CONF-8905123--1

LOAD IMPACTS OF ENERGY MANAGEMENT HARDWARE*

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DE89 010843

CONF-8905123--1

April 1989

to be presented at the

End Use Load Information and Application Conference
for Customer and Utility Communication

sponsored by

The Fleming Group

Syracuse, New York
May 16 and 17, 1989

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*Research sponsored by the Office of Buildings and Community Systems, U.S. Department of Energy, under Contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

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LOAD IMPACTS OF ENERGY MANAGEMENT HARDWARE

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ABSTRACT

The impacts that energy management systems and control strategies have on energy loads are important to both the consumer and supplier. This paper summarizes the cooling energy use and demand profile changes for a small commercial bank building in which on/off control and temperature setup/setback have been implemented via an energy management strategy centered around a programmable thermostat. The building consists primarily of office and open business areas and has approximately 4,000 sq ft of conditioned space. Space conditioning is accomplished by three split-package air conditioners and one central gas-fired hot water boiler. Occupied lighting levels average 2 W/sq ft.

The new control strategy provides an approximate 20% reduction in annual cooling energy use. Although cooling energy use has been reduced during nighttime unoccupied periods, the overall energy savings during weekdays is minimal. Cooling energy savings occur primarily during weekend periods. Nighttime thermostat setup has essentially shifted weekday energy use profiles and causes more intense energy demands during early morning hours. Monitored performance shows that the building is now using considerably less energy but still reaches approximately the same peak demand levels.

Energy management hardware is becoming more and more common in both large and small commercial buildings. In addition, wide area energy management services are now developing to provide economical energy management capabilities to many of the smaller businesses who previously found these systems impractical. Based on the findings of this work, assessment of the impacts of large-scale energy management services on both customer and utility loads may be needed. In the future, utilities may have to provide a reduced amount of energy while still required to satisfy peak energy demands at or above current levels.

INTRODUCTION

Energy management hardware or systems (EMS) are recognized technologies for demand side management (EPRI, 1987) and are most often used to control both energy consumption and electric demand (to reduce costs).. An EMS can also lead to improved overall control of a building or group of buildings by providing operator feedback on the status of systems and comfort conditions. A building simulation study of the cost effectiveness of energy conservation measures in four prototype small commercial buildings indicated that simple temperature setback/setup control had simple paybacks ranging from 0.3–2.1 years (Kedl and Stovall, 1985). The four buildings were studied for several locations and for electric rate schedules that both did and did not include electric demand charges

Hourly data on energy consumption, including end use breakdowns, of a small commercial (banking services) building in Knoxville, Tenn., were collected before and after the installation of a "smart thermostat." This thermostat is one type of EMS that controls energy consumption but not electric demand. A survey of EMS equipment in North Carolina indicated that about one-third of EMS installations are small and have ten or fewer control points, with many of these smaller systems being "merely programmable thermostats" (Buchanan et al, 1989). Programmable thermostats represent an important fraction of EMS hardware in smaller buildings. Analysis results of the major impacts of this type of EMS on the electrical energy and power use in the bank building are presented in this paper. Based on experience with this building, discussion is presented on the need for careful consideration of data requirements and analysis approaches for evaluating end use electrical loads and of the need for utilities to consider assessing the impacts of large scale EMS.

This measurement and analysis project was conducted to:

- Aid in the development of requirements for a monitoring protocol on commercial energy efficiency improvement projects (MacDonald et al, 1989)

- Support exploration of advanced methods for analyzing the performance of energy efficiency improvements in commercial buildings (MacDonald and Wasserman, 1989)
- Study field methods for use in commercial field monitoring projects

The data obtained for the project also have other potential uses, including examining electric hourly load impacts from energy management hardware. This paper presents results from an analysis of the change in energy use, hourly load profiles, and seasonal load factor for the building for the summer of 1987 and the summer of 1988. Control of building heating and cooling by the EMS was activated March 2, 1988.

DESCRIPTIONS

The Building

The building being monitored houses a branch office of a commercial banking business. The building has one story at ground level with a below-ground basement. All business services are conducted on the ground level, which is divided into three distinct sections (Fig. 1). Zones 1 and 3 consist of 2 office spaces each and Zone 2 is open business space. Zoning for basement areas is also shown in Fig. 1. The basement area is used for bathroom facilities, an employee lounge, and a large mechanical room. All spaces are conditioned except for the downstairs mechanical room.

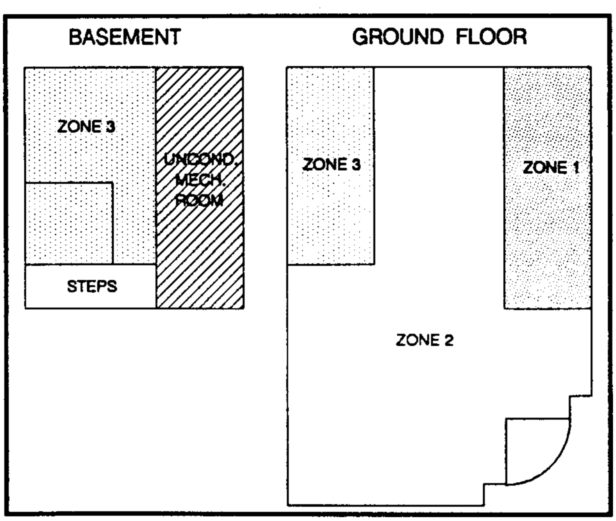

Fig. 1 – HVAC zones for the bank building.

The ground level of the building covers 3,175 sq ft (79% of the total conditioned floor area). Walls are typical 6-inch frame construction with exterior brick and have 333 sq ft of fixed-panel glass. Unshaded, southern-exposed glass area is 57 sq ft, and all windows are located in the south offices (Zone 3 of the ground floor, Fig. 1). One double-door on the ground level is the main entry to the building and is the only entry that has significant use. The partial basement covers 1,569 sq ft. The basement has 850 sq ft of 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.

Business is conducted at the site only on weekdays for a total of 42 hours per week. Clean-up occurs nightly and adds an additional two hours per day to the operational schedule beyond business hours. The regular employee occupancy is twelve people during all business hours. The number of customers who conduct business inside the bank averages 250-350 per day. Daily clean-up usually involves a single occupant.

Electrical service to the building is 120/208 V, 3-phase, 300 amp per phase service fed from a pad-mounted transformer located on-site. Three separate air handling units (AHUs) provide distribution of air for heating and cooling to the three zones (Fig. 1), and the maximum power for the AHUs is 1.8 kW. Cooling for the three zones is provided by three separate cooling units, and the range of power for these units is 13–17 kW during the middle of the day in the cooling season. Heating for the three zones is provided by a single gas-fired boiler which circulates hot water to heating coils at each AHU. Domestic hot water for the building is provided by an electric water heater. Lighting is dominated by ceiling-mounted, recessed, incandescent lighting fixtures using 75 and 150 watt flood lamps. The lighting power for the building during business hours ranges from 8–12 kW, and about 70% of this amount is incandescent. During non-business hours, the approximate lighting power was 3–4 kW in 1987 (including outdoor lighting) and is essentially all incandescent. In 1988 the lighting during non-business hours increased to about 5 kW during part of the year.

Heating and cooling systems are controlled by typical single-stage thermostats with manual fan control capabilities. No nighttime setback or setup of thermostats is practiced. 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.

The Data

Hourly electricity and gas consumption and hourly outdoor temperatures are available for this building for the period of June 17, 1987 to August 30, 1988. Approximately 93% of submetered total energy data and 85% of end-use data are available for this period. Hourly end use consumption data are available for 38 channels of data, which have been aggregated to heating, cooling, fan, lighting, water heating, and miscellaneous end use totals. Hourly run times are also available for these data channels. Hourly outdoor temperature data were also collected at the site.

The EMS

The EMS (programmable thermostat) provides start/stop and temperature setback/setup control for a seven-day schedule. The EMS has been configured to control the primary HVAC unit in the building (Zone 2) by means of temperature setback and setup. The two secondary systems (Zones 1 and 3) are shut off during unoccupied periods by the EMS through relays.

Although a full discussion cannot be presented here, there were important problems encountered with installation of the EMS. As initially designed, the control strategy did not operate as intended. Additional work with the installing contractor was required to insure that the desired control strategy was achieved. Occupant "adjustment" of the EMS temperature setpoint occurred, but the data do not indicate these changes had much effect on the EMS impacts.

EMS IMPACTS

The programmable thermostat substantially reduced energy use from that using a standard mechanical thermostat. The analysis of savings indicates a 21% reduction in cooling energy use (including air conditioning and fan energy) for 1988 compared to 1987. The major savings occur for weekend (unoccupied) days, while savings during week days (occupied days) are small.

The weekly load factors (based on weekly consumption and peak demand) for the cooling season averaged 0.51 in 1987 and 0.45 in 1988. The reduction is primarily due to less energy use and not increased demand. Some of the change in load factor occurred due to weekday effects, but weekends accounted for most of the reduction.

Energy Savings. Energy savings were determined using regressions of daily weekend and weekday energy use on average daily outdoor temperature for 1987 and 1988. Regressions were performed both with total (all end uses) daily electric energy and submetered cooling and fan energy as the dependent variables. For the total electric energy regressions, an estimate of temperature independent energy use, baseload, must be subtracted from total energy to estimate the temperature dependent cooling energy use. For this analysis, baseload was determined from submetered end use data due to the difficulty in obtaining accurate estimates using total energy data. As shown in Figure 2, identifying the apparent baseload based on total energy data alone may lead to significant error. Baseload errors can easily overwhelm temperature dependent energy use savings estimates since baseload energy use occurs every day and can also be a large part of total energy use for a building.

The results of the total energy regressions and base load values are presented in Table 1. Submetered cooling energy results are presented in Table 2. The most

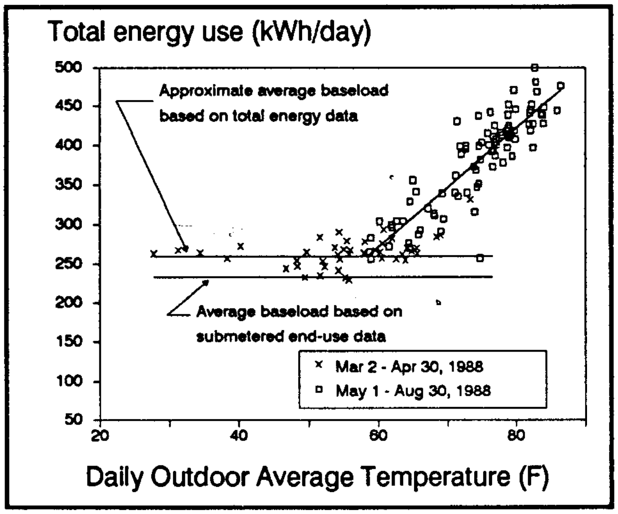

Fig. 2—Comparison of the average baseload from submetered end use data to the approximate average baseload from total energy data for weekdays, 1988.

Table 1. Total Energy Regression Modeling Results

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

	R^2	n (days)	m (kWh/day/°F)	Std Error (kWh/day/°F)	b (kWh/day)	Std. Error (kWh/day)	Base-load** (kWh/day)	Balance Point Temp.*** (°F)
1987								
Weekdays	0.68	76	8.26	(0.65)	–258	(49)	196	55.0
Weekends	0.80	30	9.27	(0.87)	–440	(66)	125	60.9
1988								
Weekdays	0.78	79	7.51	(0.46)	–179	(35)	233	54.9
Weekends	0.37	33	3.70	(0.86)	–97	(64)	160	69.5

*Models based on data recorded between May and Sept. of each year.
**Baseload is the average of the difference between total energy and the sum of air conditioning and fan end-use energy for each day.
***Balance point temperature = (–b + baseload) / m

Table 2. Cooling Energy Regression Modeling Results

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

	R^2	n (days)	m (kWh/day/°F)	Std Error (kWh/day/°F)	b (kWh/day)	Std. Error (kWh/day)	Balance Point Temp.** (°F)
1987							
Weekdays	0.81	76	8.36	(0.47)	–462	(35)	55.3
Weekends	0.83	30	8.84	(0.75)	–533	(56)	60.3
1988							
Weekdays	0.90	30	6.20	(0.40)	–310	(29)	50.0
Weekends***	0.37	33	3.70	(0.86)	–257	(64)	69.5

*Models based on data recorded between May and Sept. of each year.
**Balance point temperature = (–b / m)

significant difference between energy use models for before and after is the slope change for weekend energy use. Slope indicates the rate energy is used relative to outdoor temperature and decreased approximately 60% for weekends after implementation of setup control. This reduction is illustrated in Figure 3. A regression of submetered cooling energy on temperature for weekends in 1988 was not performed because there were not enough data points available. This occurred because the EMS eliminated most cooling energy for weekend days in 1988 and some few data points that were available were lost due to equipment problems.

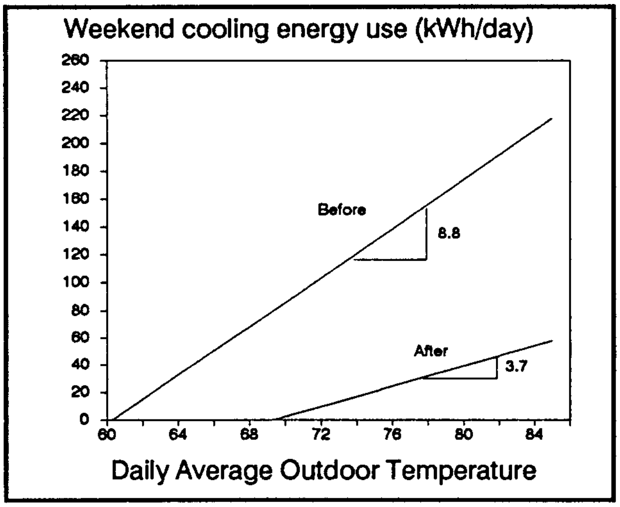

Fig. 3—Impact of thermostat setup on the rate of weekend cooling energy use.

Table 3. Impact on Seasonal Cooling Energy Use

	Seasonal Cooling Energy Use (kWh) (normalized based on 1988 weather) Before	After
Weekdays	18335	18068
Weekends	5587	850
TOTAL	23922	18918
Savings	21%	

Note: Calculations are based on cooling energy regression models. The total energy models give approximately the same results.

The energy savings for the EMS were calculated using the regression models shown in Tables 1 and 2 and daily temperature data for 1988. The results of these calculations are shown in Table 3. The calculations for both the total energy and the submetered cooling energy models indicate a savings in temperature dependent energy use of about 20%. The value for weekend energy consumption in 1988 for the submetered model is assumed to be the same as for the total energy model, which should not have an unreasonable impact on the savings estimate given the low value of this consumption.

Load Profile Changes. Load profiles were examined using 3-D contour plots and 2-D average profile plots of hourly total energy data. The 3-D plots (Figs. 4 and 5) show where most of the energy savings occurred and how the pattern of energy use changed due to the change in control. These changes are most visible in two places. The average hourly energy use during unoccupied hours (foreground in figures) was around 10 kWh in 1987 and was reduced to approximately 7.5 kWh in 1988. The nearly flat contour in 1988 indicates that the nighttime setup on the thermostat almost eliminated the temperature dependent energy use during unoccupied hours. The second visible change to the energy use contour plot is visible during weekend daytime hours. Weekend periods are more distinguished in 1988. During weekend daytime hours, temperature and solar energy dependent cooling energy use is visibly less for 1988.

Although unoccupied period energy use was lower in 1988, daytime energy peaks were generally higher. This difference occurred due to an increase in baseload of almost 2 kW in 1988. Most of the increase in baseload resulted from the replacement of non-working lamps in outdoor fixtures. These particular outdoor lamps are operated 24 hours per day.

The use of setup/setback control also changed the daily energy use profile. Before and after average weekday profiles for weeks with peak summer temperatures (in August) are shown in Figure 6. The 1988 profile is shifted left since air conditioning begins to occur earlier in the day. This shift is caused by the "smart" thermostat, which allows the system to gradually bring the building up to the occupied setpoint temperature, 5 °F per hour in this case. For the peak summer temperature period shown, the profiles indicate that weekday energy savings occur during the unoccupied period but that they are largely offset by higher energy use during morning hours near the occupied start time. Weekend profiles (Fig. 7) portray the major EMS savings indicated by the regressions for weekend temperature setup. Our results indicate that temperature setup for this building may not be needed during occupied weekdays.

THE METERING EXPERIENCE

The results of this project show that submetering of individual end uses within the building was needed to achieve an accurate estimate of baseload energy use.

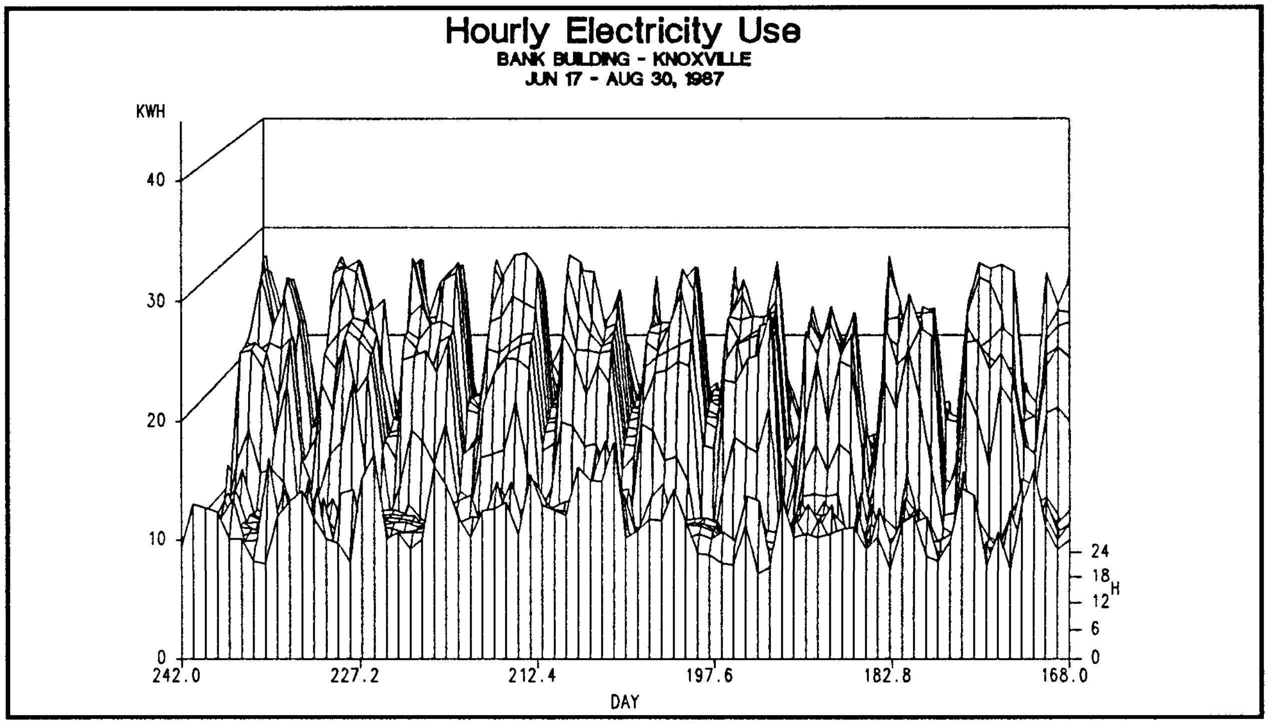

Fig. 4—3-D load contour plot for the bank building electricity use in the summer of 1987.

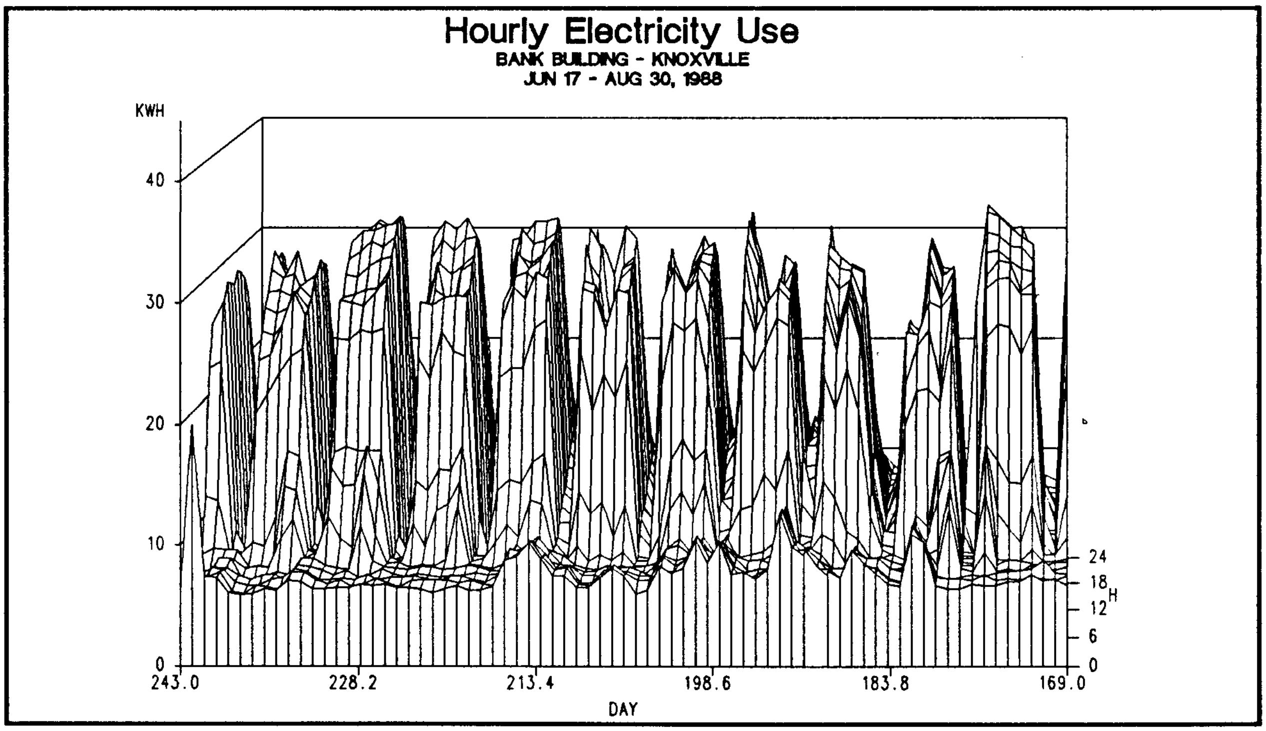

Fig. 5—3-D load contour plot for the bank building electricity use in the summer of 1988.

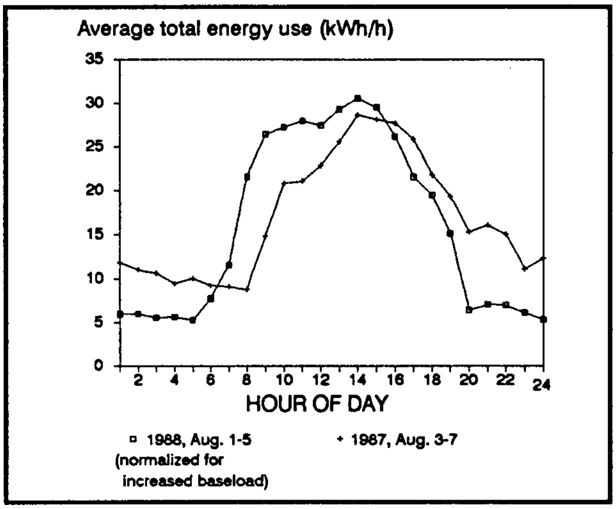

Fig. 6—Average weekday energy use profiles before and after thermostat setup for weeks with peak summer temperatures.

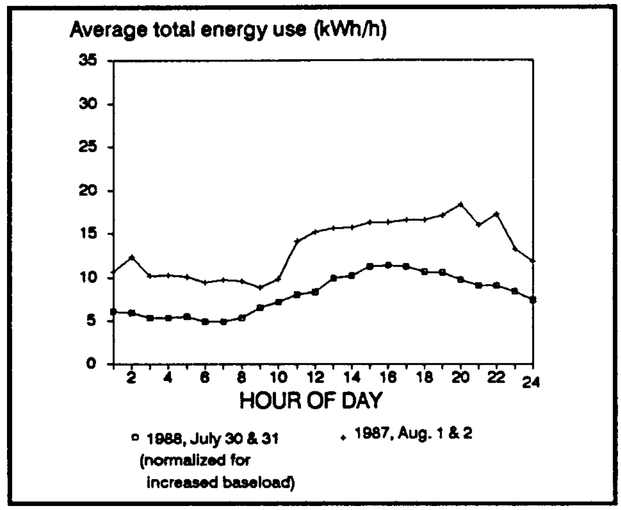

Fig. 7—Average weekend energy use profiles before and after thermostat setup for weekends with peak summer temperatures.

However, air conditioner and fan energy were the end uses requiring measurement, if combined with total energy data. Review of other end use data indicated little or no temperature dependency. As a result, a reduced monitoring effort combining both continuous monitoring of important end uses and short-term monitoring and assessment of less-important end uses could have achieved the same result. Determining metering and analysis needs based on this hierarchical ordering would have reduced the hardware needs and the amount of data collected and processed for this project.

HIERARCHICAL PLANNING

Based on our experience in this commercial building with the measurement of energy and power and subsequent analysis of collected data, we feel the benefits of different types of metered data should be explored. Most importantly, the use of short-term diagnostics data to support or supplant more extensive data collection efforts should be evaluated for any metering project. The use of short-term diagnostics data to direct further collection of more extensive or detailed time series energy use or power data can be considered a phased metering approach with a data hierarchy. To use this approach, planning of projects should address the data hierarchy. We use the term "hierarchical planning" to denote this overall approach. Hierarchical planning of a building energy or power metering project would include development of a diagnostics metering phase (or pilot). The data from the diagnostics phase would be analyzed to support the specification of overall metering and analysis approaches needed to answer the research questions of interest.

For the building presented in this paper, the electric loads that are not temperature dependent could be understood reasonably well by metering total building and HVAC energy uses on some continuous basis and performing diagnostic metering of the lighting, water heating, and miscellaneous (all other) loads. These loads did not exhibit large variations from day to day. Variations which did occur (e.g., an increase in energy use—probably due to portable heaters—was observed during the heating season) were seasonal in nature. The change to a higher base load was also a long term change. Determination of the magnitude and time scale of variations (excursions) of total and end use loads appears to be important information for planning metering projects, and the phased approach allows this determination before the final metering approach is specified.

A more thorough examination of hierarchical planning is needed based on data from many buildings. The benefits and costs of this approach could be compared to other approaches. Further work is needed to explore this concept.

LARGE SCALE EMS AND ELECTRIC UTILITIES

A large scale EMS provides high level EMS control for many buildings over a wide area and has the potential for significant impacts on utilities, cities, and energy services in the near future (MacDonald and Gettings, 1988). If large scale EMS become prevalent over the next decade, utilities may be faced with systems that have control over a significant part of their load (MacDonald and Gettings, 1988). Based on the magnitude of EMS impacts presented in this paper, assessment of the potential effects of large scale EMS on electric utility loads and utility customer energy costs may be needed to determine desirable utility interactions or responses. Early utility involvement in assessing and interacting with proponents of large scale EMS could have important utility benefits by providing load management control options of interest to the utility as part of the EMS services offered. Early involvement could also potentially lead to better relationships or partnerships with outside organizations providing wide scale EMS services. Utilities could also consider providing large scale EMS services themselves. Significant benefits or penalties could accrue to utilities from large scale EMS, and a better understanding of the impacts of EMS on both local and large scales could help in assessing those potential benefits and penalties.

CONCLUSIONS

The programmable thermostat substantially reduced energy use from that using a standard mechanical thermostat. Both building energy use and energy use profiles were affected. Energy use and profile modification due to EMS control will ultimately affect both the customer and the utility. While in general they benefit the customer, impacts to utilities may not always be positive.

EMS Impacts on Customer Energy Costs

Programmable control impacts to the customer primarily depend upon:

1) Customer's energy needs and the size of impacted end-uses,
2) Typical peak energy demands at the building, and
3) Energy and demand cost structures.

In general, programmable control should reduce energy costs for consumers. However, the process of bringing a building to the occupied setpoint after setback/setup could potentially add or increase demand costs at times during the year. Without a smart starting feature, i.e., a controlled-ramp start, the thermostat will likely call for maximum power to the building in the morning. If the building typically operates below the point where demand charges are assessed, setback/setup should provide energy savings to the consumer. Use of setback/setup when the building operates at or above the demand charge limit could result in extra demand charges and may or may not produce an overall savings. Use of the "smart" start will minimize or eliminate the potential demand increase which could reduce the overall benefit of energy savings.

A side benefit of digital programmable control is improved comfort. The digital control provides more accurate control of indoor temperature and thus, reduces the size of temperature swings associated with standard mechanical controls. A disadvantage of programmable control, especially for small businesses, is that someone will need to learn the operation of the control system.

EMS Impacts on Utilities

Two impacts that programmable controls of the type studied in this building will have on utilities are an overall reduction in energy supplied and changes to energy demands. Overall, implementation of programmable controls will usually lead to reduced energy needs by customers. There are periods however when energy needs will be increased, such as morning recovery periods. Depending on the peaking time(s) for the utility, the periodic increases in demand may or may not have a significant effect on the utility's load capacity. Overall, a loss of revenue and reduced load factor will often occur, which is usually an undesirable change.

Based on the potential for large scale EMS to provide EMS services to many buildings in a utility service area over the next decade, utilities should begin assessing potential load impacts of EMS control in large numbers of buildings and the appropriate interactions and responses that may be needed to address potential benefits and problems of large scale EMS control.

Energy Use Modeling

If daily total energy use is used for modeling, occupied and unoccupied days should be modeled separately (MacDonald and Akbari, 1987) due to differences in baseload. Baseload estimates must be accurate to produce acceptable energy use estimates of temperature dependent energy use. Submetered measurements may be required to determine an accurate average baseload. As a result, the minimum monitoring level for a building may be submetered total energy use together with air conditioning and associated fan energy use. Their difference provides a good estimate of baseload. Air conditioning and fan data should be much easier to collect than actual baseload end use data, since they can often be measured at the unit(s). This avoids entering main panel box(es), and there are almost always much fewer AC and fan circuits than baseload circuits, perhaps as little as 1/10 as many. If the required data can be reduced, overall project costs should be less due to simpler instrumentation and fewer data points to analyze and process.

ACKNOWLEDGMENTS

This work was sponsored by the Existing Buildings Efficiency Research program of the Office of Buildings and Community Systems, U.S. Department of Energy, under Department of Energy contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

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