COMMERCIAL HOURLY END-USE LOAD STUDY

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ABSTRACT

A major benefit of using end-use load data in simulating commercial building conservation strategies is the improvement in accuracy of conservation potential assessment. This paper presents the results of an analysis of a light system modification with the DOE-2.1A simulation model under two different sets of lighting inputs. The lighting retrofit is modeled with lighting inputs developed solely by a standard energy audit process and with lighting inputs taken directly from hourly end-use load data. A comparison of the two models shows that the conservation potential from the lighting retrofit was underestimated in the standard audit approach. The increased accuracy of scheduling inputs resulting from end-use load data becomes particularly important for evaluating conservation strategies where the value of the benefits of the energy savings is nearly equivalent to the costs.

INTRODUCTION

In 1982, a Northwest utility began a four-year 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 were instrumented in 1982 and 1983 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 was 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 addition to the monitoring effort, an energy conservation analysis was performed on each building. Engineering consulting firms were used to conduct audits of each facility and simulate building thermal performance with the DOE-2.1A hourly simulation model. Interactive simulation runs were made until the energy consumption predicted by the model matched monthly utility billing records within an acceptable range. Portions of the hourly end-use load data were used in six of the eight buildings to determine non-HVAC load schedules. The conservation potential of each building was assessed by evaluating the thermal performance of identified conservation improvements with respect to the base (existing) consumption under typical weather conditions. A life-cycle cost model was used to analyze the estimated benefits and costs of identified improvements on an individual and combined basis. From this analysis, an economically optimum package of conservation improvements was identified and recommended for implementation.

With the cooperation of the building owners, the recommended improvements were installed in 1985. The monitoring effort will continue for one year after implementation. Sufficient data will then be available to support a detailed assessment of the measured impacts of

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conservation on each end use at the hourly level. The Utility will compare the measured conservation savings to those predicted by the simulation model. An analysis of the differences between measured and predicted savings will be useful to the Utility in future program planning and load forecasting activities.

In November 1984, a substantial modification was made to the interior lighting system in one of the monitored buildings. This lighting retrofit was made by the building owner without any influence from the hourly end-use load data or the conservation analysis conducted by the utility in 1982. Since this building was one of the two that did not utilize end-use load data during the initial conservation analysis, this retrofit provided an opportunity to assess the value of end-use load data in analyzing conservation potential.

This paper presents the results of an analysis of this lighting retrofit with the DOE-2.1A simulation model under two different sets of lighting inputs. First, the lighting retrofit is modeled with lighting inputs developed solely by a standard energy audit process. The second set of lighting inputs includes those taken directly from the hourly end-use load data. A comparison of the differences in the two models shows that the conservation potential from the lighting retrofit was underestimated in the standard audit approach. This highlights the benefits of end-use load data in accurately assessing conservation potential.

DESCRIPTION OF STUDY BUILDING

The study building selected for the lighting retrofit analysis was a drug and sundries retail store located in Seattle. It has a total gross floor area of 22,326 ft^2 (2074 sq m). For the analysis the store was divided into three functional use areas (zones), including a sales area, a stockroom, and an employee office area. The sales area occupies 82% of the gross floor area, while the stockroom and office areas comprise 11% and 7% of the gross floor area, respectively.

The store is open for business 72 hours per week and the store hours are 9 a.m. to 9 p.m. Monday through Friday, 9 a.m. to 6 p.m. Saturday, and 10 a.m. to 6 p.m. Sunday.

The structure is constructed of concrete block with a slab on grade floor and a built-up roof. The roof has 1-5/8 inches (4.1 cm) of rigid insulation. The walls and floor are uninsulated. The windows and front doors are single pane, 1/4 inch (.6 cm) glass. The glass area is 3.4% 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 68 F (20°C) for heating and 72 F (22°C) for cooling during occupied times. The time clock controlling heating and cooling is set for an operation schedule of 5 a.m. to 9 p.m. weekdays, 5 a.m. to 6 p.m. on Saturday, and 7 a.m. to 6 p.m. on Sunday. 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 (16°C).

Prior to the lighting retrofit, the sales area was illuminated by recessed, ceiling-mounted, 400-watt, mercury vapor fixtures. These fixtures were replaced in November 1984 by 2-tube, 8-foot (2.4 m) fluorescent fixtures with 60-watt energy efficient lamps. The shelves along the perimeter of the store also have fluorescent fixtures to highlight merchandise.

The study building uses electricity as its only energy source. Utility billing records reveal that the building consumed 737,100 kWh in 1983, with an average demand of 173 kW. This consumption figure corresponds to about 112,700 Btu/ft^2 yr (355.4 kWh/m^2 yr). A historical plot of monthly electrical consumption between January 1983 and July 1985 is provided in Figure 1. From this figure it can be seen that the study building has a consistent annual consumption pattern, which cycles between a summer peak and spring minimum.

The sharp reduction in total building consumption resulting from the lighting retrofit can be seen after November 1984. Monthly aggregation of hourly electric end-use load data collected between February 1983 and November 1984 (date of retrofit) results in the end-use shares displayed in Figure 2. The end-use shares for an average winter week in 1983 are shown in Figure 3 to illustrate the weekly variation in end-use consumption. From Figure 2 it can be seen that lighting is the largest annual end-use load in the building, accounting for over 70% of total consumption. HVAC loads account for 25% of total consumption with ancillary equipment constituting the remainder. From these figures it would be anticipated that interior lighting and HVAC loads would be the major targets for an energy conservation analysis.

ANALYSIS OF LIGHTING RETROFIT

In November 1984 the existing mercury vapor lighting system in the sales area was retrofitted to ceiling-mounted, high output fluorescent fixtures. The mercury vapor lighting system was designed at 4.2 W/ft^2 (.39 W/m^2) and maintained approximately 80 footcandles at merchandise level. The new fluorescent system, was designed at 2.2 W/ft^2 (.20 W/m^2) to provide approximately the same lighting level with half of the lighting capacity. The decision to make this lighting system modification was made by the owner of the study building without any influence from the hourly end-use load data or the conservation analysis performed by the utility in 1982. The lighting modification was discovered by the utility from examination of the end-use load data for November 1984, which showed a substantial reduction in the interior lighting end use. Further investigation with the building owner revealed that the modification was made primarily as a means of improving the color rendition of the merchandise. Energy conservation was viewed as a secondary benefit. The fact that the lighting modification was made, provided the utility with an opportunity to compare DOE-2.1A predicted energy savings using lighting inputs from both a standard audit and the end-use load data. With the lighting end use being measured directly by the microprocessor, this comparison could be made with relative ease.

The lighting end use in the DOE-2.1A model is calculated by the multiplication of the peak lighting capacity in each zone by its respective hourly profile. The hourly profile is entered as a decimal fraction of the peak capacity, with a value of unity indicating that the lighting system is being utilized at full capacity. The model has the flexibility to accept a schedule of lighting that varies by hour, day, and month. As part of the energy audit conducted in 1982, the peak capacity of the lighting system was calculated using a bulb count. Hourly profile information was collected by direct observation, conversations with building personnel, and engineering judgement. The same capacity and schedule data were extracted from the pre-retrofit end-use load data using a standard statistical software package. The peak lighting capacity calculated during the energy audit for the sales area was 76 kW. The corresponding capacity value extracted from the end-use load data was 78 kW. The difference between the two values was due to the use of an inappropriate ballast factor in the energy audit. A more dramatic difference between audit and measured data can be found by examining the respective hourly lighting profiles. In both cases, unique lighting profiles were established by hour for weekdays, Saturdays, and Sundays. In the energy audit, these three weekly schedules were assumed to be consistently applied to each month of the year. The measured lighting profiles varied enough throughout the year to justify the use of unique schedules for six monthly periods. Figure 4 provides a graphic comparison of the audit and measured schedules for a typical weekday. Two of the six monthly end-use load data schedules are shown in this figure to represent the range of measured values. Profiles for the remaining four monthly periods fell within this range. From Figure 4 it can be seen that the lighting profile resulting from the audit substantially underpredicted the percentage of the lighting capacity that is actually used during nonbusiness hours. Table 1 provides a listing of the pre-retrofit end-use consumption and end-use shares from both the audit and end-use load data, as calculated by the DOE-2.1A model under typical weather conditions. From this table it can be seen that lighting consumption calculated with the combined effects of the low audit peak and nonbusiness hourly profile was 20% less than measured lighting consumption.

The difference in interior lighting consumption between the audit and end-use load data also impacts the HVAC end uses predicted by the simulation model. Table 2 shows that the simulation based upon lighting inputs from the audit results in an 83% overprediction of space heating load and a corresponding 21% underprediction of space cooling load.

For this analysis the comparison of audit and end-use load data was limited to internal lighting and the resulting impacts upon HVAC loads. However, similar comparisons between audit and end-use load data could be made for the ancillary equipment and external lighting end-use loads. Discrepancies would likely be found in such a comparison. However, their impacts in total building consumption would be less significant because they represent a much smaller fraction of total building consumption.

A similar comparison of the internal lighting end use was made using post-retrofit data. This comparison was less rigorous because the utility conservation analysis conducted in 1982 did not identify this specific conservation measure. Therefore, for the post-retrofit comparison it was assumed that the audit would have accurately predicted the modified peak lighting capacity. It was also assumed that the pre-retrofit lighting schedules did not change. Although there was sufficient end-use load data to support a reanalysis of the lighting schedule, it was not felt to be realistic to expect a standard audit to predict a change in schedule. A change in schedule may have occurred for reasons other than the lighting retrofit.

Table 2 provides a listing of the post-retrofit end-use consumption and use-use shares from both the audit and end-use load data as calculated by DOE-2.1A under typical weather conditions. Because the peak capacity was substantially reduced under post-retrofit conditions, the magnitude of the discrepancy between audit and end-use load data has been reduced. However, lighting consumption calculated with audit data was still 19% less than the measured value. As discussed previously, this discrepancy in lighting consumption impacts the predicted HVAC end uses. Table 2 shows that the simulation based upon lighting inputs from the audit results in a 22% overprediction of heating load and 7% underprediction of cooling load.

Another issue of concern in this analysis was the impact of this discrepancy in lighting and HVAC consumption upon the cost effectiveness of the retrofit. A life-cycle cost model was used to calculate the cost effectiveness of the lighting retrofit under both audit and end-use load data conditions. The life-cycle cost model calculated cost effectiveness from the utility perspective. This perspective valued energy at utility costs during peak and off-peak time periods. The value of energy savings due to conservation is based on the marginal cost of supplying energy. It is expected that the regional marginal resources will be a combination of gas turbines and a coal plant. The cost of this resource is termed marginal thermal value (MTV). In the Utility's planning efforts, conservation savings are valued at the marginal thermal value because it is assumed that these energy savings will result in less fossil fueled generation facilities built or acquired by the region to meet future demand. A measure was considered to be cost effective when the present value of the energy savings to the Utility over the life of the project (benefits) was greater than the present value of the total costs of the measure. The calculations incorporate the Utility's 3% real discount rate.

The energy savings calculated by the DOE-2.1A model under both audit and end-use load data conditions were entered into the life-cycle cost model with actual capital cost information supplied by the building owner. A comparison of the consumption data in Tables 1 and 2 show that the lighting retrofit based upon end-use load data resulted in a 45% reduction internal lighting energy. HVAC energy requirements increased by 25%. Total building energy consumption was reduced by 21%. This result is shown graphically in Figure 5.

The benefits calculated for the lighting retrofit based on audit lighting data were five times greater than the costs. The benefits of the savings based on end-use data were seven times greater than the costs. It can be seen that, in both cases, the lighting retrofit was considered to be cost effective since the benefits outweighed the costs. The benefit calculations based on end-use load data energy savings were about 40% higher than those calculated with the audit savings. However, the strategy was so overwhelmingly cost effective that even a 40% error in the benefit/cost calculation would not have affected a recommendation to implement the retrofit. These results also show that the owner made a reasonable decision to implement the lighting change without the benefit of end-use load data or a conservation analysis.

CONCLUSION

A major benefit of using end-use load data in simulating commercial building conservation strategies is the improvement in accuracy it brings to the assessment of conservation potential. Improvement in simulation results impacts not only the magnitude of the energy savings but also the end-use distribution of the predicted savings.

In the case of the study building, the use of the end-use load data for pre-retrofit lighting schedules improved the ability of the model to calculate the end-use profile of the building's total consumption. Lighting consumption calculated with standard audit data was substantially less than measured lighting consumption. This discrepancy in lighting consumption caused a corresponding overprediction of space heating and underprediction of space cooling loads. Similar results were found in the post-retrofit case.

Since the conservation analyses performed on most commercial buildings do not have the benefit of end-use load measurements, it is often difficult to detect errors in audit information. The results of this analysis illustrate the effect that such errors can have on the cost effectiveness of conservation strategies and emphasizes the importance that should be placed upon collecting accurate audit data. One recommendation for improving simulation inputs where detailed measurements are not possible is to gather additional input information such as lighting schedules and building temperatures during nonbusiness hours and/or days.

Table 1
Pre-Retrofit Consumption and End-Use Shares - DOE 2.1A

End Use	Consumption (kWh) Audit	EUL Data	% Diff.	End-Use Share (%) Audit	EUL Data
Space heating	101,047	55,315	+83	14.0	7.0
Space cooling	51,445	65,339	-21	7.2	8.3
Fans	112,881	114,039	-1	15.7	14.4
Internal lights	394,876	495,440	-20	54.9	62.7
External lights	39,115	39,115	0	5.4	5.0
Ancillary equipment	20,331	20,331	0	2.8	2.6
Total	719,695	789,579	-9	100.0	100.0

Table 2
Post-Retrofit Consumption and End-Use Shares-DOE 2.1A

End Use	Consumption (kWh) Audit	EUL Data	% Diff.	End-Use Share (%) Audit	EUL Data
Space heating	188,689	155,240	+22	31.2	24.8
Space cooling	24,454	26,288	-7	4.1	4.2
Fans	110,766	110,924	-.1	18.3	17.7
Internal lights	220,773	273,797	-19	36.5	43.8
External lights	39,115	39,115	0	6.5	6.3
Ancillary equipment	20,331	20,331	0	3.4	3.2
Total	604,128	625,695	-3	100.00	100.00

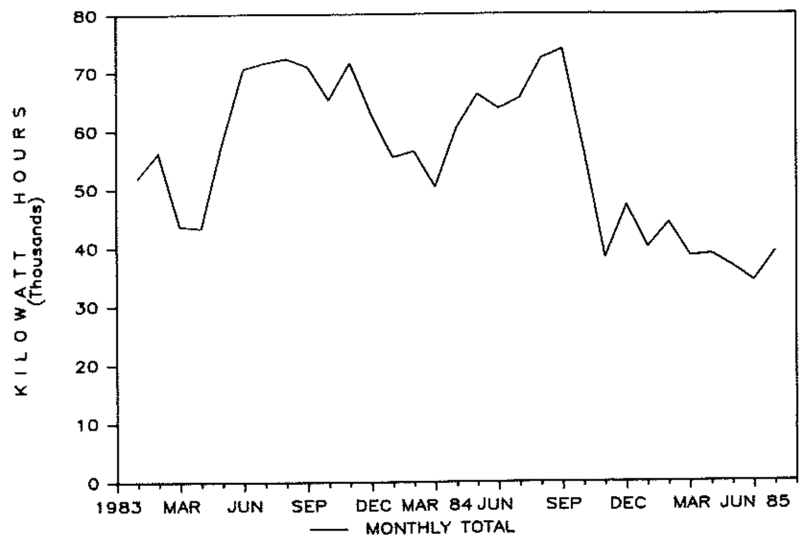

Figure 1. Electrical energy consumption, 1983 through 1985

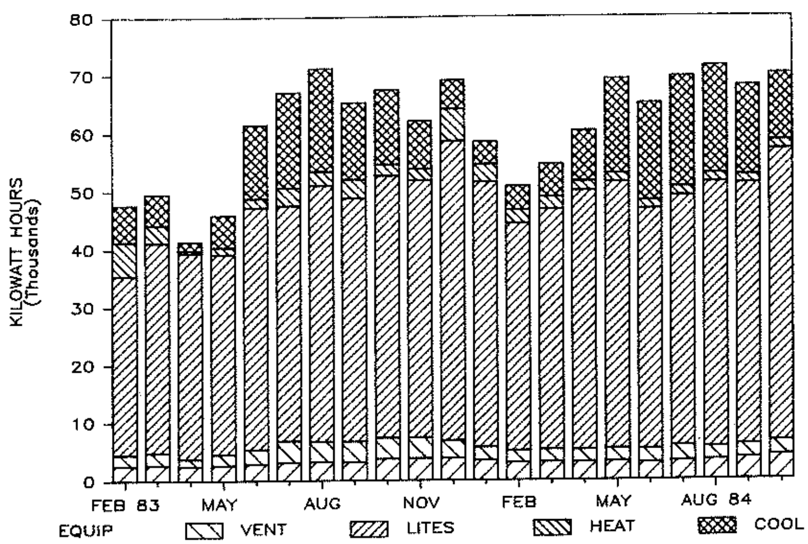

Figure 2. Average monthly consumption by end use (preretrofit)

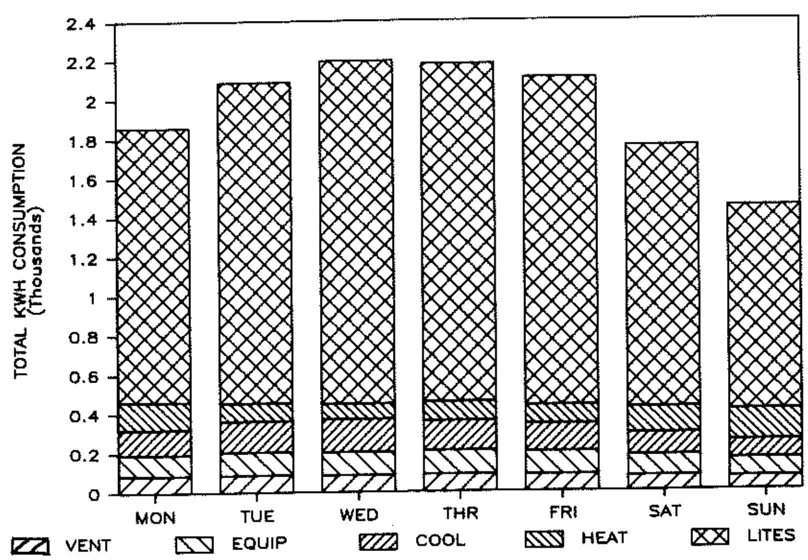

Figure 3. Average weekly consumption, Winter 1983

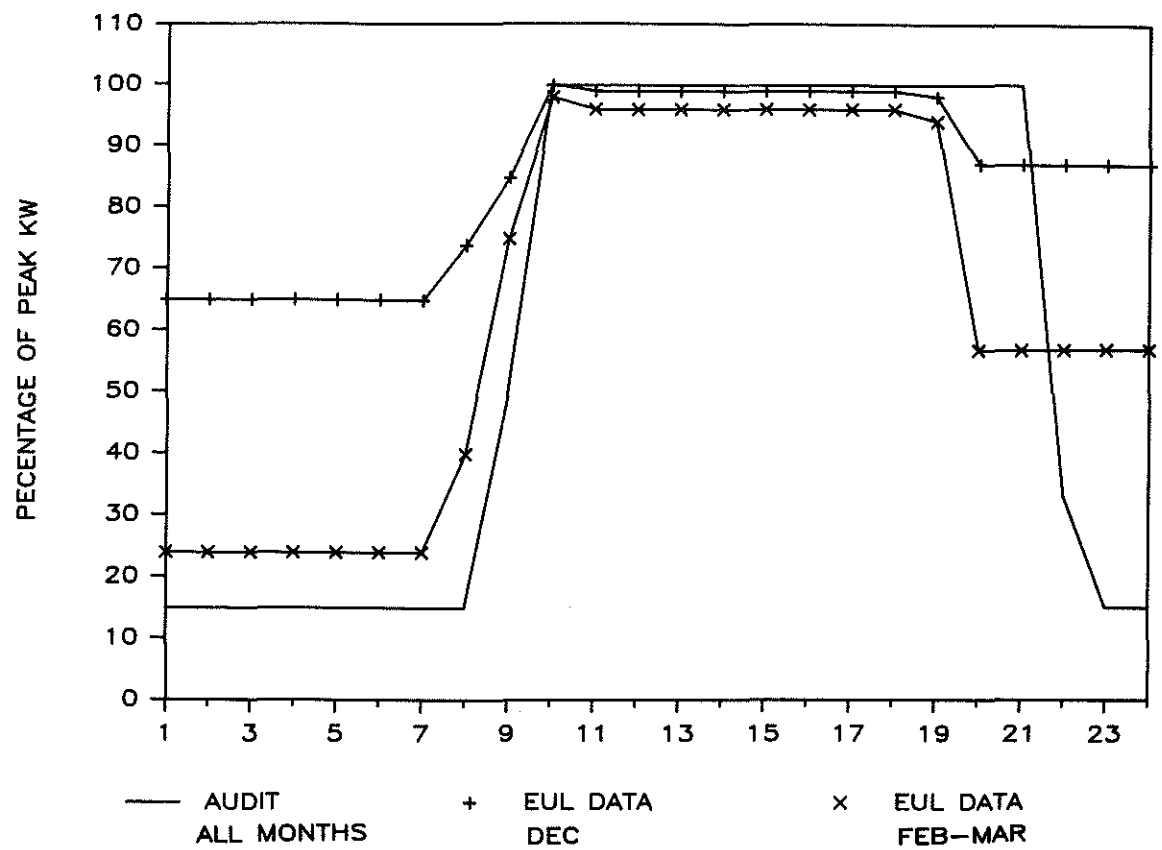

Figure 4. Lighting schedule-audit vs. load data: audit peak = 76 kW, end-use load peak = 79 kW

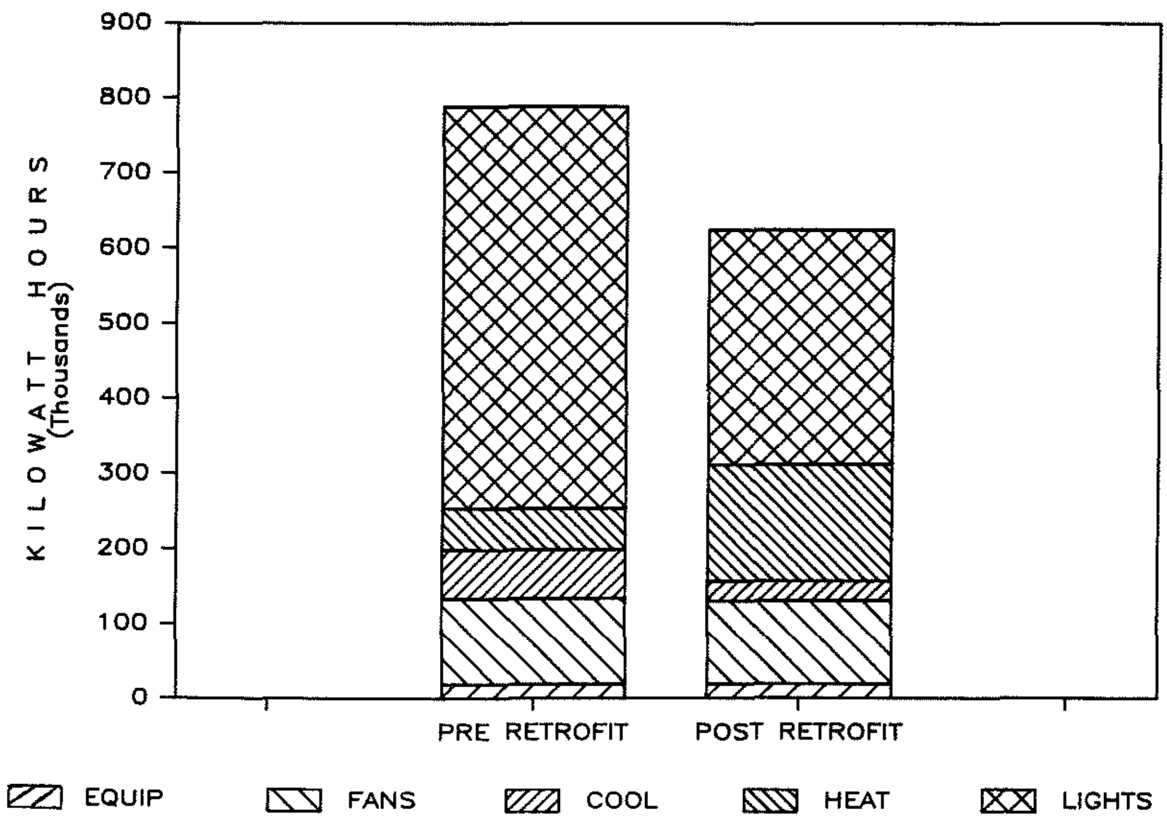

Figure 5. DOE-2 predicted end-use loads for lighting schedule