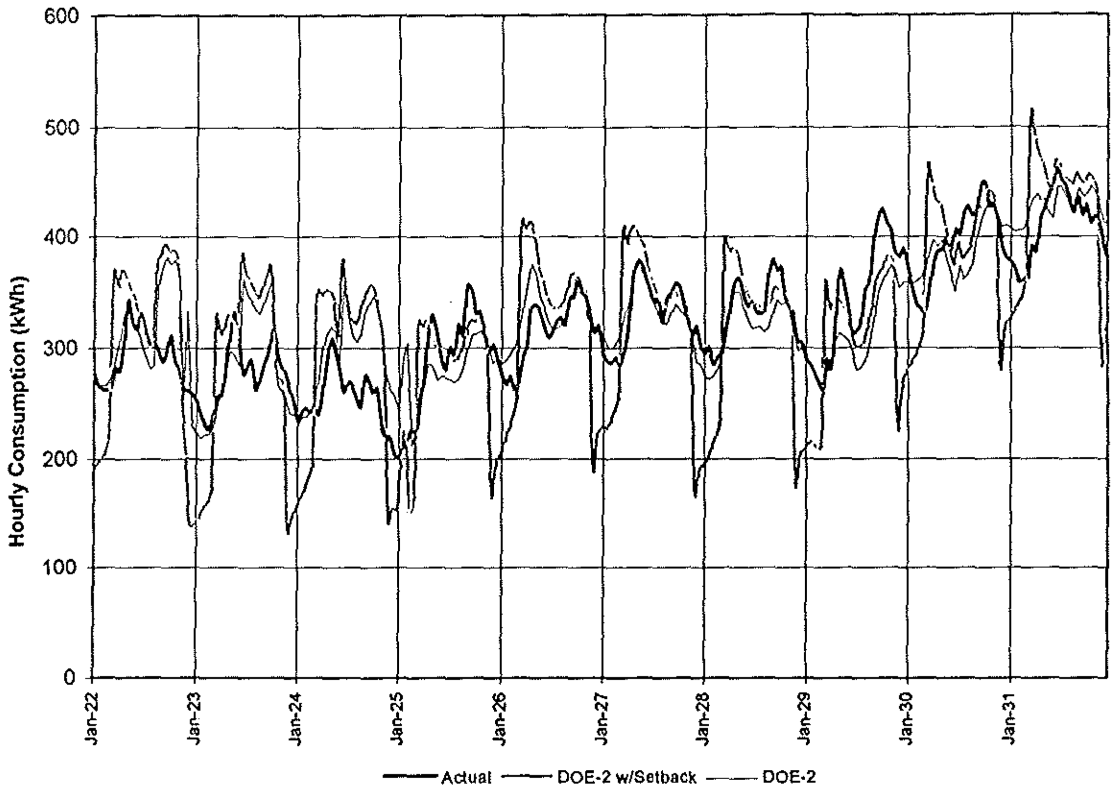

Figure 1c *Comparison of actual building consumption and DOE-2 non-setback (as-is) model with DOE-2.1D setback model, on an hourly basis, January 1992.*

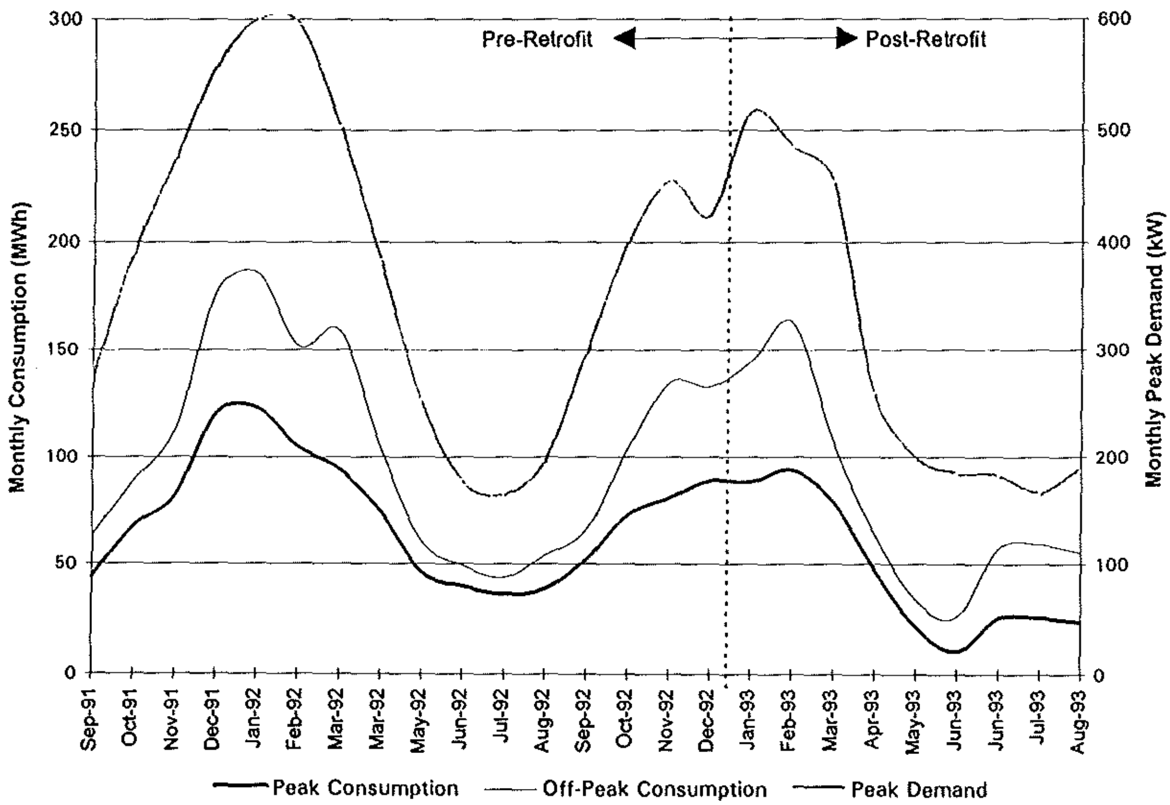

Figure 2 *Peak and off-peak consumption profiles for building, from monthly utility bills (BECo 1993).*

decrease in energy consumption and demand for the first few months after retrofit, the full benefit of the building retrofit cannot be determined until weather effects are normalized. The computerized simulation model may be used to determine the weather-normalized building response to retrofits.

Computer Simulation

Monthly comparisons of normalized peak and off-peak energy consumption are presented in Figure 3a for pre- and as-is post-retrofit conditions (without nighttime setback). In the normalized post-retrofit model, total annual consumption is reduced by 325 MWh (1,109 MBtu). More than 60% of these savings occur during off-peak hours, due to the heating system relief provided by the improved insulative effects of retrofit windows. Total energy savings are more prevalent during the heating season and reflect an average reduction in annual consumption of 15%. Similarly, the demand comparison for the normalized model is shown in Figure 3b. Monthly peak demand is reduced, on average, by 61 kW (208 kBtu/h) and the maximum peak is reduced by 17%, or 100 kW (341 kBtu/h), in January. Demand savings are most significant during colder months as retrofit windows reduce the demand for electric-resistance heat. Using hourly simulation results and the 1993 utility company rate structure, monthly utility costs were estimated for the weather-normalized model of the apartment building. Annual pre-retrofit utility costs were $190,000, while post-retrofit costs were $162,000. Figure 4 shows the monthly cost comparisons for pre- and post-retrofit consumption and demand. The total annual savings of $28,000 represent a 15% reduction in utility costs.

As mentioned previously, more than 60% of all energy savings occurred during off-peak hours. Unfortunately, lower off-peak rates reduce the potential for cost savings associated with a large reduction in consumption. As a result, average avoided costs are higher for peak consumption, at 0.0668 $/kWh (0.0196 $/kBtu), compared to 0.0525 $/kWh (0.0154 $/kBtu) for off-peak consumption.

The annual savings in demand costs represent a 16% reduction in pre-retrofit levels and account for 33% of total utility cost savings. Demand-cost savings, which are enhanced during winter months and minimized during the summer, reflect the success of the window retrofit in reducing demand for electrical heat.

A routine in DOE-2.1D performs an analysis of energy consumption by end-use for the building. Table 1 shows the pre- and post-retrofit consumption, by component, on a per square foot of floor area basis. The electric-resistance heating system in the building constitutes nearly half of the whole-building energy consumption. Post-retrofit measures reduced space-heating requirements by 2.60 kWh/ft^2 (27.95 kWh/m^2) and lighting consumption by 0.68 kWh/ft^2 (7.31 kWh/m^2). The large contribution of

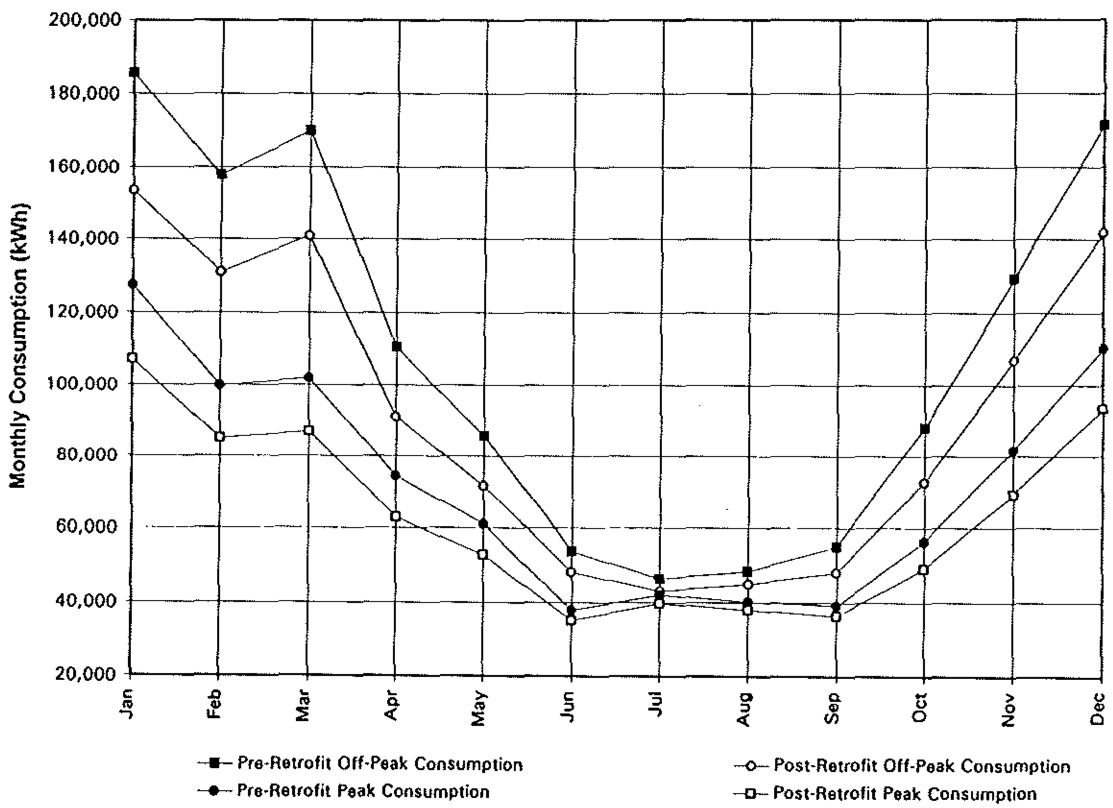

Figure 3a *Normalized monthly on-peak and off-peak consumption, pre- and post-retrofit.*

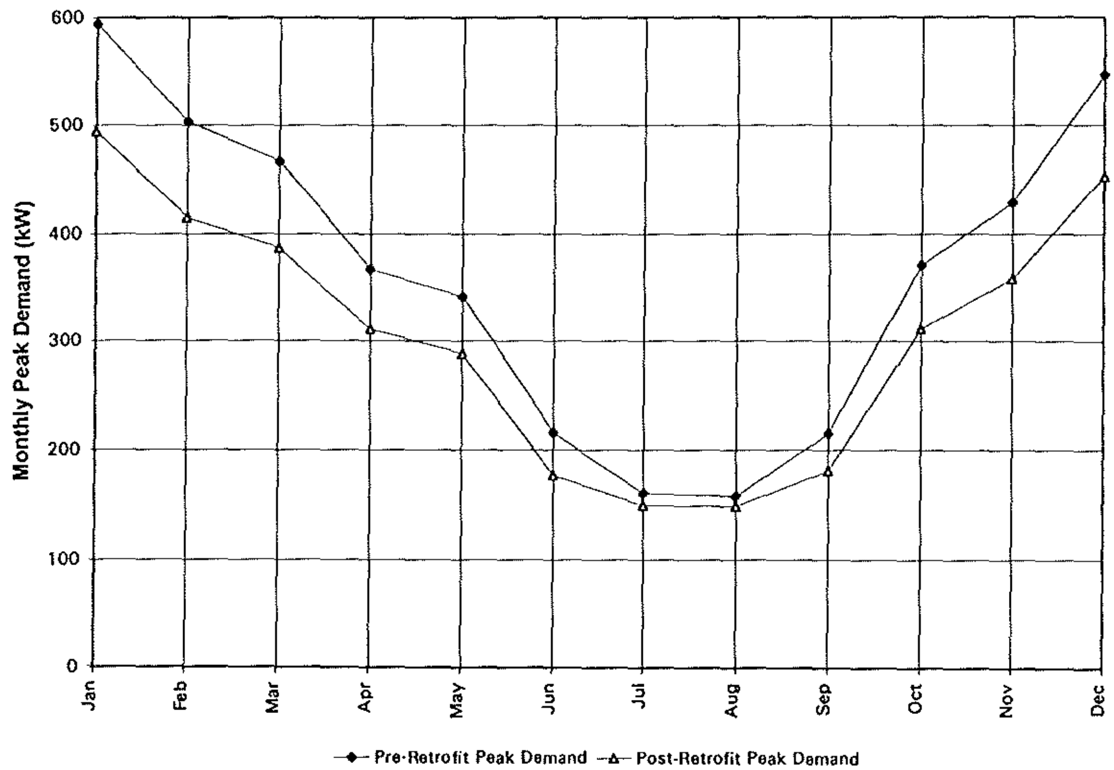

Figure 3b *Normalized monthly peak demand, pre- and post-retrofit.*

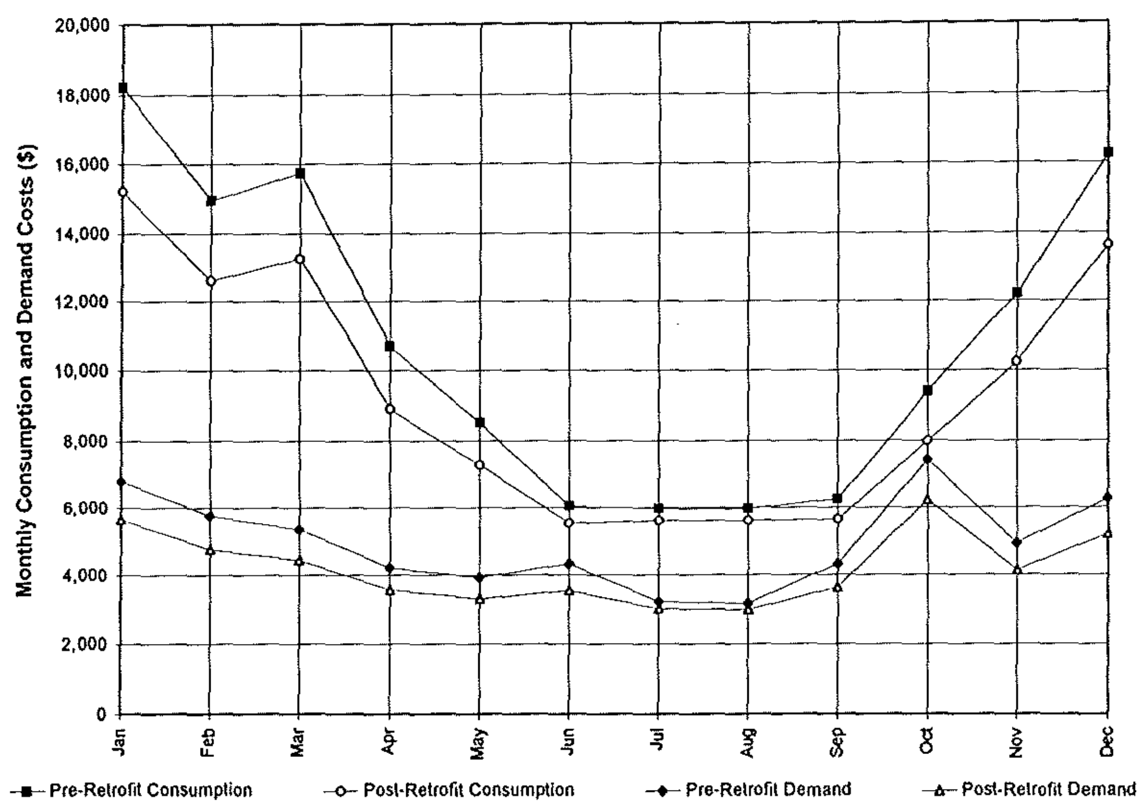

Figure 4 *Monthly consumption and demand costs, pre- and post-retrofit, for normalized model.*

space heating to whole-building consumption indicates the vast potential for conservation in this area. National data on residential energy use show that multifamily buildings, in a similar climate, consume approximately 5 to 6 kWh/ft^2 (54 to 64 kWh/m^2) for space heating (EIA 1993). While space-heating consumption was reduced with the retrofit, at 8.5 kWh/ft^2 (91.5 kWh/m^2), there still appears to be room for improvement.

TABLE 1 **Components of Energy Consumption for the Building, as Determined by Normalized Simulation Model**

Component	Pre-Retrofit Consumption kWh/ft^2/yr (kWh/m^2/yr)		Post-Retrofit Consumption kWh/ft^2/yr (kWh/m^2/yr)	
Space Heating	11.10	(119.32)	8.54	(91.81)
Space Cooling	0.04	(0.43)	0.04	(0.43)
Domestic Hot Water	2.07	(22.24)	2.06	(22.14)
Lights	3.65	(39.24)	2.97	(31.93)
Elevator	0.695	(7.46)	0.695	(7.46)
Misc. Equipment	4.08	(43.86)	4.08	(43.86)
Total	21.63	(232.55)	18.38	(197.63)

*Total building area is 100,880 ft^2 (9,372 m^2)

Thus, the contribution of the heating system to building consumption is quite large. In searching for cost-effective conservation measures, one should examine the potential impacts of the candidate retrofits on the affected building load (in this case, heating), which is the major source of the building's demand for electricity. Table 2 lists the effects on heating load of each of the retrofits considered for the building. Notice that the window retrofit has the largest impact on the reduction of the heating load, while the lighting retrofit actually has a negative impact. Reprogramming setbacks will reduce the overall demand for heat from the building's baseboard heaters.

TABLE 2 **Reduction in Annual Heating Load by Retrofit Scenario**

Scenario	Reduction in Total Heating Load MBtu (kWh)	
Post-Retrofit (as is)	883	(258,791)
Windows	1000	(293,082)
Lighting	−124	(−36,343)
Post- w/Setback	994	(291,325)

The effects of individual and combined retrofits were examined on a monthly basis. These examinations were conducted to help understand interaction effects with the building and with each other. The results of these runs are presented in Figures 5 and 6 and summarized in Table 3, for consumption and demand savings, respectively. Note that these figures represent savings relative to weather-normalized pre-retrofit conditions and not to actual consumption and demand values.

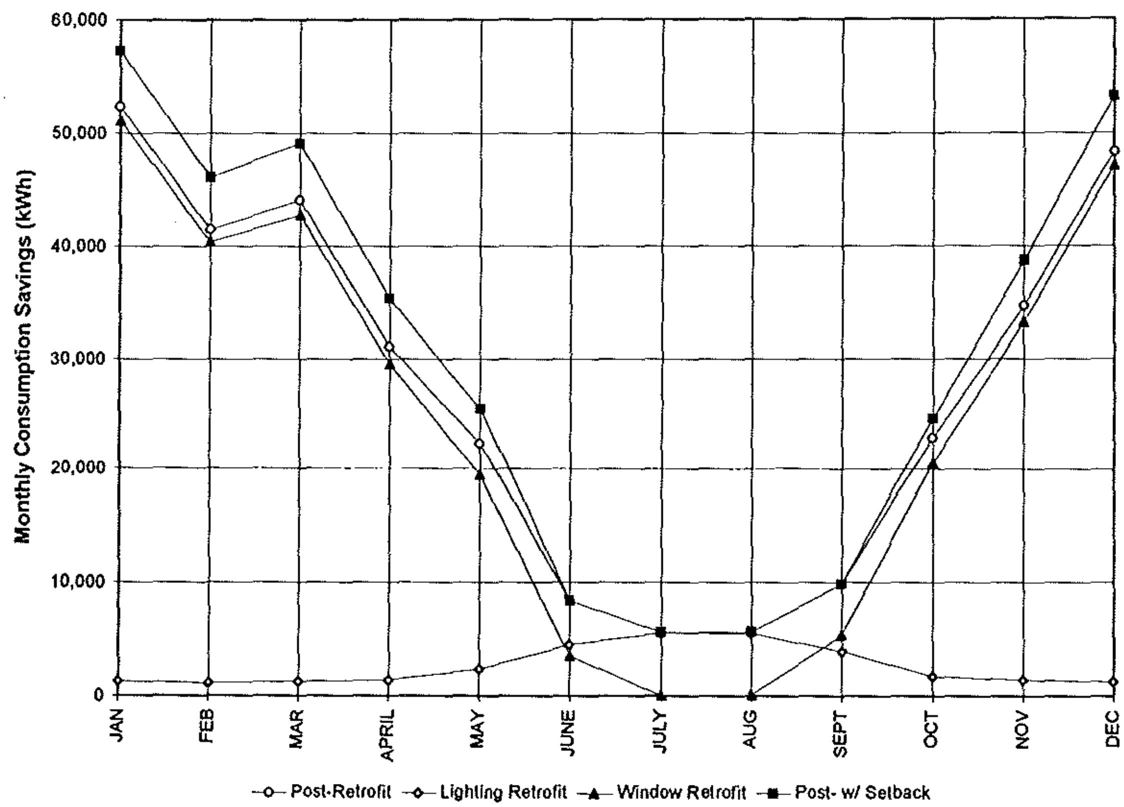

Figure 5 *Building electrical consumption savings of retrofit models relative to pre-retrofit conditions.*

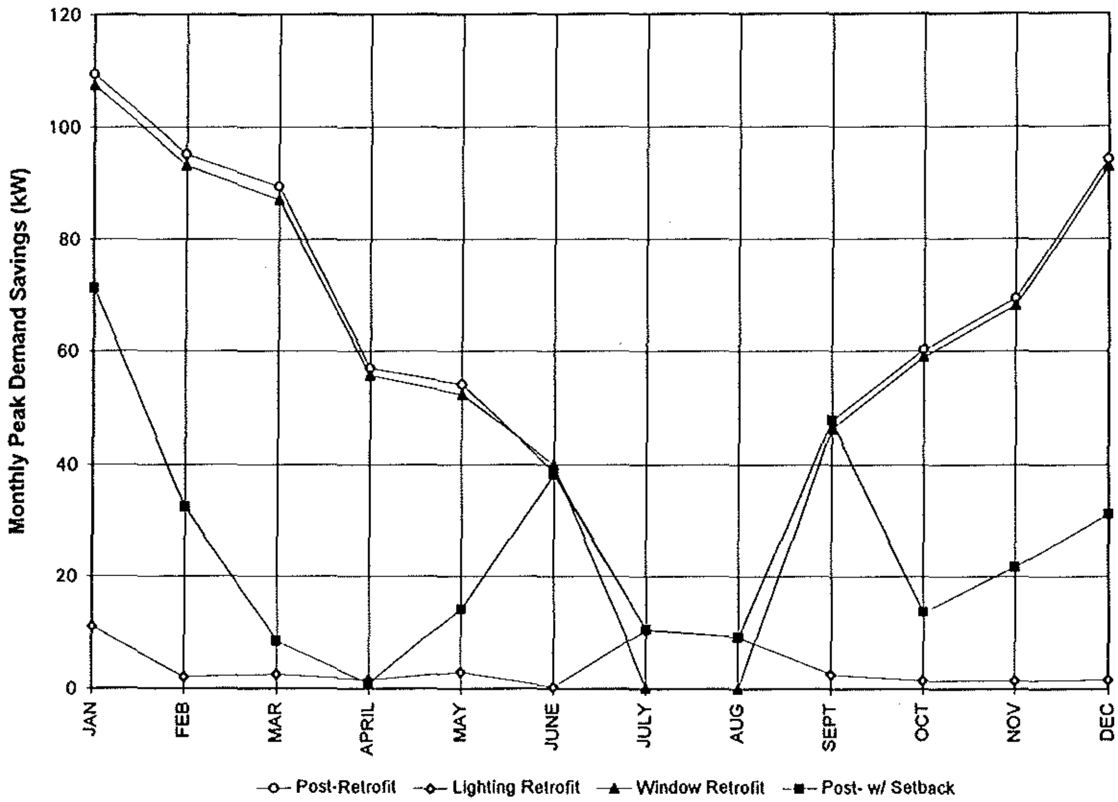

Figure 6 *Building electrical peak demand savings of retrofit models relative to pre-retrofit conditions.*

TABLE 3 **Summary of Annual Consumption and Demand for the Building**

Scenario	Energy MWh (MBtu)	Energy Savings MWh (MBtu), %	Peak Demand kW (kBtu/h)	Demand Savings kW (kBtu/h), %
Pre-Retrofit	2,174 (7,418)		594 (2,027)	
As-Is Post-Retrofit (EMCS disengaged)	1,849 (6,309)	325 (1,109) 15%	494 (1,685)	100 (341) 16.8%
Lighting	2,143 (7,312)	31 (106) 1.5%	593 (2,023)	1 (3) 0.2%
Window	1,883 (6,425)	291 (993) 13.4%	496 (1,692)	98 (334) 16.5%
Post-w/EMCS Setback	1,817 (6,200)	357 (1,218) 16.4%	534 (1,822)	60 (205) 10.1%

Lighting Savings Savings from lighting retrofits, both in consumption and demand, are more prevalent during summer months, when a heating demand is virtually nonexistent. Peak savings in lighting consumption occur in July, at 5.6 MWh (19 MBtu), or 6% of July pre-retrofit consumption. Similarly, peak demand in July is reduced by 10.5 kW (35.7 kBtu/h), a 6.5% reduction. The results show that during colder months the portion of the heating demand previously met by the lighting was shifted to the electric-resistance baseboards. This shift was large enough to significantly reduce the conservation benefits gained from the lighting reduction. A study on lighting retrofits found similar results: shell-dominated buildings in colder climates experience an increase in heating requirements with certain lighting conservation measures (Higgins and Tichy 1992).

Window Savings The consumption and demand savings from the window retrofit were large, as conduction and infiltration losses were reduced, resulting in the reduction in demand for electric-resistance heat. Savings are strongest in January, at 51 MWh (174 MBtu) and 98 kW (334 kBtu/h). These savings reflect 16% reductions in both consumption and demand during the month of January.

As-Is Post-Retrofit Savings Recall that, presently, the EMCS is not being used for implementing setback temperatures. Actual post-retrofit savings due to window and lighting measures alone are nearly the sum of the individual retrofits. Maximum monthly consumption and demand savings for the post-retrofit model occur in January. Including lighting and window retrofits, these savings are 52.3 MWh (178 MBtu) and 100 kW (341 kBtu/h), or 17% of pre-retrofit consumption and demand. The window retrofit supplies the majority of the total consumption and demand savings, at 89% and 99%, respectively.

Additional Savings with Setbacks A weather-normalized model was run to determine additional benefits and/or penalties associated with resuming temperature setbacks at night. The largest savings in consumption occur during the winter months, as demand for nighttime heating is reduced with the setbacks. Additional annual savings in energy over existing post-retrofit conditions are nearly 32 MWh (109 MBtu). The model shows that peak demand would probably increase if the setbacks are implemented as designed. This is the result of an increase in the morning demand for space heat occurring at the end of the setback period.

Billing Cost Savings Table 4 summarizes measure costs, annual utility costs, and simple payback for the retrofit scenarios examined. The utility cost savings, according to the 1993 electric company rate structure, are reflective of the consumption and demand savings discussed above. The total annual cost savings of the retrofits, as implemented, are $28,000, with a simple payback of 13.2 years. The window retrofit provides the majority of the utility cost reduction, at $25,400, and has the lowest payback period of 7.5 years. Replacement lighting only saves approximately $2,550 annually, with a larger payback of 9.2 years. If the EMCS was to be re-engaged, cost savings would fall to $25,490 and the payback period would increase to 14.7 years. This occurs because as the designed temperature setbacks are implemented, the rate structure is such that cost benefits are negative, based on the nature of the adjusted consumption and demand profiles. It may be possible to minimize this problem with careful programming of setbacks to reduce consumption spikes during the utility's on-peak period.

TABLE 4 Summary of Measure Costs, Utility Costs, and Simple Payback for the Building

Scenario	Measure Cost ($)	Annual Utility Cost ($)	Annual Utility Cost Savings ($)	Simple Payback (yrs)**
Pre-Retrofit		189,880		
Lighting	23,500	187,330	2,550 (1.2%)	9.2
Window	192,000	164,480	25,400 (13.4%)	7.5
As-Is Post-Retrofit* (EMCS disengaged)	372,000	161,880	28,000 (14.6%)	13.2
Post-w/EMCS Setback	372,000	164,390	25,490 (13.3%)	14.7

*Includes cost of installed EMCS, at $156,500

**The simple payback does not include the effects of escalating energy costs, interest rates, inflation or tax rates.

CONCLUSIONS

Whole-building consumption data and computer simulation models proved to be effective tools for evaluating the success of energy conservation retrofits in the apartment building, a multifamily residential tower. Lighting, window, and thermostat-control retrofits were analyzed to determine individual and combined energy, demand, and utility cost savings. The methods followed in the study are easily transferable to other residential and commercial building types.

The analysis followed several basic steps. First was the development of the DOE-2.1D simulation model, which was calibrated using hourly and monthly consumption data for the building and local hourly weather data. Second, utility costs for the calibrated simulation results were calculated using the 1993 utility rate structure. Simulations and corresponding costs were run for retrofit scenarios covering individual and combined installations. The results of the simulations were then used to evaluate the effectiveness of the retrofits, as installed, by examining the building loads and consumption levels on a per-component basis, and through side-by-side consumption comparison of the different scenarios.

The post-retrofit annual energy reduction for the apartment building was calculated to be nearly 325 MWh (1,109 MBtu), with a peak demand savings of 100 kW (341 kBtu/h). These savings result in annual utility bill cost savings of $28,000. Most of the energy and cost savings occur during winter months, as the demand on the electric-resistance heating system is reduced.

The majority of the energy and cost savings was attributed to the installation of insulative windows throughout the building. Worn double-pane windows and sliding-glass doors were replaced with new double-pane argon-filled windows and doors. The energy and demand savings, accompanying window replacement, were calculated to be 291 MWh (993 MBtu) and 98 kW (334 kBtu/h). Corresponding annual energy cost savings were more than $25,000. Weatherization of the building decreases the demand on the electric-resistance heating system, which is the largest consumer of energy in the building.

Lighting retrofits produced some savings in energy but little savings in peak demand. The replacement of the original incandescent lighting in the apartments with reduced-wattage fluorescent fixtures produced an estimated annual energy savings of 31 MWh (106 MBtu) and demand savings of only 1 kW (3 kBtu/h). Energy savings were reduced because the space heating supplied by the old lights decreased after the retrofit and had to be supplemented by the electric-resistance heating system. The interaction of lighting retrofits with building heating and/or cooling systems must always be considered. In this study, heating energy penalties were significant for the electrically heated building located in the Boston climate.

The building's rehabilitation also included the installation of an energy management control system (EMCS). The EMCS was programmed to implement a nighttime setback of 4°F (2.2°C) during colder months. The study found that the setbacks were not used and thus anticipated energy savings were not realized. If the setbacks were to be implemented, additional annual energy savings could be 32 MWh (109 MBtu). Notably though, peak demand is expected to increase by nearly 40 kW (136 kBtu/h) due to the increase in space-heating demand in the morning hours after setpoints are returned to their original values. The resulting overall cost savings from the EMCS were negative for several strategies that were examined, including the design strategy of setback of 4°F from 11 p.m. to 6 a.m.

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