

MEASURED END-USE SAVINGS vs. PREDICTED SAVINGS
OF A COMMERCIAL LIGHTING CONSERVATION RETROFIT

Colleen Cleary, Seattle City Light,
and Marc Schuldt, United Industries Corporation

ABSTRACT

This paper discusses the results of an analysis of a major lighting system modification in an all-electric retail store. Comparisons of the measured hourly end use data obtained in one year before and after the installation provide detailed assessment of the impact of the retrofit on end use energy consumption, annual and seasonal daily load shapes, and annual peak day consumption. Overall, the annual total consumption decreased 32 percent, from 34.3 kWh/ft² to 23.4 kWh/ft². Lighting consumption, the largest annual load, decreased 33 percent from 24.1 kWh/ft² to 16.2 kWh/ft².

The measured energy savings from this retrofit are then compared with the DOE 2.1B simulation results based on actual weather data for end use energy consumption. Actual energy savings were greater than predicted primarily because cooling and heating loads did not change as predicted by the model. The reduction in the cooling load from the pre-retrofit level of 5.9 kWh/ft² to 2.5 kWh/ft² was greater than the level of 3.1 kWh/ft² predicted by the model for the post-retrofit period. The pre-retrofit measured level of the heating load (1.2 kWh/ft²) did not increase to 2.1 kWh/ft² as predicted by the model, but remained at approximately the same level. The implications of using simulation results for utility conservation program planning are discussed.

MEASURED END-USE SAVINGS vs. PREDICTED SAVINGS
OF A COMMERCIAL LIGHTING CONSERVATION RETROFIT

Colleen Cleary, Seattle City Light,
and Marc Schuldt, United Industries Corporation

INTRODUCTION

Seattle City Light is currently conducting a comprehensive research effort to analyze the energy consumption of commercial buildings in its service area. This research effort will provide data on the energy conservation potential in the commercial sector to support conservation program planning and load forecasting efforts in the utility. Eight commercial buildings have been instrumented with microprocessors to continuously monitor electric end use loads on an hourly basis. These buildings include two office buildings, two restaurants, two food stores, and two retail stores.

Hourly electric load data measurements were collected on end uses such as space heating, space cooling, ventilation, internal lighting, external lighting, refrigeration, hot water heating, HVAC auxiliaries, and ancillary electric equipment.

In November 1984, a substantial modification was made to the interior lighting system in one of the monitored retail stores. According to the building owner, the primary reason for the change was to improve the color rendition of the merchandise. This lighting retrofit provided an opportunity to assess the value of end use load data in analyzing conservation potential.

Following a description of the study building, this paper presents the results of an analysis of the lighting system modification by comparing measured hourly end use consumption one year before and one year after the installation. In the next section, the measured energy savings from this retrofit are then compared with energy consumption estimates from the DOE 2.1B simulation model that was developed to predict the energy savings from the retrofit. Implications of the findings for utility conservation program planning are discussed at the end of the paper.

DESCRIPTION OF STUDY BUILDING

The study building for the lighting retrofit analysis is a drug and sundries retail store located in Seattle. It has a total gross floor area of 22,326 ft². The sales area occupies 82 percent of the gross floor area, while the stockroom and office areas comprise 11 percent and 7 percent of the gross floor area, respectively. Electricity is the only energy source for this building.

The store is open for business 77 hours per week. The hours are 9 a.m. to 9 p.m., Monday to Friday, 9 a.m. to 6 p.m. Saturday, and 10 a.m. to 6 p.m. Sunday. These hours did not change in the two-year study period. According

to the building owner, business activity also has remained at the same level in the past two years.

The structure is constructed of concrete block with slab on grade floor and a built-up roof. The roof has 1-5/8 inches of rigid insulation. The walls and floor are uninsulated. The windows and front doors are single-pane, 1/4-inch glass. The glass area is 3.4 percent of the total gross floor area.

The sales and office areas are conditioned by a single zone heating and cooling system (electric resistance heating and direct expansion cooling) with duct work located above the suspended gypsum board ceiling. The space temperature is maintained at 65° F for heating and 68° F for cooling during occupied times. A time clock is used to control the operation of the heating and cooling system. The system has a manually adjusted damper to regulate outside air volume. The storage area is heated by a ceiling hung, electric resistance unit heater. The space temperature of the storage area is maintained at 60° F.

In November 1984, the existing 400-Watt mercury vapor lighting system in the sales area was replaced with ceiling-mounted, two-tube, eight-foot, high-output fluorescent fixtures. The mercury vapor system was designed at 4.2 W/ft² and maintained at approximately 80 footcandles at merchandise level. The new fluorescent system was designed at 3.1 W/ft² to provide approximately the same lighting with 75 percent of the previous lighting power requirements. The sales area peak lighting load measured during the pre-retrofit period was 78 kW. The corresponding capacity measured during the post-retrofit period was 56 kW. The store's lights are manually controlled.

No new major equipment items were installed and there were no changes in maintenance schedules for the building and equipment. The general consistency in this building's operation provides a unique opportunity to evaluate the impact of the lighting retrofit on electrical loads.

ANALYSIS OF THE IMPACT ON MEASURED LOADS

Monthly and Annual Consumption Load Changes

This building consumed 769,121 kWh during the pre-lighting retrofit period (November 1983-October 1984) with an average demand of 154 kW. In the post-retrofit period (November 1984-October 1985), the building consumed 525,693 kWh with an average demand of 141 kW.

The sharp reduction in total building consumption as a result of the lighting retrofit in November 1984 can be seen in Figure 1 from a plot of the building's monthly end use energy consumption over the two-year study period. These monthly aggregations show a reduction in lighting loads all year long and a reduction in the cooling load in the summer months. The building's monthly total load shifted from peaking in the summer to peaking in the winter, but at a lower level of consumption throughout the year.

Not surprisingly, the lighting load accounts for over 70 percent of total annual consumption. The monthly variation in the lighting levels reflect the store's business cycles. Increased activity during the nonbusiness hours for restocking the store's inventory, such as in the Christmas shopping season, results in 10 to 13 percent more lighting consumption during those months.

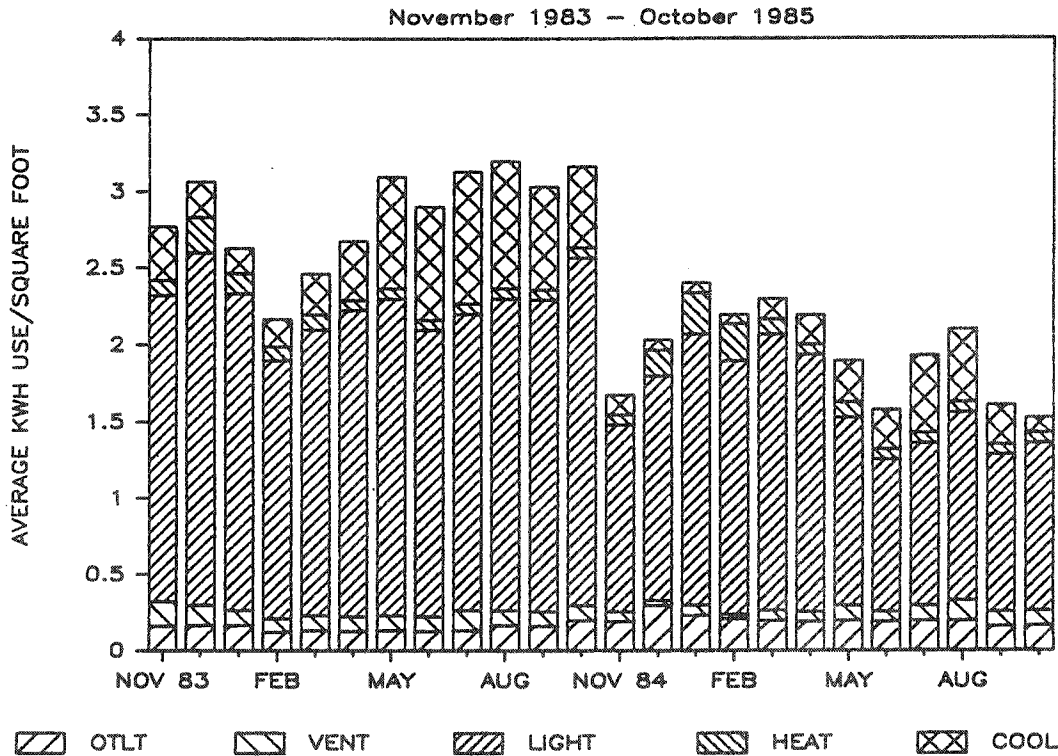


Figure 1. Monthly consumption by end use.

The impact of this retrofit on annual consumption is summarized in Table I. On an annual per-square-foot basis, consumption dropped 11 kWh/ft² (32 percent) from 34.3 kWh/ft² to 23.4 kWh/ft², after the lighting system change.

Table I. Pre- and post-period annual consumption.

	Pre-Period kWh/ft ²	Post-Period kWh/ft ²	Difference kWh/ft ²	%
Lighting	24.1	16.2	-7.9	-33
Cooling	5.9	2.5	-3.4	-42
Heating	1.1	1.3	+ .2	+11
Vent	1.3	1.0	- .3	-24
Other	1.9	2.4	+ .5	+26
Totals	34.3	23.4	-10.9	-32%

As Table I shows, reductions in two loads, lighting and cooling, accounted for the majority of the savings from the retrofit. The 8 kWh/ft² savings in lighting consumption (33 percent reduction) resulted from the combination of decreased power requirements for the new lighting system and reduced usage due to changes in lighting schedules. Some changes in the operation of the lights were related to the lighting system modification. For example, the new fluorescent lights are turned on simultaneously, rather than in stages (one bank of lights at a time) as the mercury vapor lights were operated. Other post-retrofit lighting schedule changes were unrelated to the retrofit, but affected the lighting savings. For example, a new store policy of restocking shelves during business hours resulted in a lower incidence of late night lighting in the post-retrofit period.

The next largest load noted in Table I, cooling, dropped 3 kWh/ft² (42 percent) in annual consumption after the lighting retrofit. Less cooling was required in the post-retrofit period because of the reduced internal lighting loads.

As for the heating load, the small increase in the post-retrofit period was not significant. A finding of no change in the annual heating load was not anticipated because the heating load was expected to increase when the internal lighting load decreased. The balance point of the building calculated from the measured data was 55° F during both the pre-retrofit and post-retrofit periods.

An examination of the heating and cooling degree days (base 65° F) shows that the weather in the pre-retrofit period was not substantially different from the weather in the post-retrofit period. In the post-period where the heating loads did not change, the winter weather was slightly cooler with 5,321 heating degree days compared with 4,916 heating degree days in the pre-period. In the summer post-period where cooling loads decreased, temperatures were somewhat warmer with 204 cooling degree days compared with 118 cooling degree days in the pre-period.

As shown in Table I, the ventilation load decreased a small amount, .3 kWh/ft², due to decreased usage in the post-retrofit period. The outlet load increased slightly, .5 kWh/ft², in the post-retrofit period, probably resulting from the usage of portable heaters in the sales area behind the merchandise counters staffed by store employees and increased usage of the storeroom heater.

Annual and Seasonal Hourly Load Shape Changes

The annual load shape by hour of the day changed noticeably after the new lighting system was installed. Figure 2 shows that the annual weekday total building load profile in the pre-retrofit period was mainly shaped by the lighting load and the late afternoon cooling load. In the post-retrofit period, displayed in Figure 3, the total building load also closely conforms to the shape of the lighting load, with some influence of heating in the early morning and cooling in the afternoon business hours. By comparing

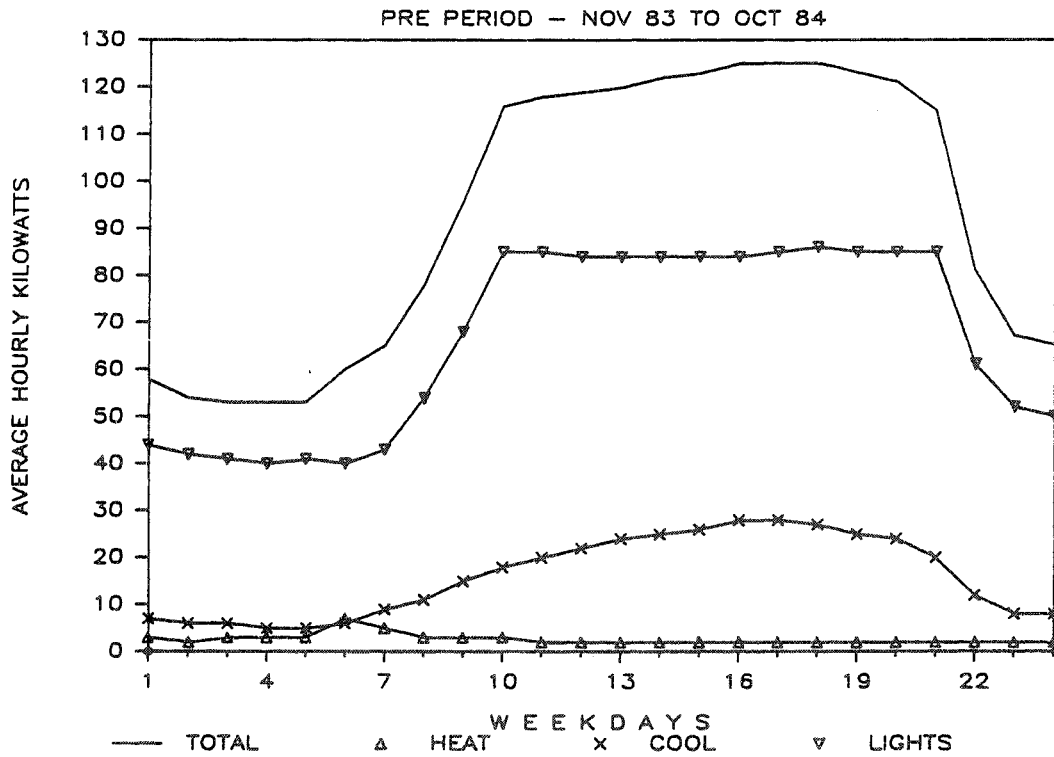


Figure 2. Annual average hourly load shapes in the pre period.

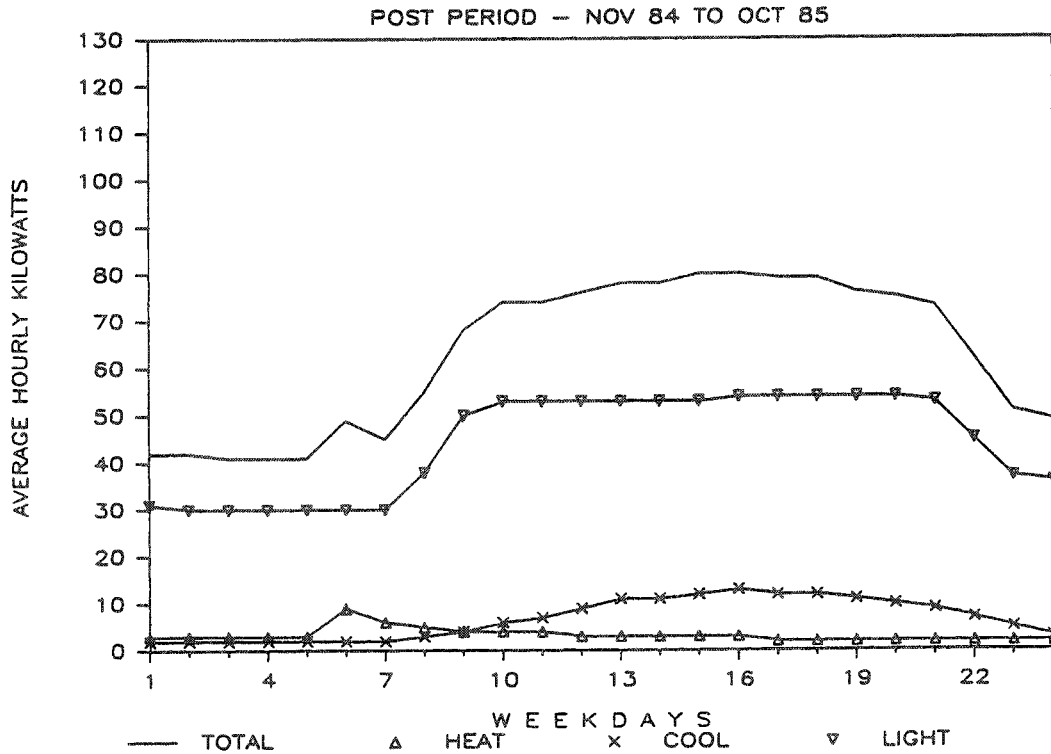


Figure 3. Annual average hourly load shapes in the post period.

these total building load profiles in Figures 2 and 3, the building's total annual consumption dropped by 36 percent during the building's business hours and 23 percent during the building's evening hours.

The early morning heating spike was not reflected in the total building load shape in the pre-retrofit period because of the morning schedule for lighting and the resulting immediate rise in the cooling load. According to the building manager, the old lighting system heated up the building very quickly. In the post-retrofit period, the one hour shift in the morning lighting schedule is reflected, along with a later rise in cooling load under the new lighting system.

In the summer months (June, July, and August), the building load profiles for the pre-retrofit and post-retrofit weekdays resembled the same reduction pattern observed in the annual load profiles. Not surprisingly, the building's summer total load pattern was chiefly shaped by the combination of lighting and cooling loads in both the pre-retrofit and post-retrofit period.

However, the lighting retrofit had a considerable effect on the winter (December, January, and February) daily load profiles, as shown in Figures 4 and 5. In the pre-retrofit period, the daily winter weekday total load shape closely corresponded to the lighting load, with heating in the early mornings and some cooling in the afternoons. In the post-retrofit period, the building no longer had an afternoon cooling load on winter weekdays. Also, the heating spike in the morning hours was slightly higher in the post-retrofit period at about 6 a.m., the time when the temperature setback controls were no longer in effect and the lights were generally off. This difference between the pre-retrofit and post-retrofit periods was not attributable to the lighting system change, but probably due to a 5° F degree difference in the average outdoor temperature at that time of the morning. The average hour temperature for the hour ending at 6 a.m. was 38.9° F during the pre-retrofit period winter weekday mornings, compared with 34.2° F for the post-retrofit period.

Annual Peak Day Changes

The peak day in the pre-retrofit period occurred on a weekday in October at an average hourly level of 125 kW, or 5.6 W/ft²/hr. In the post-retrofit period, the peak day occurred on a weekday in January at an average hourly level of 84 kW, or 3.8 W/ft²/hr (a 32 percent reduction). Table II shows the end use shares of the average hourly consumption for these peak days. While the lighting load decreased in the post-retrofit period, lighting's relative share of total load increased primarily due to a reduction in the cooling load in the post-retrofit period.

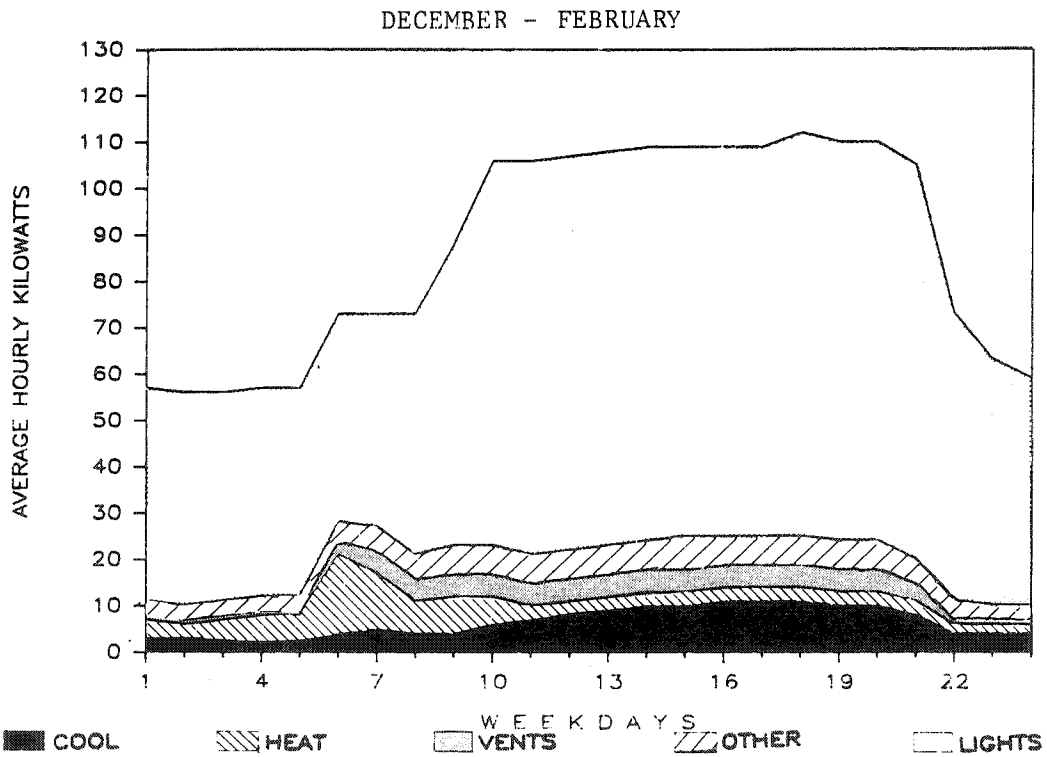


Figure 4. Pre period hourly load shapes by end use.

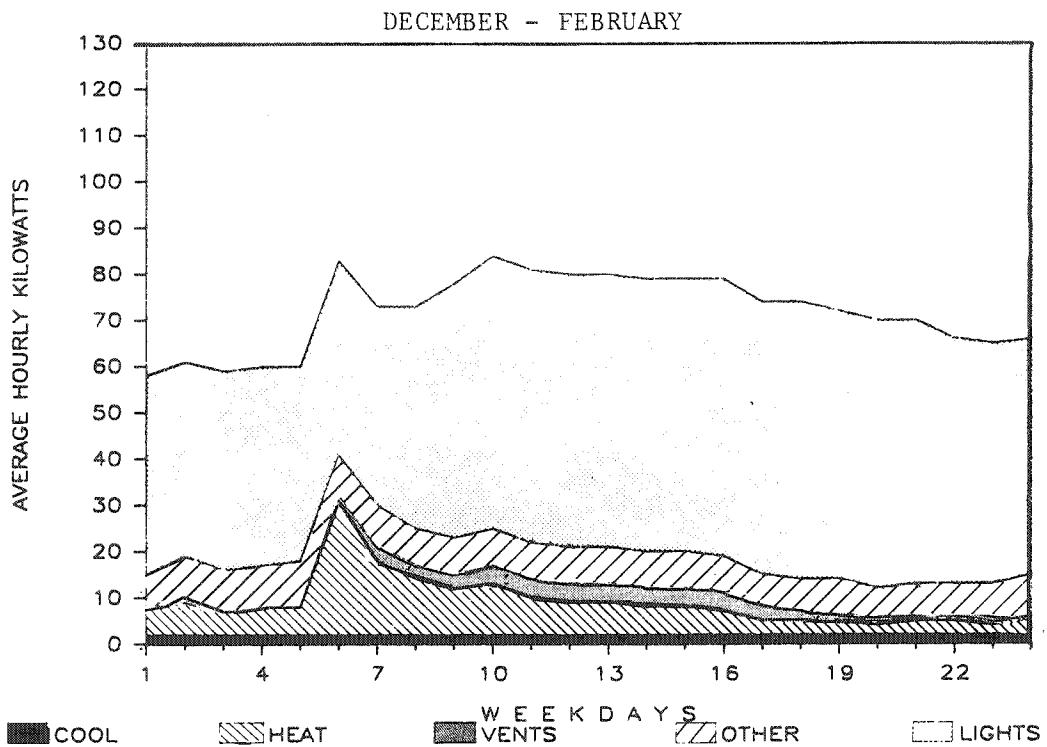


Figure 5. Post period hourly load shapes by end use.

Table II. Peak day average hourly loads.

	Pre-Retrofit Period (10-5-84)		Post-Retrofit Period (1-11-85)	
	W/ft ²	Percent	W/ft ²	Percent
Lights	3.7	66.1	2.9	76.3
Cooling	1.3	23.1	.5	13.2
Heat	.1	1.8	.1	2.6
Vent	.2	3.6	.1	2.6
Other	.3	5.4	.2	5.3
Total	5.6	100.0%	3.8	100.0%

From the analysis of the measured end use consumption of this building, the impact of the lighting system retrofit can be summarized as significantly reducing lighting and cooling loads without a major influence on the other building loads, including heating. The building is not a particularly weather-sensitive building because over 80 percent of its energy consumption in both the pre-retrofit and post-retrofit periods is dominated by the weather-independent but seasonally varying lighting loads. With the reduction of waste heat from the new lighting system, the cooling load has dropped significantly in the summer months and has become nearly nonexistent in the winter months.

COMPARISONS WITH THE COMPUTER SIMULATIONS

The availability of measured end use load data can provide valuable insights into the ability of computer simulations to predict energy savings from conservation strategies. The measured energy savings from the lighting retrofit can be compared with the estimates from the DOE 2.1B energy analysis program. The intent of this comparison is not to validate the program or prove its accuracy, but rather to lend insight into its suitability for energy savings estimates from a conservation strategy in a specific building.

The energy consumption for this retail store was simulated using lighting and equipment peak capacities and use schedules taken directly from the hourly end use load data. The model calculated heating, cooling, and ventilation consumption in response to the lighting and equipment internal loads, and thermostat set points. The simulation used actual weather data from the same period as the hourly end use load measurements. Using separate data-derived lighting and equipment peak capacity and use schedules for the pre-retrofit and post-retrofit conditions allowed for the model to take into account small changes in night restocking patterns and miscellaneous outlet usage for calculating consumption in the post-retrofit period.

A comparison of actual monthly energy consumption to the DOE 2.1B predicted consumption is shown in Figure 6 for the pre-retrofit and post-retrofit periods. The predicted monthly load shape was similar to the observed monthly load shape. The discrepancies in several months were due to

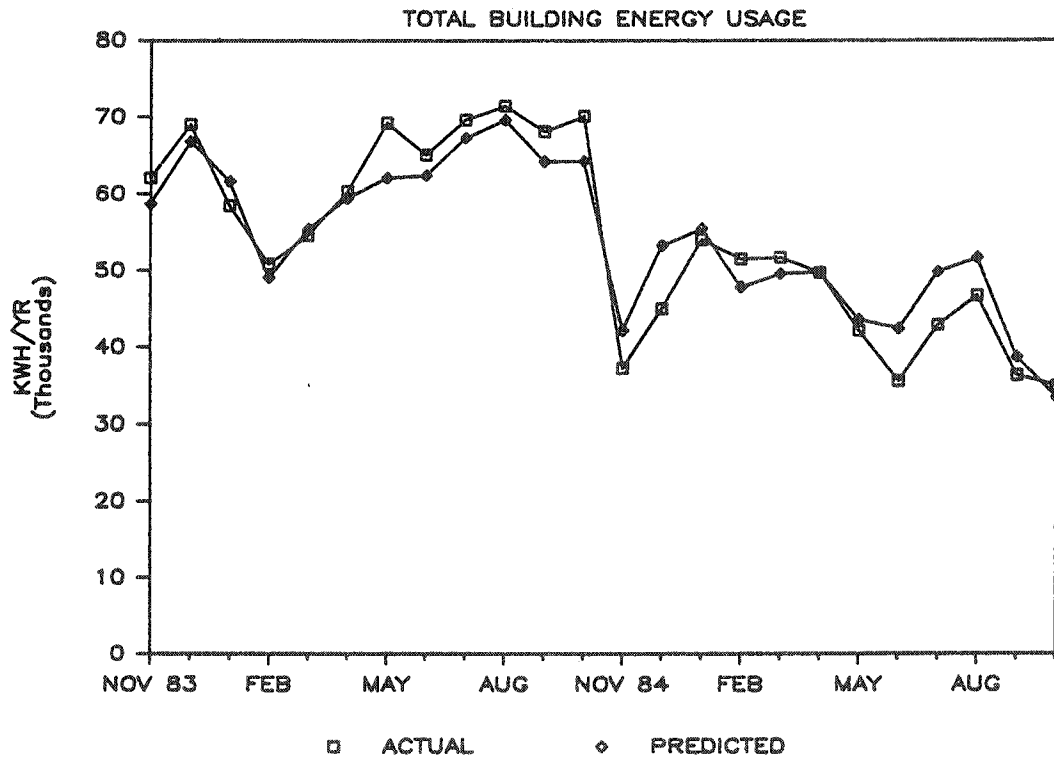


Figure 6. A comparison of actual and DOE2.1B predicted monthly electrical consumption. POST PERIOD - NOV 84 TO OCT 85

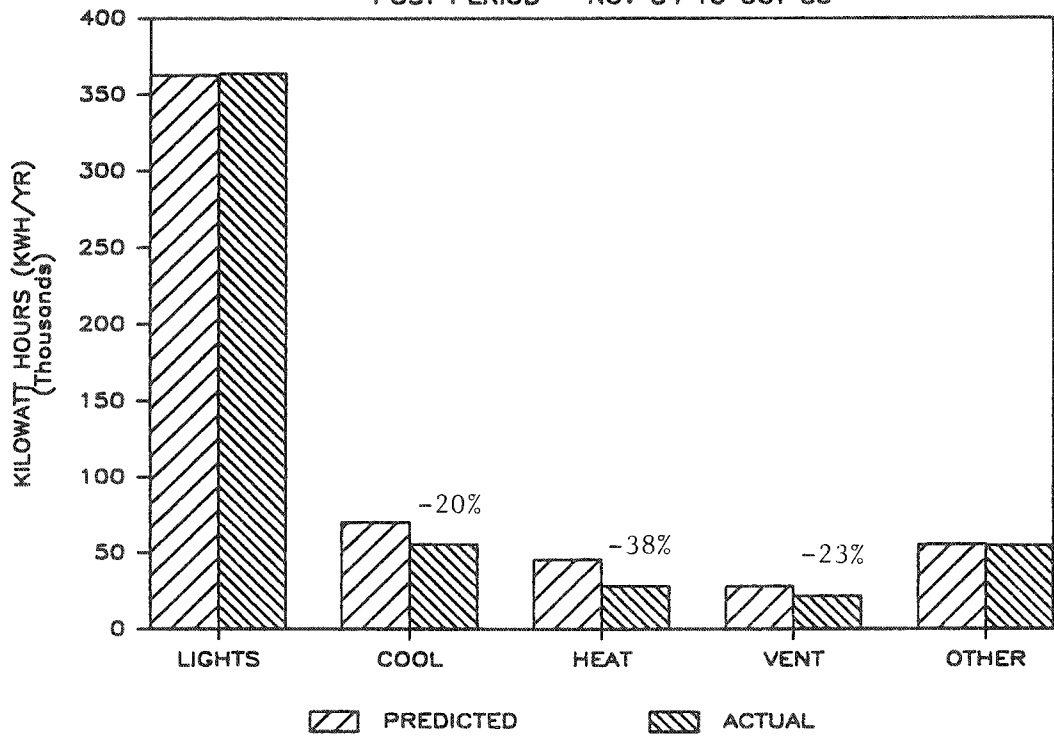


Figure 7. Differences between DOE2.1B predicted and actual usage by end use in the post period.

the inability of the model to accurately predict the monthly heating, ventilation, and cooling loads (HVAC). Table III contains the predicted and actual consumption by end use for the pre- and post-retrofit periods.

Table III. Predicted and actual levels of annual consumption.

	Pre-Retrofit Usage (kWh)		Post-Retrofit Usage (kWh)	
	Predicted	Actual	Predicted	Actual
Lights	536,349	539,243	362,982	363,986
Cooling	105,221	133,500	70,473	55,898
Heat	24,476	25,603	46,122	28,510
Vent	33,995	29,402	28,623	22,075
Other	41,160	41,373	55,845	55,224
Total	741,201	769,121	564,045	525,693

In the pre-retrofit period, the model underpredicted both heating and cooling loads and overpredicted the actual ventilation load. In the post-retrofit period, the predicted levels of the annual HVAC loads was greater than observed. The differences between the actual and predicted levels in the post-retrofit period are displayed in Figure 7. The model overpredicted HVAC loads. A major reason for this overprediction was the way in which the system was operated. Control of the HVAC system was less consistent in the post-period because the time clock was often manually overridden by the occupants for a variety of reasons relating to the desired comfort level of the conditioned space. This behavior resulted in reduced operating hours for the HVAC system. Irregularly scheduled HVAC loads at the weekly and/or daily level are difficult to simulate. An attempt was made to model these irregularities by examining HVAC consumption patterns in the data set. Due to schedule limitations in the model and the unknown duration of the manual control of the HVAC system, these schedules were aggregated to the monthly level. This averaging effect resulted in HVAC schedules that overpredicted HVAC consumption.

Based on annual total consumption, the actual energy savings from the lighting retrofit were greater than predicted primarily because the cooling and heating loads did not change as predicted by the model. On a per square foot basis, the reduction in the cooling load from the pre-retrofit level of 5.9 kWh/ft² to 2.5 kWh/ft² was greater than the level of 3.1 kWh/ft² predicted by the model for the post-retrofit period. The pre-retrofit measured level of the heating load (1.2 kWh/ft²) did not increase to 2.1 kWh/ft² as predicted by the model, but remained at approximately the same level.

IMPLICATIONS FOR UTILITY CONSERVATION PROGRAM PLANNING

While this is only one case study, it can provide insight into the application of simulation results for estimating conservation energy savings. For purposes of discussion, assume this building is typical of the retail

stores in the utility's service area. If all these buildings were to undergo similar lighting system retrofits, what would be the impact of using the simulation model's results in the planning of utility conservation programs?

Utility conservation program planning decisions are based in part on the dollar value of the energy saved from conservation improvements. For the calculation of the value of conservation savings from the Seattle City Light's perspective, the utility determines not only the magnitude of the electricity savings but also when these savings occur. The cost of electricity is higher to the utility during the "high demand" colder periods, called peak and intermediate periods. Conservation savings during these periods are worth more, thus valued higher, than the savings that occur during "lower demand," warmer periods, called off-peak.

Seattle City Light's definitions of peak, intermediate, and off-peak periods are:

- o Peak Period. The highest 200 hours of demand for electricity falling within the period mid-November to mid-March, Monday through Friday, between 7 a.m. and 10 p.m.
- o Intermediate Period. The next highest 1,000 hours of demand for electricity, falling within the same time period as the peak period.
- o Off-Peak Period. All other hours (excluding the 1,200 hours in the peak and intermediate periods).

Table IV shows the predicted and actual time differentiated savings from the lighting retrofit.

Table IV. Post-retrofit annual energy savings (kWh/year).

	<u>Predicted</u>	<u>Percent</u>	<u>Actual</u>	<u>Percent</u>
Peak	-140	-.01	3,403	1.4
Intermediate	17,860	9.2	24,809	10.2
Off-Peak	<u>172,430</u>	<u>90.8</u>	<u>214,777</u>	<u>88.4</u>
Total	190,150	100.0%	242,989	100.0%

The utility could be less inclined to offer a major lighting retrofit program because of the absence of savings during the peak period predicted by the simulation. Actual consumption results indicate that peak energy savings were obtained. The present value of these energy savings is shown in Table V. Since the simulation model predicted less energy savings, particularly in the peak and intermediate periods, the actual value of the retrofit over the life of the measure to the utility was greater than predicted.

Table V. The present value of energy savings to the utility (1983 dollars).

	<u>Predicted</u>	<u>Actual</u>
Peak	\$ -318	\$ 7,750
Intermediate	6,219	8,639
Off-Peak	<u>55,214</u>	<u>68,775</u>
Totals	\$61,115	\$85,164

CONCLUSION

The results of this case study suggest that the energy savings from lighting retrofits may be greater and valued higher by Seattle City Light than results predicted by simulation models. In this particular case, lighting reductions did not result in a substantial heating load increase; in fact, the cooling load during high energy cost time-periods for the utility decreased more than predicted by the model. Should these findings be typical of other retail stores in the utility's service area, lighting retrofit programs for these customers may be more cost-effective to the utility than current planning estimates developed from simulation models would predict.