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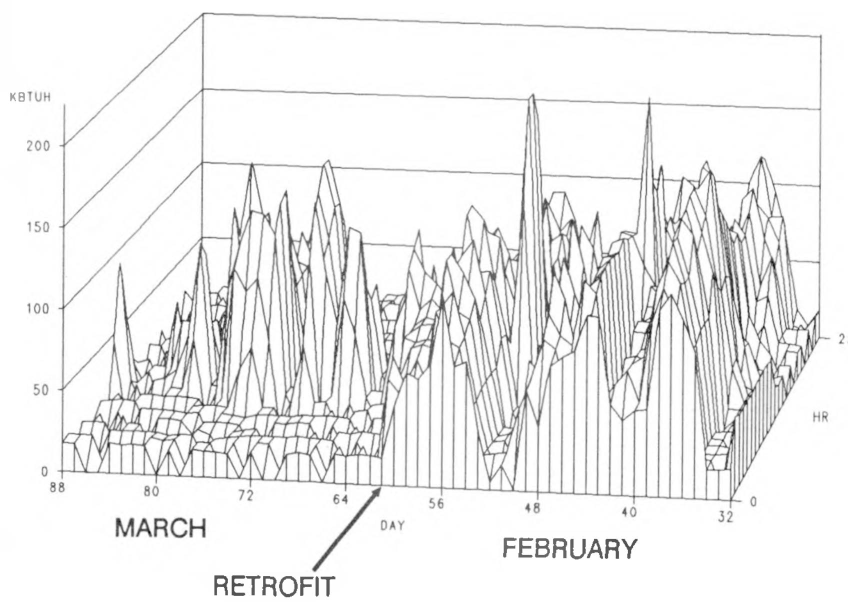
MARTIN MARIETTA

Measurement of Energy Performance in a Small Bank Building

T. R. Sharp

J. M. MacDonald



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DEPARTMENT OF ENERGY

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Energy Division

Measurement of Energy Performance in a Small Bank Building

T. R. Sharp
J. M. MacDonald

April 1990

Existing Buildings Efficiency Research

Research Sponsored by the

Office of Buildings and Community Systems

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OAK RIDGE NATIONAL LABORATORY
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ABSTRACT

This report summarizes the measured results from a field study of the performance of a low-cost controls retrofit in a small bank building in Knoxville, Tennessee. The retrofit consisted of an upgrade of heating and cooling system controls and new operating strategies. The study was undertaken to better understand how commercial energy use measurement studies should be performed and to demonstrate the effectiveness of a low-cost controls retrofit in a small commercial building. This report describes the details of the project, including building and building system characteristics, the HVAC control changes implemented, energy end use patterns, and the heating and cooling energy savings achieved.

An improved control strategy involving thermostat setback/setup and on/off control was devised around a single replacement programmable thermostat. The strategy allowed thermostat setback/setup control of the primary HVAC system in the building and provided on/off (time-of-day) control for the two secondary systems. The energy efficiency improvements provided a 33% reduction in heating and a 21% reduction in cooling energy consumptions. Simple payback for the retrofit, including installation cost, was less than 1 year. In addition to reducing the energy needs of the building, the replacement electronic thermostat provided improved interior comfort.

EXECUTIVE SUMMARY

This report summarizes the energy end use patterns, costs, and energy savings resulting from an upgrade of HVAC controls and operational strategy. The project was undertaken to demonstrate the potential of low-cost retrofitting in a small commercial building. Its purpose was also to better understand (1) how to measure commercial building energy use, and (2) how to use measured data to determine baseline and improved performance after installation of an energy retrofit. The project was conducted by the Oak Ridge National Laboratory (ORNL) as part of the U.S. Department of Energy's program on Existing Buildings Efficiency Research. Since commercial buildings were estimated to consume slightly less than one-third of total electrical use in the U.S. in 1987, and current estimates indicate that more than 96% of all U.S. commercial buildings are less than 50,000 sq ft in size (small and medium), energy savings in small- to medium-sized commercial buildings are needed to achieve significant reductions in overall commercial energy use.

The improvement was implemented in a small, stand-alone building used as a branch office for a local bank in Knoxville, Tennessee. The structure has one story above ground and a below-ground basement with approximately 4,000 sq ft of conditioned space and 850 sq ft of unconditioned space. Business is conducted approximately 42 hours/wk on weekdays only. The branch office typically has a 12-person staff and averages around 200 to 300 customers per day.

The conditioned space has three separate zones, two office and one open business space, which are heated and cooled by three separate split-package air conditioners and one central gas-fired boiler. System capacities total approximately 12 tons of cooling and 188,000 Btu/h of heating. The building uses three-phase power and contains approximately 60 separate electric circuits that were measured. Lighting at the site is approximately 70% incandescent and totals approximately 8.3 kW during business hours and 3 kW during non-business hours. All lighting is manually operated except for the external sign.

The efficiency improvement consisted of replacing the mechanical thermostat on the primary (largest) heating and cooling unit with a programmable thermostat and interfacing it to control the two secondary units. Thus, limited changes to existing control hardware were made. The new operating strategy consisted of setback/setup control on the primary unit and on/off control on the two secondary units. The weekly operational times of the three units were changed from 100% normal operation for all units to 30% normal - 70% setback/setup for the primary unit and 30% normal - 70% off for the two secondary units.

Data analysis indicated that the 1988/89 winter heating energy use was reduced by 33%, saving approximately $500 ($0.12/sq ft). Air conditioning energy use for 1988 was reduced by 21%, saving approximately $300 ($0.07/sq ft). Payback for the retrofit was well under 1 year since the installed cost was $600.

The new operating strategy shifted the electric demand profile slightly but was not a concern, since typical building loads were well below 50 kW where electric demand charges are assessed. In addition to energy and expense savings, occupants noted an improvement in comfort in the area controlled by the programmable thermostat. The energy and cost savings results from this project demonstrate that a small building with multiple heating and cooling systems can have controls upgraded to improve energy efficiency both economically and effectively.

1. INTRODUCTION

1.1 PURPOSE AND SCOPE

This project was undertaken to demonstrate the potential of low-cost retrofitting in a small commercial building. Its purpose was also to better understand (1) how to measure commercial building energy use, and (2) how to use measured data to determine baseline and improved performance after installation of an energy retrofit. The project was conducted by the Oak Ridge National Laboratory (ORNL) as part of the U.S. Department of Energy's program on Existing Buildings Efficiency Research.

The project scope included: surveying potential commercial buildings and selecting a suitable candidate for retrofit, negotiating with the building owner to have an energy retrofit installed, selecting and installing metering equipment to measure the energy use of the building, selecting and installing the retrofit, collecting energy use data before and after retrofit, analyzing the data to determine the efficiency improvement, and presenting the results.

Previous results have been presented from this project on the screening of energy use patterns in buildings[1,2] comparisons of hourly with monthly energy data,[2] and electrical energy savings and load impacts during the cooling season.[3]

This report documents results covering energy savings for both heating and cooling. The report includes descriptions of the building, systems within the building, hardware and control strategy changes, the heating and cooling energy savings achieved by the retrofit, costs and cost savings for the retrofit, and conclusions from the project.

1.2 BACKGROUND

Commercial buildings are estimated to consume slightly less than one-third of total electrical use in the U.S. in 1987,[4] thus, reducing electricity use in commercial buildings is an important part of improving the overall efficiency of the U.S. building stock. The growth of electricity use in the commercial sector has been startling, with more than 40% of the growth in electricity consumption for the nation from 1972-1986 attributable to the commercial sector.[5]

Current estimates indicate that more than 96% of all U.S. commercial buildings are less than 50,000 sq ft in size (small and medium), and buildings in this size range account for approximately half of all commercial square footage.[6] As a result, energy savings in small- to medium-sized commercial buildings are needed to achieve significant reductions in overall commercial energy use.

1.3 DISCUSSION

The commercial sector, composed of small- to medium-sized buildings, has been identified as requiring assistance in implementing energy conservation measures. While larger businesses often have staff dedicated to the problem of energy conservation and sufficient capital to invest in such projects, smaller businesses usually have neither. Many electric and gas utilities already extend programs to the commercial sector,[7] but many of these programs are not applicable to small buildings or they lack the incentives needed to induce widespread participation by the businesses. Private companies, such as energy service companies (ESCOs), typically cannot provide services to small businesses due to the small scale of the individual buildings relative to the investment requirements for ESCOs.[8] This project is intended to demonstrate the attractive energy savings potential in small commercial buildings through low-cost retrofit. The process of achieving these kinds of improvements on a wide scale involves building screening, matching appropriate retrofits to individual buildings using simplified analysis methods, and documenting savings through field studies to improve confidence in expected savings.

This project has demonstrated successful building screening, identified important potential simplified analysis methods (readers should also study current work at Princeton[9,10] for more information on potential analysis methods), and documented the savings of a promising retrofit for small buildings. Future projects can build on the knowledge base developed from this study.

2. THE BUILDING AND BUILDING SYSTEMS

2.1 BUILDING DESCRIPTION

The building that was studied is a branch office of a commercial banking business. The structure has one story above ground and a partial below-ground basement. All business services are conducted on the ground level, which has three distinct zones as shown in Fig. 2.1. Zones 1 and 3 consist of office space and Zone 2 is open business space (lobby). Zoning for the basement is also shown in Fig. 2.1. The basement is used for an employee lounge, bathroom facilities, and a large mechanical room. All spaces are conditioned except for the downstairs mechanical room.

2.1.1 Building Construction

The ground level of the building covers 3,175 sq ft (79% of the total conditioned floor area). Walls are typical 6-in. frame construction with exterior brick and have 333 sq ft of fixed-panel glass. Unshaded, southern-exposed glass area is 57 sq ft and is all located in the south offices (Zone 3 of the ground floor, see Fig. 2.1). One double-door on the ground level is the main entry to the building and is the only entry that sees significant use.

The partial basement covers 1,569 sq ft. Only 850 sq ft of the basement is conditioned space (21% of the total conditioned floor area). The basement is block construction on a concrete slab. Approximately 85% of the basement wall is below ground. Exposed basement walls have no windows.

2.1.2 Business and Occupancy Schedules

Business is conducted at the site only on weekdays for a total of 42 h/wk. Clean-up occurs nightly and adds an additional 2 hours per day to the operational schedule beyond business hours. The regular

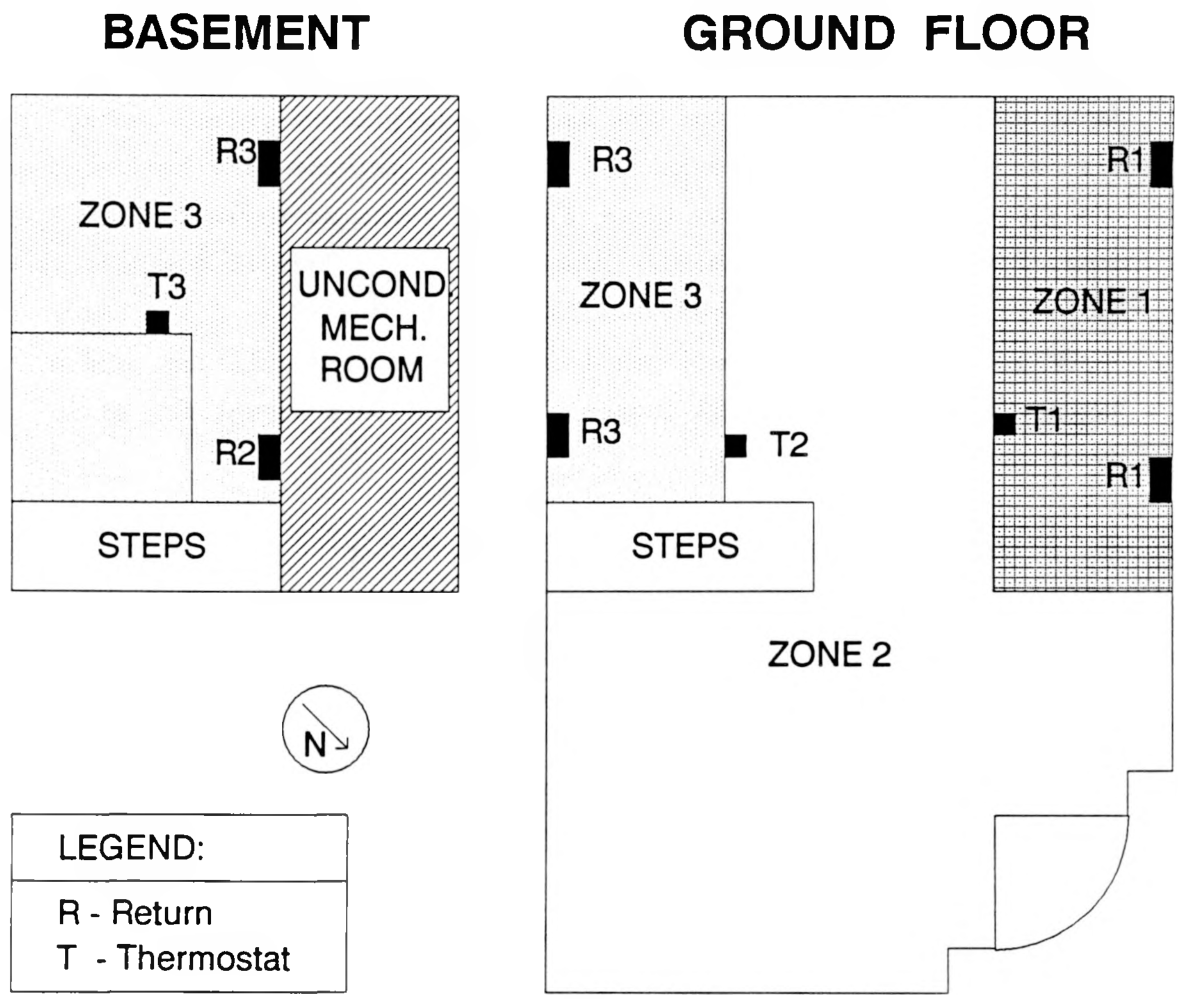

Figure 2.1. HVAC zoning and controls.

employee occupancy is twelve people during business hours. The number of customers who conduct business inside the bank normally ranges between 200 and 300 per day. Daily clean-up usually involves a single occupant after business hours.

2.2 BUILDING SYSTEMS

2.2.1 Electrical Distribution

Electrical service to the building is 208V, 3-phase, 300 amp per phase service fed from a pad-mounted transformer located on-site. Loads are connected at the transformer using a 4-wire, wye configuration. Power comes into the building through Panel B which distributes power directly to the single and three-phase, 208V heating and cooling equipment and to Panels A and C. Panels A and C support lighting and miscellaneous uses including wall receptacles and business machines.

2.2.2 Heating and Cooling Systems

The building is divided into the three zones shown in Fig. 2.1 for heating and cooling purposes. The zone descriptions are as follows:

Zone 1 - north-side office space (366 sq ft)
Zone 2 - customer services area (2,588 sq ft)
Zone 3 - south-side office space and downstairs lounge and baths (1072 sq ft).

Three separate air handling units (AHUs) provide conditioned air to the three zones. Zonal thermostat and return locations are also shown in Fig. 2.1. Two design complexities of the heating and cooling systems should be noted in Fig. 2.1: (1) the return for Zone 2 is located within the perimeter of Zone 3 in the basement (away from the rest of Zone 2), and (2) the Zone 3 thermostat (T3), located downstairs, controls conditioned air distribution to the upstairs Zone

3 office space. Cooling for the three zones is provided by three split-system air conditioners. Heating for the three zones is provided by a single gas-fired boiler, which circulates hot water to heating coils at each AHU. Approximate heating and cooling system capacities are summarized in Table 2.1. Domestic hot water for the building is provided by an electric water heater.

2.2.3 Lighting

Lighting is dominated by ceiling-mounted, recessed, incandescent lighting fixtures using 75 and 150 watt flood lamps. The approximate lighting use during business hours is 8.3 kW. Seventy percent of this amount is incandescent. During non-business hours, the approximate lighting use is 3 kW and is essentially all incandescent. Interior and exterior lighting loads during non-business hours are approximately equal. Although incandescent is the dominant type of lighting used, a significant amount of fluorescent lighting is provided from fluorescent ceiling fixtures distributed throughout the building.

2.2.4 Operations and Controls

Heating and cooling systems are controlled by standard, single-stage, mechanical thermostats with manual fan control capabilities. Since a single boiler supplies hot water to the three separate air handling units, zonal thermostats control solenoid valves which start and stop the flow of hot water to the heating coil of each associated AHU. The boiler fires as needed to maintain a constant water temperature. This is different from the cooling mode, where each zonal thermostat controls the respective cooling system directly. Prior to installation of the control retrofit for this study, no nighttime setback or setup of thermostats was practiced. The boiler is typically operated year round. Changing of AHU filters is done on a scheduled bi-monthly basis.

Table 2.1. Approximate heating and cooling system capacities.

Zone	Area (sq ft)	Cooling Capacity (Btuh)	Heating Capacity (Btuh)	Design Flow Rate (cfm)
1	366	18,000	24,000	425
2	2,588	96,000	126,000	4075
3	1,072	29,000	38,000	900

Interior lighting is manually controlled by switches which provide power to groups of lights. Lighting is manually cut off to nighttime levels on a regular basis. Most exterior lighting at the building is on 24 hours per day. Lighting for an exterior sign is the only lighting at the building which is automatically controlled. A time clock allows illumination of the sign for approximately 10 hours per day, seven days per week.

3. DATA ACQUISITION

3.1 DATA LOGGERS

The data acquisition system consisted of two Fowlkes Engineering Remote Data Acquisition Systems[a] and one Campbell Scientific Inc., Model 21x Micrologger[b]. The Fowlkes Engineering data loggers were used to measure ambient temperatures and electric currents in approximately 60 circuits. The Campbell Scientific data logger was predominantly used for totalizing pulses from a pulse-emitting watt-hour meter which were later converted to hourly electric energy consumptions.

3.2 DATA COLLECTION

Circuit currents were sensed using current transformers and stored as hourly averages. Circuit currents were converted to energy consumptions by using the appropriate line voltages and power factors determined from periodic measurements. The hourly run times of building systems were measured by checking their on/off status approximately every 10 seconds (the sampling interval of the data loggers). Total electric energy use to the building was measured by recording the pulses from a utility-supplied pulse-initiating watt-hour meter and stored on a 15-minute basis. Gas consumption was measured on an hourly basis by using calibrations of the burner firing rate and measuring the hourly on-time of the gas burner. Ambient temperatures were measured using electronic thermistors and recorded as hourly averages.

Pre-retrofit data were collected between June 1987 and March 1, 1988. Post-retrofit data ran from March 2, 1988 through August 1988. Data were collected under the following end-use classifications: total electricity, cooling, heating, lighting, fans, and miscellaneous energy

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[a]Fowlkes Engineering, Bozeman, Montana.

[b]Campbell Scientific, Inc., Logan, Utah.

use. Utility billing data were tracked during the entire monitoring period. Since the whole building and all systems were considered as candidates for retrofit, all energy systems at the site were measured as opposed to only measuring a targeted end use.

4. THE RETROFIT: CHANGES TO HVAC CONTROL

4.1 HARDWARE AND STRATEGY CHANGES

Building heating and cooling system controls were modified to allow a different operating strategy during unoccupied hours, as opposed to pre-retrofit where occupied and unoccupied operations were the same. Control changes were made to both hardware and operating strategy. The retrofit was designed to obtain substantial energy savings while minimizing new equipment and installation costs (approximately $600). The replacement of all thermostats within the building was avoided because occupants wanted to retain familiar controls where possible. To accomplish this and still achieve programmable control in all zones, a strategy was designed around a single programmable thermostat. The strategy provided setback/setup control in Zone 2, the primary (largest) zone in the building, and on/off control in the perimeter office areas (Zones 1 and 3).

The mechanical thermostat in Zone 2 was replaced with a programmable thermostat to provide temperature setback/setup in this zone. The programmable thermostat has auxiliary contacts which operate as on/off switches activated by occupied and unoccupied setpoints. On/off system control in the secondary zones was achieved by connecting the auxiliary contacts to relays that control the power to each of the secondary zone thermostats. Thus, the auxiliary contacts on the programmable thermostat shut off the heating and cooling units in Zones 1 and 3 during the unoccupied periods. Zones 1 and 3 have no local thermostatic control during unoccupied periods with this arrangement. Zones 1 and 3 thermostats are activated through the auxiliary contacts if the fixed emergency temperature setpoints of the programmable thermostat (45^{o}F in heating and 95^{o}F in cooling) are somehow reached in Zone 2 during the unoccupied period.

Turning off the HVAC systems for the office areas during unoccupied periods is acceptable since the office areas still receive some conditioning through interaction with the primary zone. This strategy and the perimeter location of the offices causes unoccupied space temperatures in Zones 1 and 3 to exceed those in the setback/setup-controlled Zone 2. However, Zone 2 interacts enough with other zones to minimize the more extreme temperatures that would risk pipe freezing or other problems.

4.2 SCHEDULE AND SETPOINT CHANGES

Business hours at the bank begin at 8 a.m. each weekday and end at 4 p.m. except for Friday when business hours are extended to 6 p.m. To maintain comfortable conditions indoors during nightly cleanup periods, the programmable thermostat is set to maintain occupied temperatures two hours beyond the end of business hours (6 p.m. Monday - Thursday, and 8 .p.m on Friday). Occupied temperature setpoints were not changed from their pre-retrofit values. Unoccupied temperature setpoints were changed to allow setback/setup in Zone 2. Occupied temperature setpoints were occasionally changed by occupants both during the pre-retrofit and post-retrofit periods. Occupancy and temperature setpoints for the post-retrofit period are summarized in Tables 4.1 and 4.2.

Table 4.1. Post-retrofit programmed occupancy setpoints.

	Day of the Week						
	M	T	W	T	F	S	S
Occupied start time (a.m.):	8	8	8	8	8	-	-
Unoccupied start time (p.m.):	6	6	6	6	8	C*	C

* C - continuous

Table 4.2. Post-retrofit programmed temperature setpoints.

	Zones 1,2,3 occupied	Zone 2 unoccupied	Zone 1,3 unoccupied
Heating setpoint (^oF):	68	55	none
Cooling setpoint (^oF):	74	90	none

5. RESULTS

Energy savings resulted from changes made to the HVAC control schemes in each of the three building zones. Previously, all systems operated at normal setpoints continuously (168 h/wk). In the larger Zone 2, the implementation of thermostat setback/setup resulted in the primary system operating at normal setpoints for only 52 h/wk and at setback/setup temperatures 116 h/wk. The shutdown of the two smaller units during unoccupied periods resulted in operation of these units at normal setpoints only 52 h/wk and complete shutdown during the remaining 116 h/wk. The resulting operational changes for the three zones are summarized in Table 5.1.

5.1 HEATING ENERGY SAVINGS

The control changes had a major impact on the amount of gas required for winter heating. The impact to billed gas use is clearly visible in Fig. 5.1. As a rough approximation, if the average gas use rate from these billing data profiles is used to project savings, the retrofit reduced gas use by 37%.

Linear models (daily space heating gas use as a function of average outdoor temperature) were used to examine changes in energy use patterns and to provide more accurate estimates of the energy savings achieved. The actual data were well represented by the models since all model correlation coefficients (R) were above 0.92 except for the post-retrofit weekend model (0.71). The heating models, model coefficients, and related parameters are summarized in Appendix A. The models, shown in Figs. 5.2 and 5.3, were generated from submetered daily space heating gas use totals and daily average outdoor temperature data. They illustrate the varying impacts of the new control strategy on weekday and weekend gas use.

The differing rates of gas use for pre-retrofit weekdays and weekends occur because of higher internal heat generation (heat added

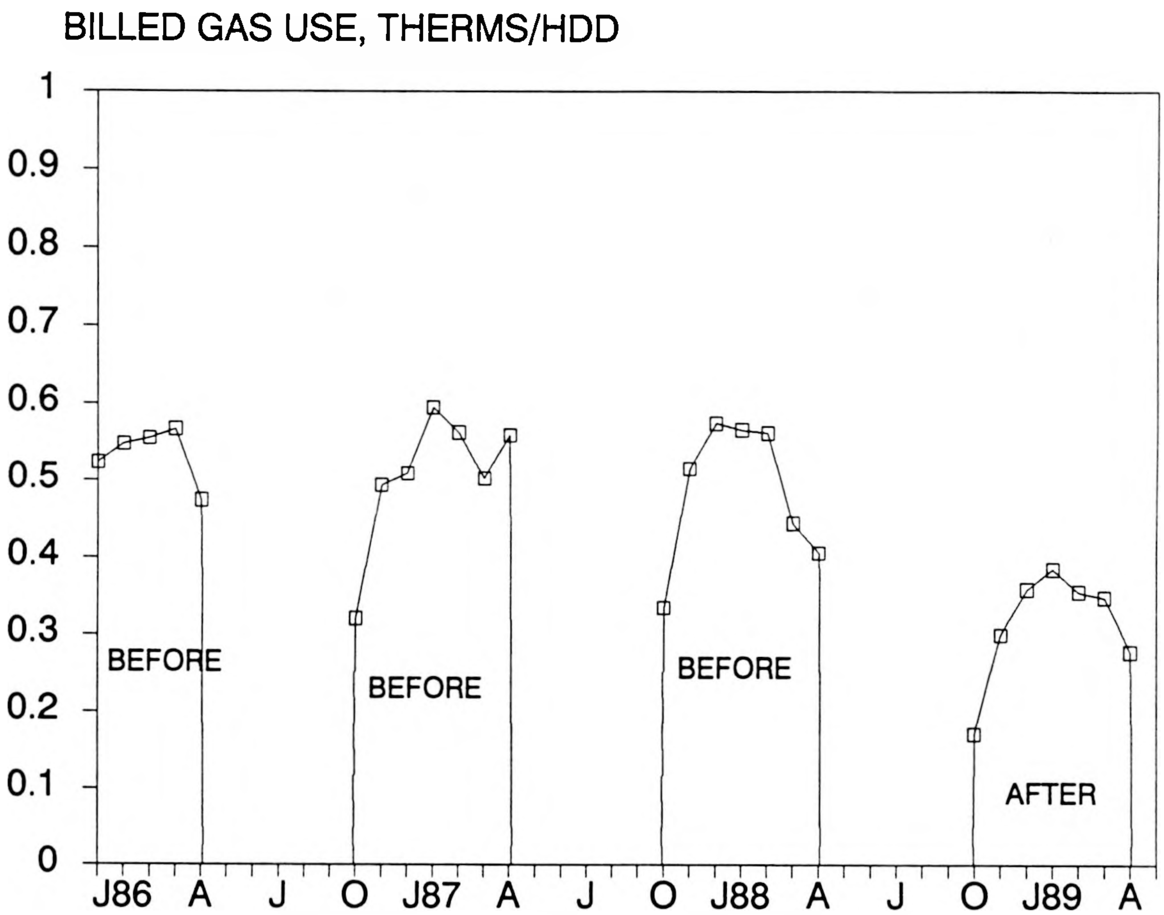

Figure 5.1. Billed gas use per billing period heating degree day, HDD, for pre-retrofit and post-retrofit winters.

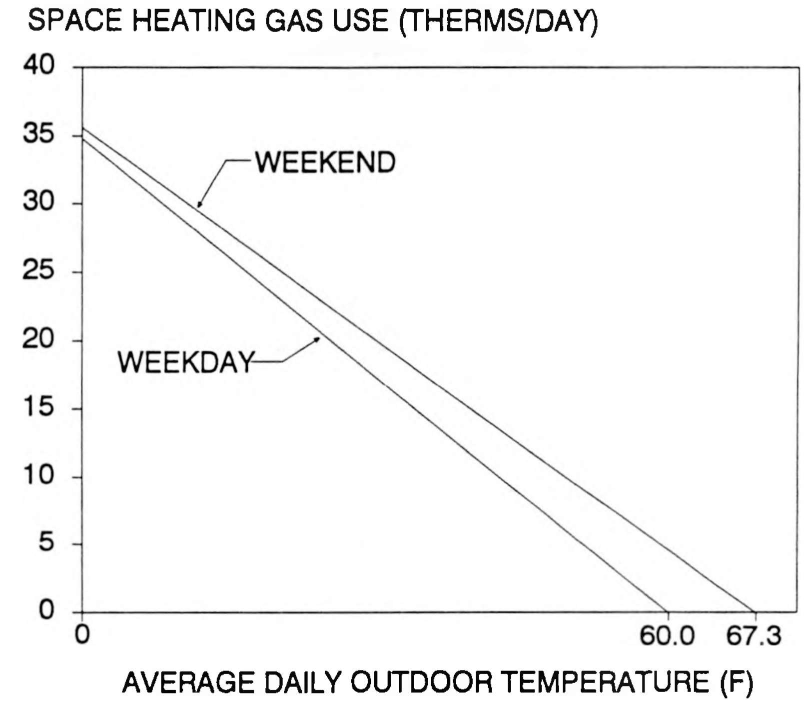

Figure 5.2. Pre-retrofit gas consumption models.

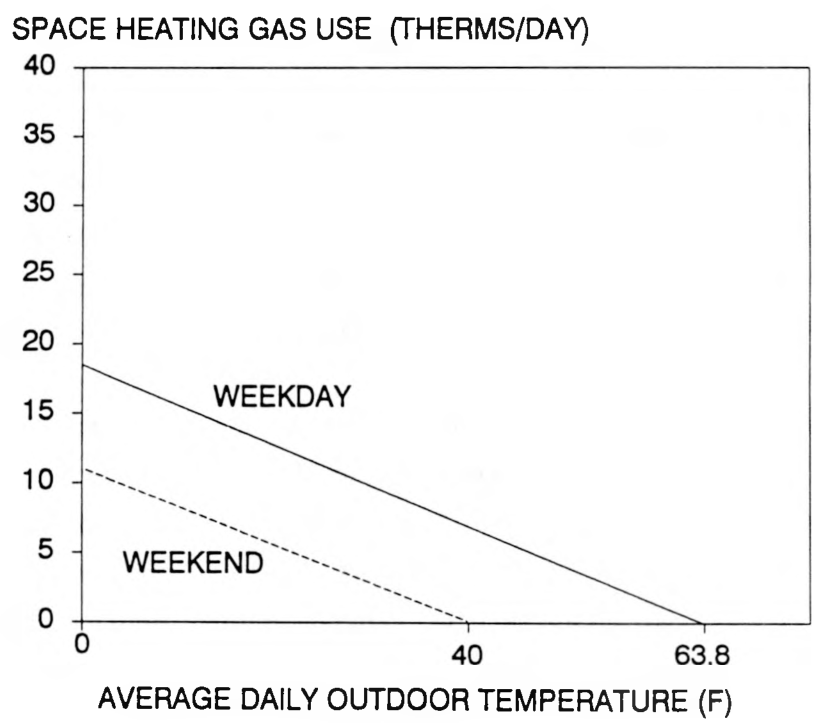

Figure 5.3. Post-retrofit gas consumption models.

Table 5.1. **Weekly HVAC operational hours: before and after retrofit.**

Units	Weekly Operational Status
1 & 3 -	Before: 100% Normal On
	After : 30% Normal On & 70% Off
2 -	Before: 100% Normal On
	After : 30% Normal On & 70% Setback/Setup On

to interior spaces from lights, equipment, and people in this case) during occupied periods. This increased internal load reduces weekday gas heating needs approximately 4 therms/d (100 Btu/sq ft/d) below weekend requirements at all outdoor temperatures.

Similar post-retrofit models are shown in Fig. 5.3. Comparisons of Figs. 5.2 and 5.3 show that the weekday space heating gas use rate has been reduced approximately 50% and that the weekend rate during moderate winter temperatures (40°F and above) was reduced to zero (the model slope in Table A.1 is near zero, indicating almost no dependence between space heating gas use and outdoor temperatures above 40°F). A lack of data on lower-temperature weekends required the post-retrofit weekend model to only represent weekends with average daily temperatures above 40°F. At some average outdoor temperature, around 40°F or lower, the post-retrofit weekend model will experience a slope similar to the weekday model when outdoor temperatures plunge low enough that gas heating is required to maintain the indoor setback temperature. To approximate this gas use, the slope of the post-retrofit weekday model was used to represent the slope of the needed temperature-dependent portion of the post-retrofit weekend model for 40°F and below (the dashed line in Fig. 5.3). This resulted in a slightly conservative estimate of weekend energy savings since the slope of the temperature-dependent portion of the weekend model will likely be less than that of the weekday model due to the more extreme weekend operating strategy. Error in this approximation should have little impact on estimated energy savings. This results since the post-retrofit weekend temperature-dependent gas use (since it occurs only on weekends and at daily average temperatures below 40°F) is only a small part of the total post-retrofit gas use.

The linear models shown in Figs. 5.2 and 5.3 were evaluated with 1988/89 winter temperature data (to normalize for outdoor temperature variations) to estimate the normalized space heating gas use for the winter of 1988/89 with and without the retrofit. The estimates indicated that major heating energy savings were achieved during both weekdays and weekends. Space heating energy needs have been reduced by approximately 33% ($500 in 1988/89) and savings are approximately equally split between weekday and weekends.[c]

The hourly impacts of the new control strategy are visible in the two months of data shown in Fig. 5.4. The profile peaks during February (days 32 through 60) typically occur during all hours of the day. In contrast, the new control strategy resulted in peaks being essentially restricted to only occupied periods during March (days 62 through 88). The decrease in profile peaks during business hours when moving from February to March is predominantly due to milder temperatures in March. However, the near elimination of peaks during non-business hours is almost entirely attributable to the new control strategy.

5.2 COOLING ENERGY SAVINGS

The control changes also had a major impact on cooling energy use but the resulting savings are not that evident from billing data. Since building cooling is electric-driven, cooling electricity use is embedded in electric billing data along with baseload electric use, which includes lighting, water heating, refrigeration, and other electric loads, which are normally independent of outdoor

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[c]The 33% heating energy savings is based on gas savings alone and does not include the electric energy savings resulting from the reduced run times of the air distribution fans.

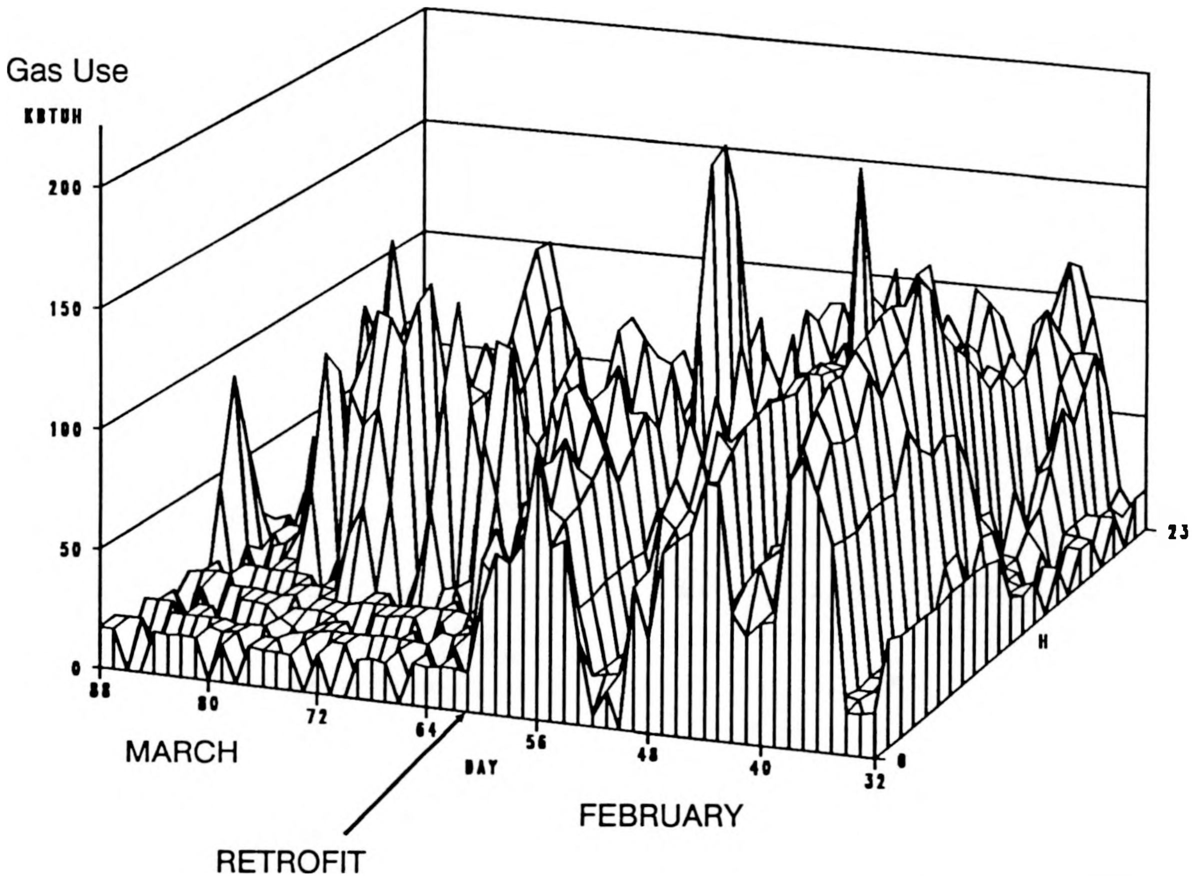

Figure 5.4. Hourly gas consumption profile one month before and after retrofit, 1988.

temperature except perhaps for water heating. As a result, the reduction in cooling energy use is difficult to discern using billing data in the form presented in Fig. 5.5. Even when baseload electric energy is subtracted out, billing data do not clearly show the cooling energy savings.

Cooling energy models, model coefficients, and related parameters were generated from submetered daily air conditioning energy use data and are summarized in Appendix A. The models, shown in Figs. 5.6 and 5.7, illustrate the varying impacts of the new control strategy on weekday and weekend air-conditioning (AC) energy use. The higher rate of AC energy use in Fig. 5.6 for pre-retrofit weekdays, as compared to weekends, occurs because of more internal heat generation during occupied periods. More cooling is needed during weekdays to remove heat generated by people, lights, and other sources. The increased internal load during weekdays increases AC energy needs by approximately 32 kWh/d (0.33 w/sq ft). The post-retrofit models (Fig. 5.7) show the change in AC energy use due to the new control strategy. Comparison of Figs. 5.6 and 5.7 indicates that weekday energy savings were small while weekend energy savings were substantial. Thermostat set-up turned the HVAC systems on over the weekends at an average daily outdoor temperature that was approximately 10^{o}F higher than its pre-retrofit value (70^{o}F vs. 60^{o}F).

The linear models shown in Figs. 5.6 and 5.7 were used with summer 1988 temperature data to predict normalized cooling energy use for the summer of 1988 with and without the retrofit. The results indicated that cooling energy needs have been reduced by approximately 21% ($300 in 1988) and that most of the cooling energy savings occur on weekends.

The hourly impacts of the new control strategy on summer cooling energy use can be seen in the comparison of Figs. 5.8 and 5.9. Most cooling energy savings are attributable to the near elimination of cooling energy use during weekends (shown by the clearer distinction between the weekday spikes of the 1988 summer data, Fig. 5.9, as

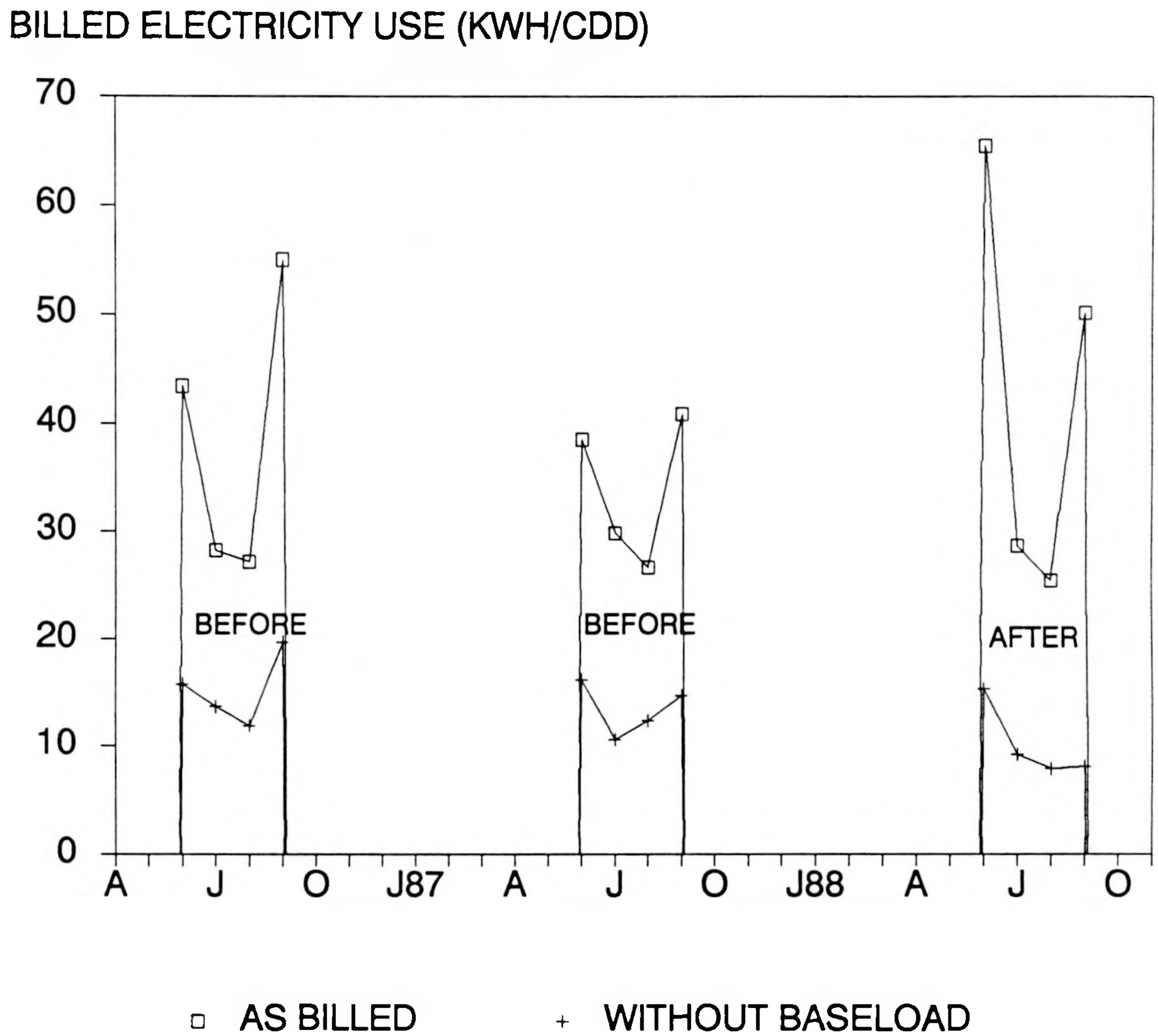

Figure 5.5. Billed electricity use per billing period cooling degree day, CDD, for pre-retrofit and post-retrofit summers.

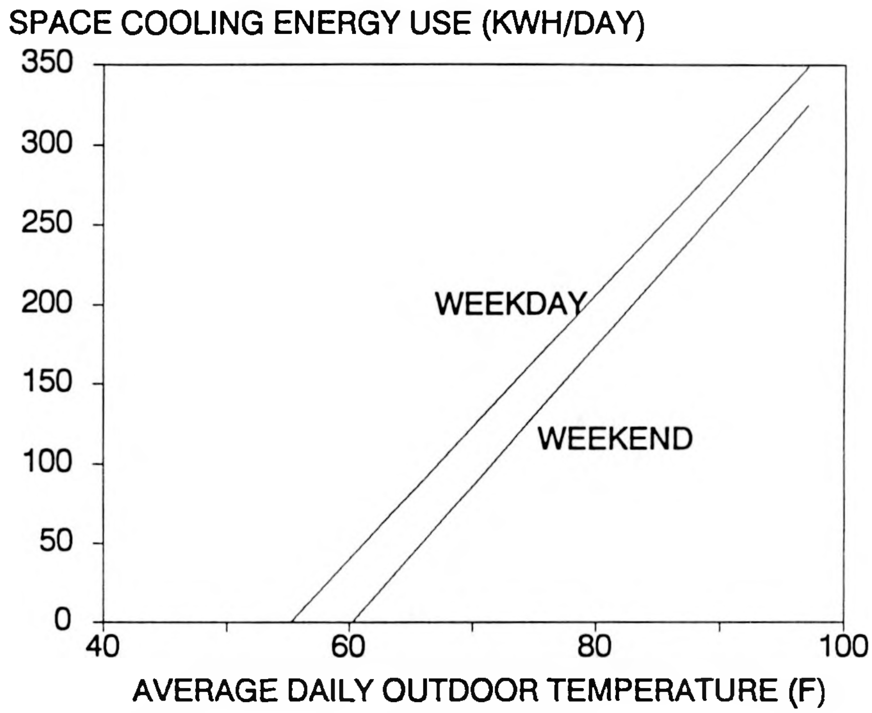

Figure 5.6. Pre-retrofit air conditioning models.

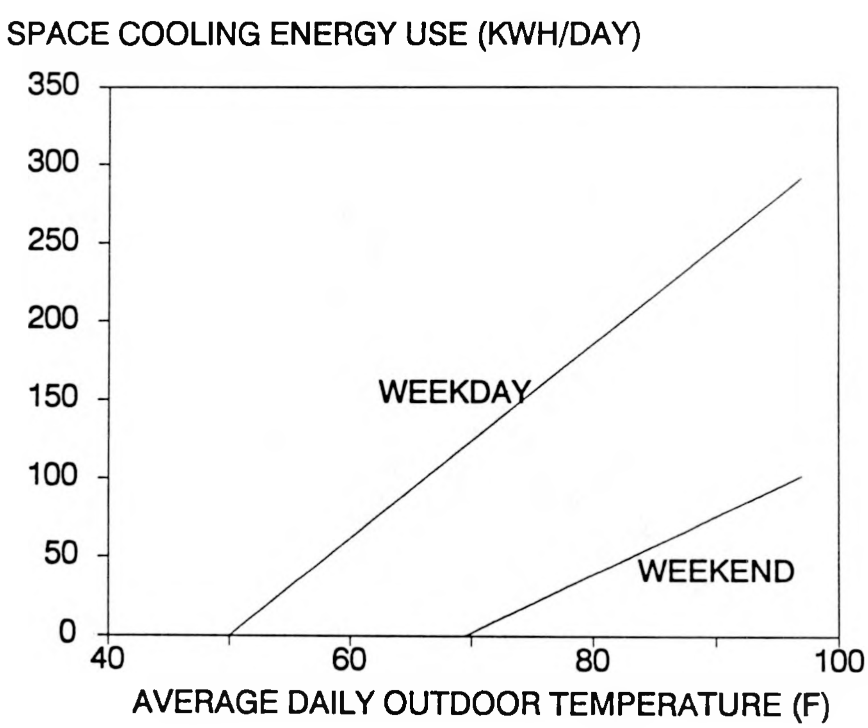

Figure 5.7. Post-retrofit air conditioning models.

Electricity Use

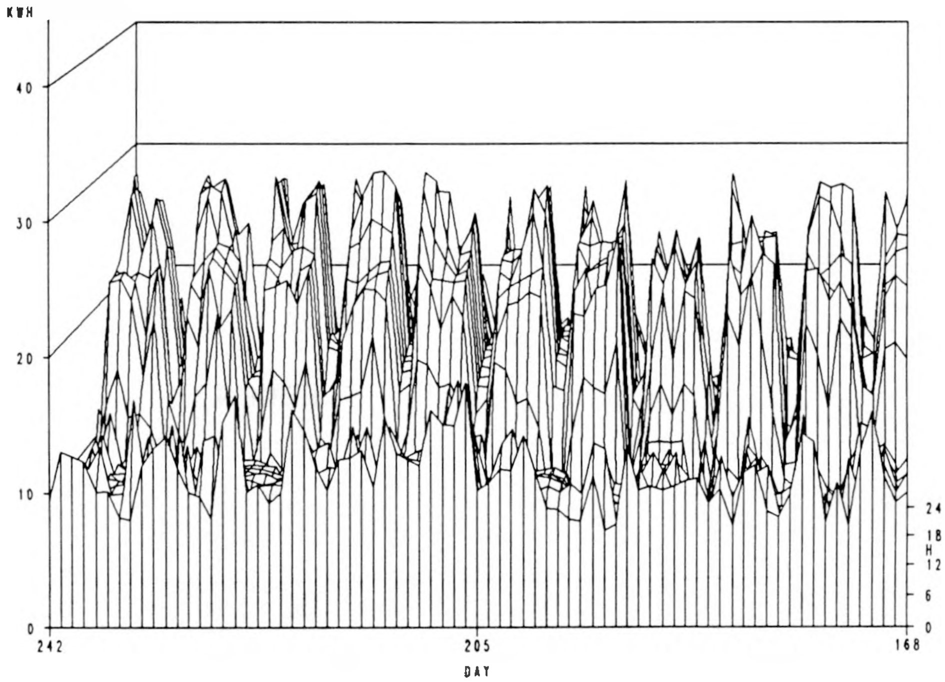

Figure 5.8. Hourly total electricity use profile for the pre-retrofit summer, 1987.

Electricity Use

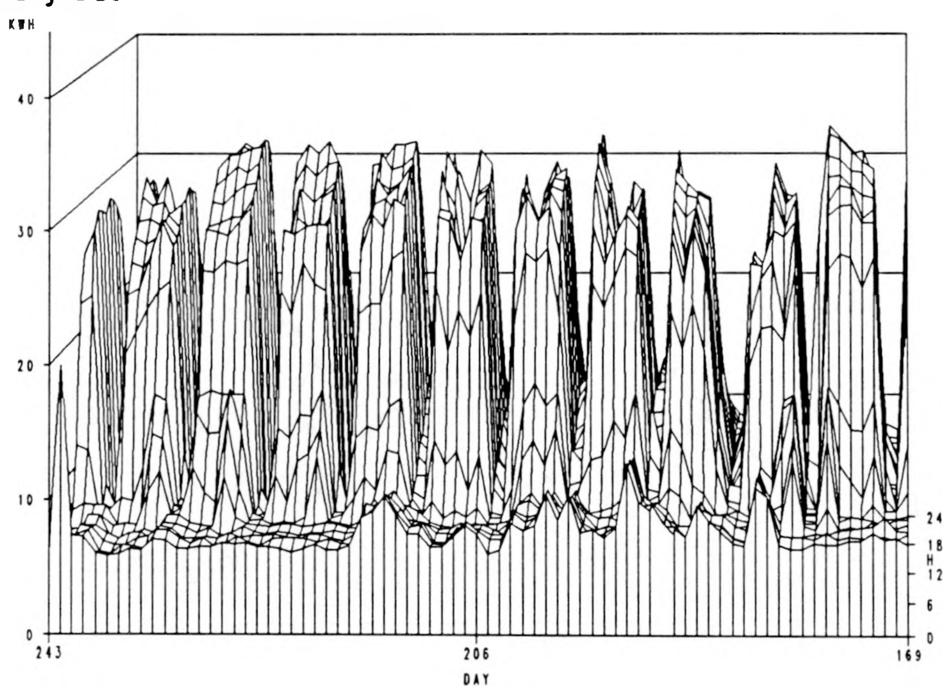

Figure 5.9. Hourly total electricity use profile for the post-retrofit summer, 1988.

compared to the 1987 data, Fig. 5.8, where valleys in the profile are less deep, indicating higher weekend energy use). Some of the cooling energy savings are also attributable to the near elimination of energy use spikes during unoccupied weekday hours (visible from the comparison of the foregrounds of the two figures). Another noticeable difference between the two profiles is that weekday business hour peaks were higher in 1988. This difference resulted from an increase in baseload electric use in 1988, of which part was due to the replacement of non-working incandescent floodlamps. This baseload electric increase was accounted for when comparing before and after electric energy use to determine actual cooling energy savings.

5.3 IMPACTS TO LOAD PROFILES

The setback/setup and on/off control scheme altered the daily electric demand profiles for the building, as shown in the comparisons of similar days in Figs. 5.10 and 5.11. The "smart-start" feature of the thermostat caused the building to begin recovery before the occupied period begins. Recovery causes a higher morning demand than normal and therefore causes the visual time-of-day shift between the before and after daily demand profiles in Fig. 5.10. The "smart-start" feature provides gradual recovery and therefore minimizes the surge in electric demand that would occur if recovery was initiated at the occupied period start when all building lights are switched on. The "smart-start" was not a necessary feature for the thermostat since the electric demand for this building was always far below 50 kW, the level at which the local utility begins to assess electric demand charges. If this building were larger and the new control strategy happened to increase electric demand charges, the increased costs would offset some of the dollars saved through energy savings.

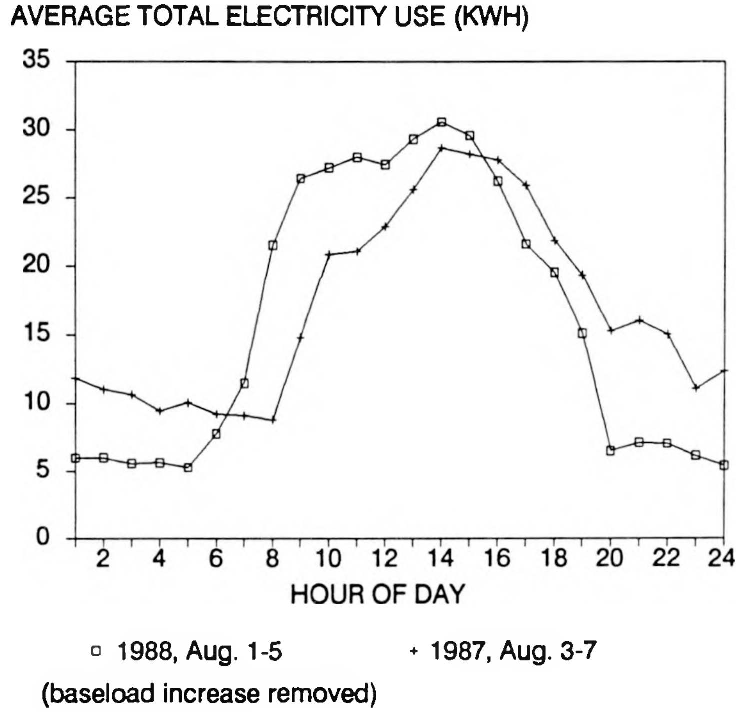

Figure 5.10. Average electricity energy use profiles before and after thermostat setup for weekdays with peak summer temperatures.

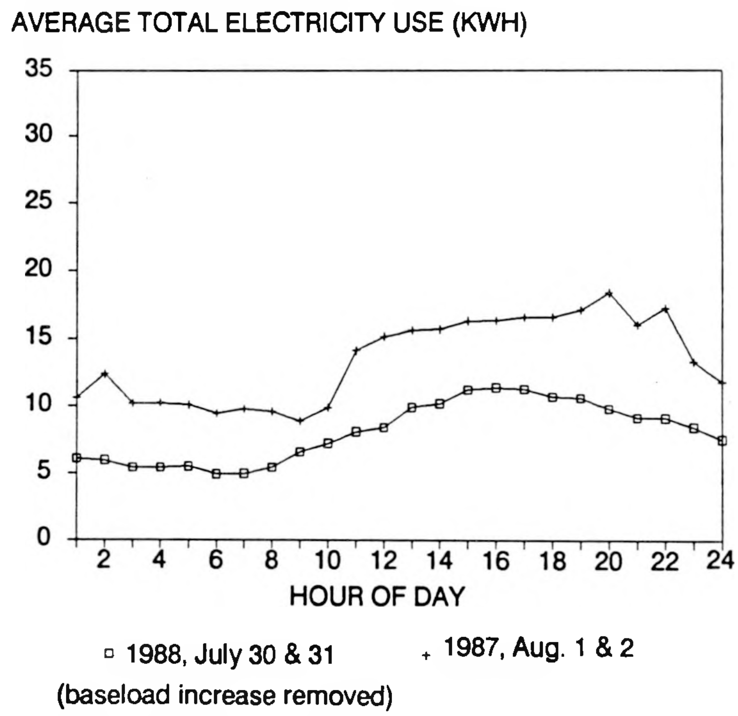

Figure 5.11. Average electricity energy use profiles before and after thermostat setup for weekends with peak summer temperatures.

5.4 COMFORT CHANGES

Building occupants indicated that a noticeable improvement in comfort occurred in Zone 2 after the retrofit was installed. Prior to the retrofit, portable heaters were often used during the winter. The improvement in comfort is likely due to the tighter bands on temperature control that the digital electronic thermostat has compared to the original mechanical thermostat. This reduced the magnitude of ambient temperature swings between the on and off cycles of the Zone 2 unit.

6. CONCLUSIONS

Depending on the level of detail, the measurement of energy performance in commercial buildings can easily become complex. Commercial buildings are often complicated by the use of three-phase power, the existence of numerous electrical circuits, and by multiple heating and cooling systems. Multiple systems may lead to the need for collecting more data, which can complicate data collection and processing. Though relatively small in size, the bank building studied is similar to many commercial buildings in that it has multiple heating and cooling systems that condition different zones of the building. Division of the conditioned zones into office space and open business or other open-area space is also common. As a result, the retrofit strategy implemented is applicable to a large number of small, and medium, and perhaps large commercial buildings.

The changes made to the HVAC control strategy were very effective in reducing energy use and provided an attractive payback of less than one year. Although small savings are achieved during weekdays, weekend non-business days were responsible for most cooling savings. In contrast, heating energy savings were approximately evenly split between weekdays and weekends. This type of retrofit is most effective for commercial buildings having a weekday business schedule where manual or automatic setback/setup is not already providing savings. The dramatic reduction in the annual run times of the two secondary units as a result of the retrofit will pay off in terms of saved energy (avoided energy costs) and perhaps in extending the life of these units.

Unit 2 operates at the occupied setpoint temperature only 30% of the week, whereas before it operated 100%. Unit 2 operates in the setback/setup mode the remaining 70%. Units 1 and 3 are operational only 30% of the week because of being shut down during unoccupied periods. Prior to retrofit, Unit 3 ran excessively during many parts of the year since its thermostat is in the basement where the load is almost continuous because of ground contact with walls and floor. The operational scheme that allows Unit 2 to handle the entire unoccupied building load would have been an even better strategy if Unit 2 had a higher operating efficiency than the two secondary units.

The temperature setback/setup and on/off control strategies as implemented in this building impact building energy use profiles. If a building pays demand charges or at times operates near that point, care should be used in implementing these types of control strategies. Demand costs, if increased, can easily negate much of the costs avoided by reduced energy consumption. The new operating strategy shifted the electric demand profile slightly, but was not a concern since typical building loads were well below the point where the electric utility assessed demand charges (50 kW).

In addition to energy and expense savings, a programmable electronic thermostat can improve comfort by reducing the larger temperature swings that often occur when using mechanical thermostats. These results demonstrate that a building with multiple heating and cooling systems can have controls upgraded to improve energy efficiency both economically and effectively.

Upgrading controls in commercial buildings having multiple heating and cooling systems does not necessarily require the replacement of all existing controls or the installation of costly energy management control systems. The new operating strategy here required replacement of only one of the three existing thermostats. Thus, the upgrade was done with little impact on existing system controls. Simple, low-cost control changes and modified control strategies can be implemented affordably and can provide substantial energy use and cost reductions for small commercial buildings.

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APPENDIX

Heating and Cooling Energy Models

Table A.1. Space heating energy regression modeling results.

*Model: Daily Space Heating Gas Use = m x T_{avg} + b

	R	n (days)	m (therms/d/°F)	Std. Error	b (therms/d)	Std. Error	Balance Point Temp.** (°F)
Before							
Weekdays	0.93	16	-0.572	(0.062)	34.4	(2.7)	60.0
Weekends	0.95	6	-0.530	(0.086)	35.7	(2.9)	67.3
After							
Weekdays	0.93	20	-0.293	(0.028)	18.7	(1.4)	63.8
Weekends***	0.71	8	-0.018	(0.007)	0.9	(0.4)	49.7

*Models based on data recorded between February 1 and March 28, 1988. A baseload (temperature-independent) gas use equal to 2.55 therms/d was used to maintain boiler water temperature. This gas use did not contribute to space heating and is therefore not reflected in the models.
**Balance point temperature = -(b/m).
***This model represents data recorded at winter daily average temperatures of 40°F and above. Since the slope, m, is approximately zero, it essentially represents temperature-independent gas use, i.e., baseload.

Table A.2. Cooling energy regression modeling results.

*Model: Daily Cooling Energy Use = m x T_{avg} + b

	R	n (days)	m (therms/d/°F)	Std. Error	b (therms/d)	Std. Error	Balance Point Temp.** (°F)
Before							
Weekdays	0.90	76	8.36	(0.47)	-462	(35)	55.3
Weekends	0.91	30	8.84	(0.75)	-533	(56)	60.3
After							
Weekdays	0.95	30	6.20	(0.40)	-310	(29)	50.0
Weekends***	0.61	33	3.70	(0.86)	-257	(64)	69.5

*Models based on data recorded between May and September of each year.
**Balance point temperature = -(b/m).
***Model based on total electric energy measurements due to lack of submetered cooling energy data at extreme summer temperatures (daily cooling energy use = daily total electric energy use - daily electric baseload).

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