WHOLE FACILITY ENERGY USE MONITORING

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ABSTRACT

Pacific Northwest Laboratory (PNL) is conducting numerous field monitoring studies of the enduses of energy in buildings. Energy use monitoring techniques have been developed to provide reliable empirical measurements of energy consumption according to enduse and time of day. These measurements are analyzed in conjunction with climate and site characteristics data to determine energy use efficiencies and identify energy conservation and load management opportunities. This paper draws upon this experience to advance an approach to minimize the cost and maximize the benefits of field data collection projects for entire facilities.

A "top-down" approach to energy use monitoring is being applied to the U.S. Department of Energy Hanford Site. Microprocessor-based data acquisition systems in over 50 locations are interrogated over telephone lines to indicate hourly electrical consumption levels for entire buildings. While these data are aggregated for utility billing purposes, PNL has collected concurrent data on the site characteristics and Hanford climatology to evaluate apparent energy conservation potentials. The hourly profile data is then studied to select a subset of the sites where sub-metering of energy use is likely to confirm hypotheses of energy cost reduction opportunities drawn from these data. When selected measures are installed, this sub-metering can also serve to confirm the actual levels of energy savings achieved.

An important aspect of this effort is the initial collection and analysis of empirical data from a limited number of points to identify locations where additional metering is likely to be cost-justified. This is particularly important in large and complex facilities where the cost of fully instrumenting every building and load center is likely to be prohibitive although the benefits of strategically collecting empirical data is likely to be cost-justified.

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INTRODUCTION

Pacific Northwest Laboratory (PNL) has assembled the largest database of end-use energy consumption for buildings in the world. Beginning with a project in 1983 to measure end-use energy consumption in seven restaurants, PNL is now accumulating time series energy consumption data for over 500 buildings ranging in size from small houses to a hotel of over 1 million ft². While the size and scope of this database is an excellent basis for scientific examination of energy use cause and effect, much can be learned from this accumulated knowledge to more strategically select sites and measurement points for future evaluation. With a sound approach and strategic application of metering technology, the costs associated with collection of these types of data in the future are likely to be offset by the savings that result from the insights that are gained.

Such an approach is being applied to the 450-mi² Hanford Site operated in southeastern Washington State for the U.S. Department of Energy (DOE). The annual electric bill for this broad assembly of office, laboratory, and production buildings exceeds $10 million per year, of which nearly $3 million is for demand charges for a noncoincident peak of over 73,000 kW. Until recently, the energy use was metered at the facility boundaries for utility billing purposes only.

Energy costs were allocated among the various contractors who operate facilities on the site on a percentage basis with no knowledge of actual levels of energy use. This had the unfortunate effect of failing to differentiate those contractors who have made strides to reduce energy use intensities from those who have not. Furthermore, the facility energy managers had very little empirical data upon which to establish energy enduses and conservation potentials.

This situation changed in fiscal year 1989, when PNL and Westinghouse-Hanford Company (WHC) employees completed the installation of field data acquisition systems at strategic locations on the Hanford Site. This work was funded by DOE's In-House Energy Management Program to measure the electrical use of the various building clusters and the largest facilities on the site, to better estimate each contractor's share of the electric bills. The necessary sensors and data loggers were provided by PNL, and training was provided to WHC staff to install and maintain the equipment. PNL also provided the Personal Computer Data Acquisition System (PCDAS) software for a desk-top computer to automatically collect, store, and process the metered data.

Because the loggers are automatically interrogated over telephone lines, a decision was made to collect data at hourly intervals. In this way it would

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be possible to not only disaggregate electrical energy charges, but also equitably split the peak demand charges. Another benefit of collecting time-series data is to understand daily energy use profiles and thereby identify potential energy efficiency and load management improvements.

This paper summarizes a simple research project conducted by PNL using these data and a limited amount of ancillary data to identify buildings where further energy use sub-metering appears to be cost-justified. The paper describes how a limited amount of data on the characteristics of the monitoring sites is used to identify areas of high energy use intensity, how climate data is incorporated to estimate heating and cooling requirements, and how daily average hourly energy use profiles are used to identify apparent energy savings opportunities.

TECHNICAL APPROACH

The work proceeded in a step-wise fashion. First, an examination was made of all the measurement points and the length of data streams to identify 41 buildings for which at least 6 months of concurrent data was available. The hourly data were aggregated to daily means for subsequent data processing, and an average power level over the 6-month period was computed for each building. Data on the area and the description of each of the sites was assembled during an initial site visit, and hourly temperature data from a nearby weather station was acquired.

From this information, a series of normalizations was made and graphical depictions prepared to compare the energy performance of the individual sites. The average electrical power densities and average electrical demands were calculated and compared to identify a subset of sites for further study. For these sites the daily average power levels were plotted against the average daily outdoor temperatures, to provide an indication of the temperature sensitivity of the site. Next, hourly profiles of average weekday and week-end day energy use for summer and winter months were prepared and evaluated to examine the typical patterns of energy use. Finally, followup site visits were made to the buildings to discuss energy use levels and patterns with the building managers and to identify or confirm energy cost reduction strategies. Each of these stages is described in greater detail below.

Data Assembly and Review

The buildings evaluated include office buildings, trailers, nuclear process buildings, shops, warehouses, and life science buildings with live animal support facilities. Forty-five data loggers have been measuring total hourly electrical energy input at the service entrances to the facilities. Four data loggers had insufficient data for this analysis. Hourly data was aggregated for the remaining 41 buildings to create daily data for further investigation. For this study, periods between February 1, 1988, and July 31, 1988, were examined. The daily data during these periods was averaged and normalized by building area. Also for these 41 buildings, characteristics

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data such as total area, building material, window area, average occupancy levels, and fuel types were gathered during initial site visits. Figure 1 shows an example of a completed Building Information Sheet. This information is used to determine the building use, area, and other physical characteristics.

Data Normalization and Comparison

The average daily electric demand divided by the building area was the first criterion used for the selection of sites to further study. All buildings with an average energy intensity above 3.7 W/ft² were chosen. A horizontal line drawn in Figure 2 depicts this criterion. Exceptions to this were two pump houses that used more energy per area than any other buildings. The energy consumption of these two buildings was due mainly to the pumping load. These sites were excluded from consideration because of the predominance of the process load. Thus, 15 sites between two vertical lines on Figure 2 were chosen for further analysis.

In addition to these 15 buildings, 2 others with average electrical demands above 100 kW were selected, as indicated in Figure 3. The order of the buildings in Figure 3 is the same as that in Figure 2; the horizontal line represents the 100-kW cutoff point. Table 1 includes the numbers, average power densities, average electrical demands, and descriptions of the 17 buildings selected for further investigation.

Examination of Outdoor Temperature Data

For the 17 sites selected, average hourly profiles for weekdays and weekend days for the months of February and July were created. To gain insights into the amount of energy consumed and the energy usage patterns, it was necessary to understand outdoor temperature profiles for the same periods. The temperature data used in this analysis is from the Hanford Meteorological Station. Figure 4 depicts the mean daily outdoor temperature during February 1, 1988, to July 1, 1988. The mean outdoor temperature profiles of February (Figure 5) show that there is a gradual increase in the temperature between 7:00 am to approximately 3:00 pm and a gradual decrease between 3:00 pm to 7:00 am. The February profiles indicate that the weekend mean hourly outdoor temperatures, represented by triangles, were significantly higher than the weekday mean hourly temperatures. The higher temperatures during the weekends can be explained by looking at the calendar. February 1, 1988, was a Monday and, as the month progressed, the outdoor temperature increased. Because the weekends always came later in February 1988, the weekend temperatures were warmer. This knowledge aids in understanding the difference between weekday and weekend energy profiles for the buildings in February. Figure 6 shows that, in July, there is very little difference between the weekend and weekday temperature profiles.

FDAS #: 42A   Building #: 43   Area: 300   Contractor: WHC
Building Name: 338 MOCK-UP MAINTENANCE Site/Parm: 43A   Channel #: 70,71

1. Total Area: 20869 ft²

2. Total Heated Area: 17500 ft²   Ave. Setpoint: 68
   a) *heating fuel type (Primary): ELECTRICITY
       other heating fuel type:
   b) **heating system type (Primary): HEAT PUMPS
       other heating system type: RESISTANCE HEATERS

3. Total Cooled Area: 17500 ft²   Ave. Setpoint: 72
   a) *cooling fuel type (Primary): ELECTRICITY
       other cooling fuel type:
   b) **cooling system type (Primary): HEAT PUMPS
       other cooling system type:

4. Window Area: 0 ft²   % of Window: 0%   Window Type: 0

5. Hour of operation: 7 am to 4 pm, Monday through Friday

6. Ave. # of occupants: 47   Max. occupants: 60

7. Building use:
   a) % Office space: 6.0%
   b) % Lab Type: 0.0%; Radiation: 0.0%
                        Life Science: 0.0%
                        Other Lab: 0.0%
   c) % Shop space: 60.0%
   d) % Warehouse space: 14.0%
   e) % Other use 1: 20.0%
       Other use 1 description: COMMON
   f) % Other use 2: 0.0%
       Other use 2 description:

8. Building material summary:
   Wall type: METAL SIDING   Roof type: METAL

9. Change of mission? NO   Anticipated date: / /
   a) What specific plan:

10. Contact information. Who: JOHN DOE
    Contact's phone number:

11. Type of restriction: NONE   Who:
    Escort's phone number:

12. Comments:

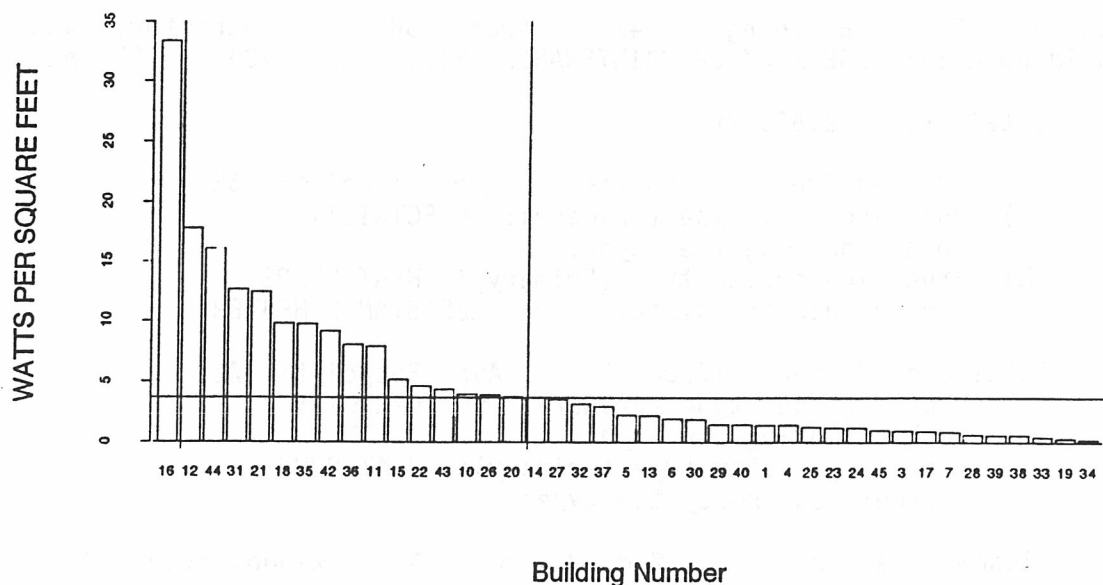Figure 1. Sample Building Information Sheet

Figure 2. Average Electric Power Densities for Hanford Buildings During the Period February 1, 1988, through July 31, 1988
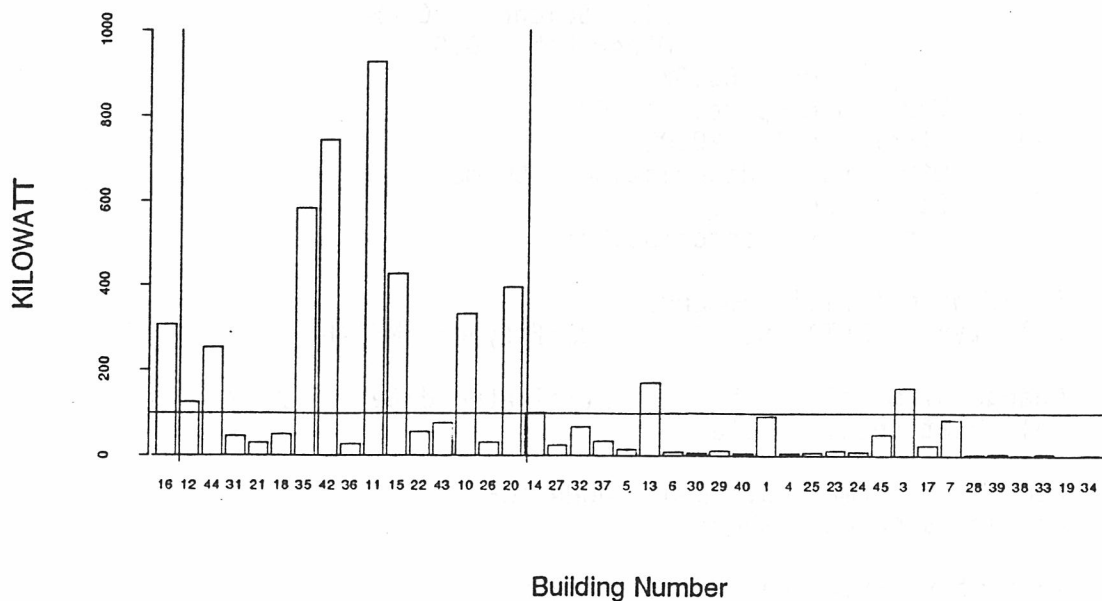
Figure 3. Average Electric Demands for Hanford Buildings During the Period February 1, 1988, through July 31, 1988

Table 1. Hanford Buildings Selected for Further Analysis

Building Number	Average W/ft²	Average Demand, kW	Building Description
12	17.7	124.6	Virology Lab and Dog Kennel
44	16.0	253.6	Computer Facility
31	12.6	46.2	Retention & Neut. Building
21	12.4	31.7	Generator Building
18	9.8	50.0	Radioactive Physics Bldg.
35	9.7	584.4	Plutonium Lab
42	9.1	744.6	Chemical Engr. Lab
36	8.0	27.6	Gamma Irradiation Facility
11	7.9	926.3	Life Science Building
15	5.1	426.2	Fabric Dev. Lab & Met. Shop
22	4.7	56.7	Office Building
43	4.4	77.0	Mock-Up Maintenance Bldg.
10	4.0	332.1	Process Treatment Building
26	3.9	32.4	Fire Station
20	3.7	395.4	High Temp Sodium Facility
13	2.2	171.4	Manufacturing Building
3	0.9	157.5	Spare Parts Warehouse
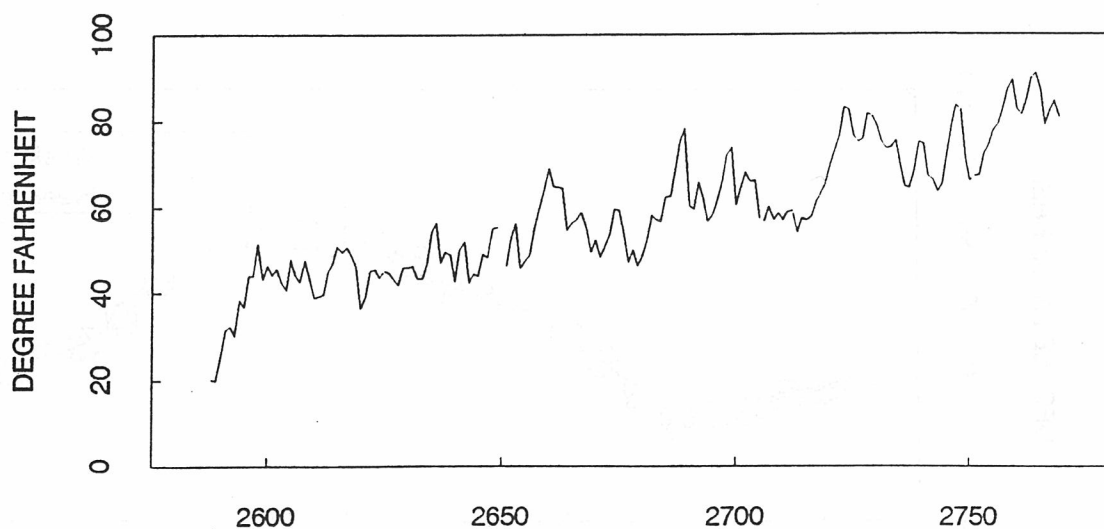
ELCAP Days

Feb 1, 1988 - Jul 31, 1988

Figure 4. Average Daily Outdoor Temperature at the Hanford Meteorological Station from February 1, 1988, through July 31, 1988
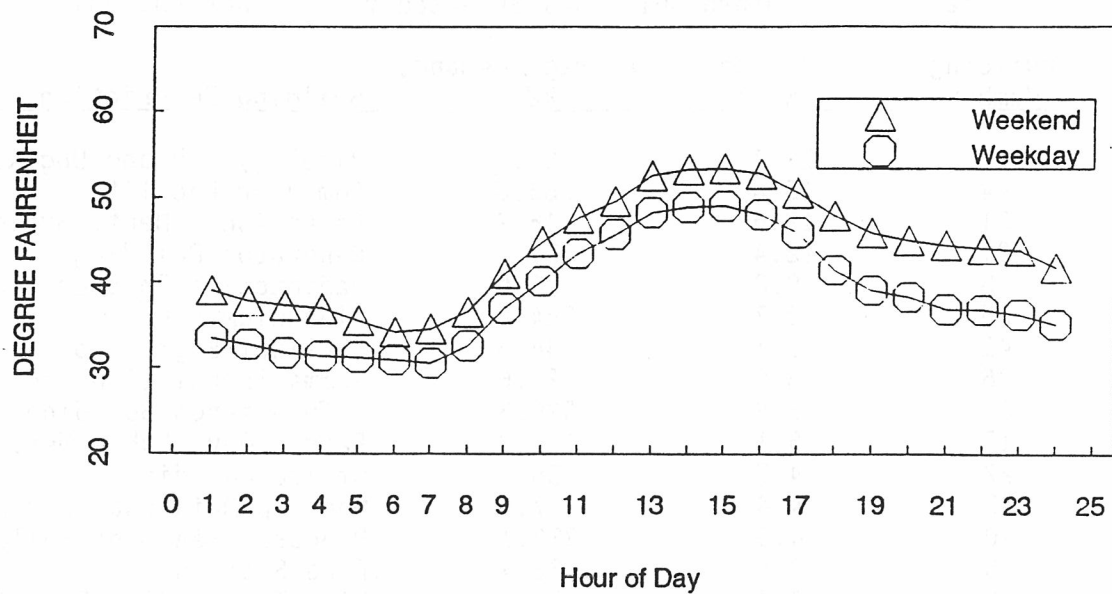
Figure 5.   Average Hourly Outdoor Temperature Profiles During
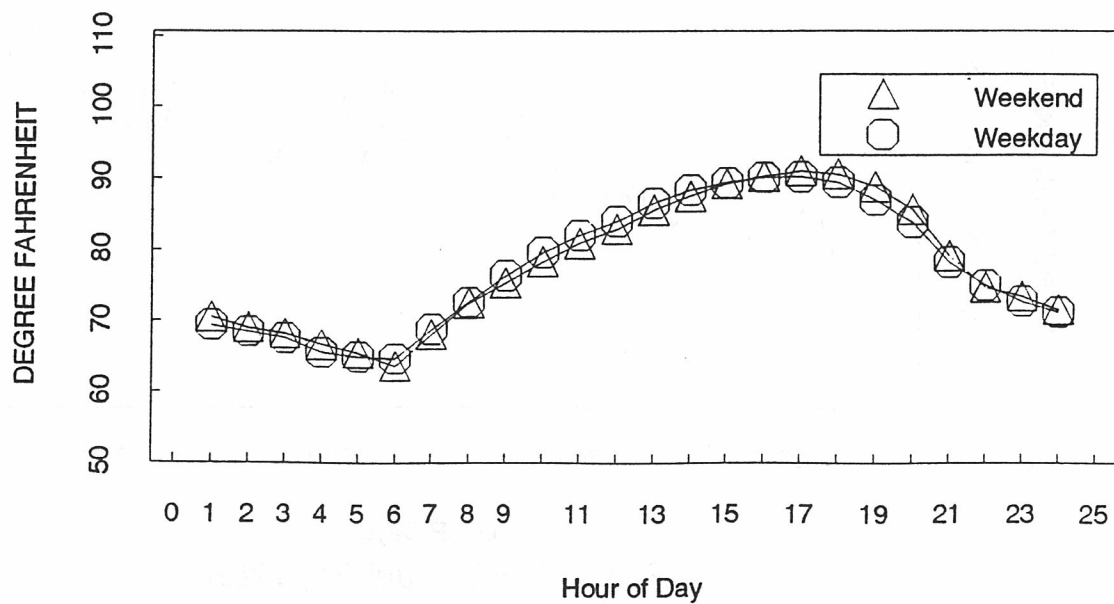February 1988 at the Hanford Meteorological Station

Figure 6.   Average Hourly Outdoor Temperature Profiles During
July 1988 at the Hanford Meteorological Station

Examination of Mean Electrical Use and Concurrent Outdoor Temperatures

Plots of mean daily outdoor temperature versus mean daily electric demand are very useful to compare building energy performance. These plots reveal the electrical loads that are sensitive to outdoor temperature and can reveal if electricity is used for space heating and/or cooling. Figures 7 and 8 display the data for two of the Hanford buildings. A number corresponding to the day of the week (0 for Sunday through 6 for Saturday) is positioned and then a curve is fit to the weekend and weekday data, respectively.

Figure 7 depicts u-shaped curves typical of buildings that are electrically heated and cooled. The minima of these curves indicates a "balance point" around 55°F. Moving away from this point in either direction, more energy is consumed, indicating that these loads are functions of the outdoor temperature. On the other hand, Figure 8 shows a building heated by steam from one of the central coal-fired heating plants. The winter electric load is about the same as the balance point. However, when approaching the summer time period, there is an increase in the energy consumption due to the electric air-conditioning load.

These plots aid in understanding the uses of electricity and how space-conditioning systems are actually operated. These plots can also assist in monitoring building performance from year to year because they graphically adjust for temperature differences. Both of the buildings have lower energy consumption on weekend days. However, the slopes of these curves are about the same or greater during the weekends. This could possibly indicate that the building occupants are not turning off the heating or cooling systems during the weekends. The lower consumption during the weekend can be explained by the fact that occupants leave the lights off. Therefore, by looking at plots like these, one can postulate possibilities for conserving energy in these buildings.

Examination of Hourly Energy Use Profiles

The analysis of hourly energy use profiles for one of the buildings (Building 43) is described. This building uses four large electric heat pumps and a small heat pump to heat and cool the entire building. Figure 9 depicts the mean electric consumption profiles for July 1988. From this plot, one can make the following conjectures. Between 6:00 am and 7:00 am, about the time work starts, there is a sharp increase in the energy consumption. Approximately the same amount of sharp decrease is shown around 4:00 pm, which is about the time workers go home. This suggests that the sharp increase and decrease are probably due to the turning on and off of indoor lights and equipment. As the internal gains and the outdoor temperature increase, the cooling load can be expected to increase between 7:00 am to 3:00 pm. After 4:00 pm, there is a continuous decrease in the cooling load because of the decrease in internal gains and outdoor temperature. For the weekends, represented by triangles, there is an increase in the cooling load between 10:00 am and 5:00 pm. This indicates that the building was cooled even though it was unoccupied during the weekends. Figure 10 indicates that the lighting
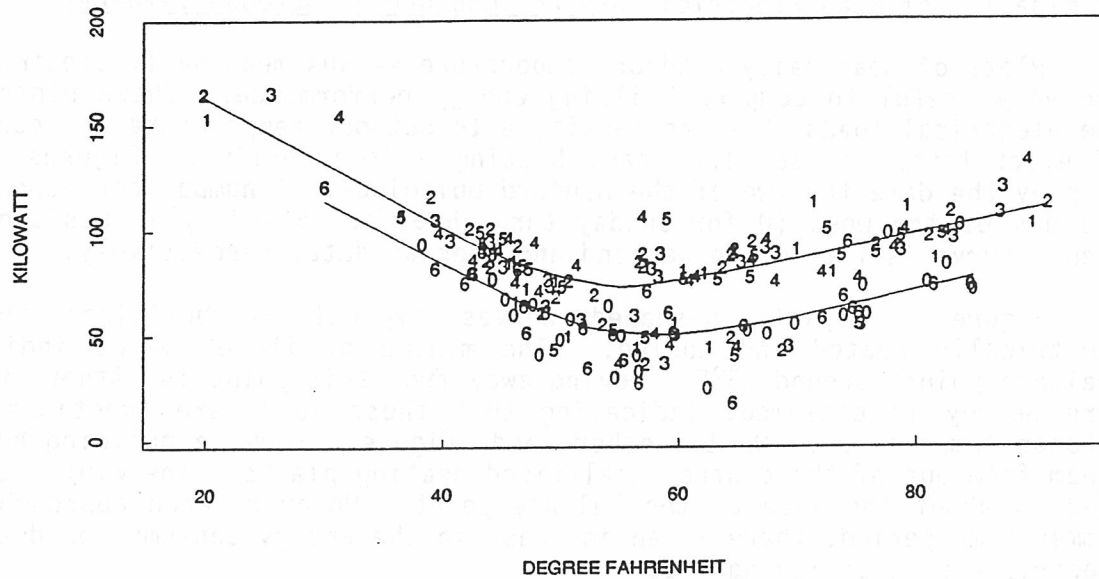
Figure 7. Average Daily Electrical Demand versus Average
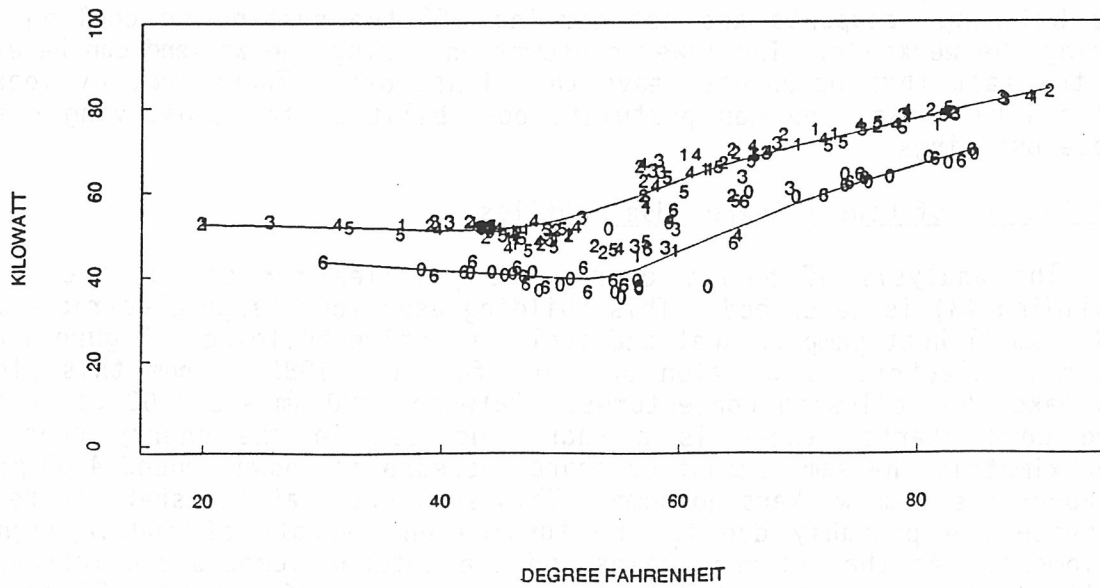Daily Outdoor Temperature for Building 43

Figure 8. Average Daily Electrical Demand versus Average
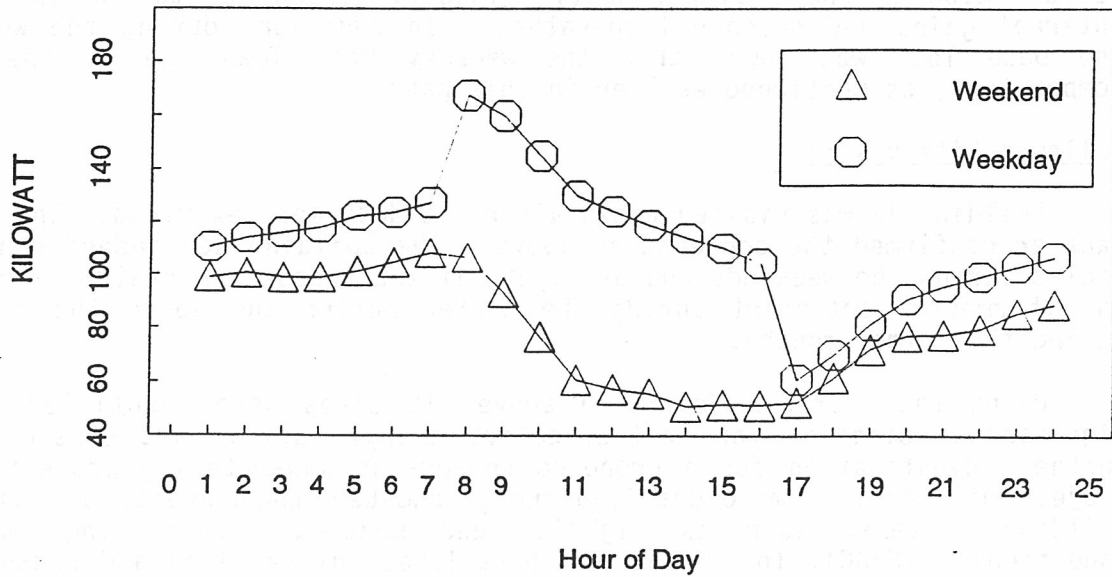Daily Outdoor Temperature for Building 22

Figure 9. Average Hourly Electrical Demand Profiles for
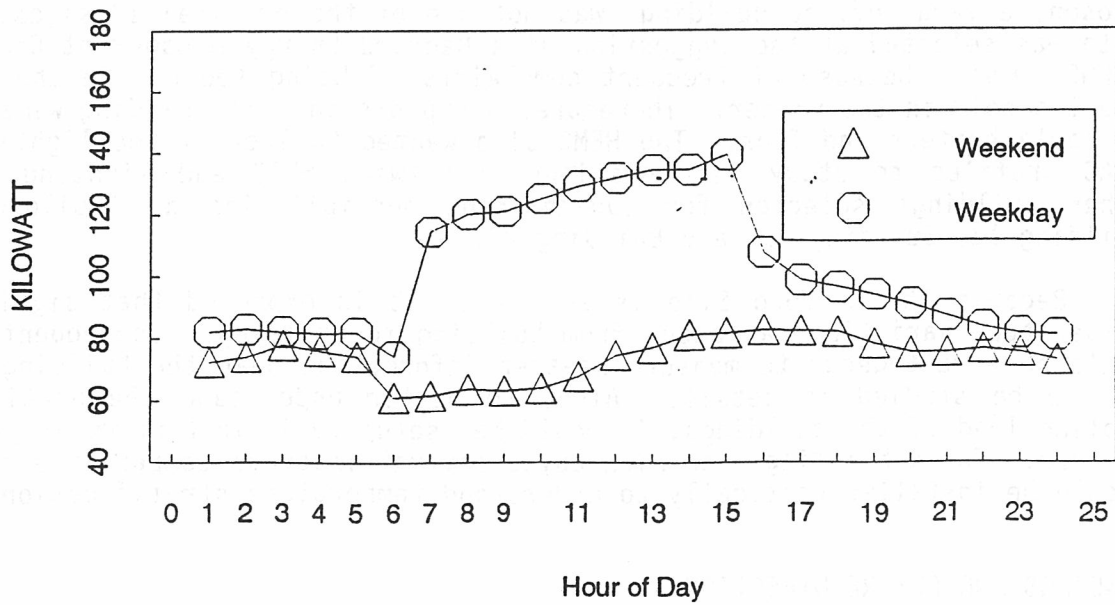Building 43 During February 1988 .

Figure 10. Average Hourly Electrical Demand Profiles for
Building 43 During July 1988

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load in the month of February is about the same as it is in July. However, between 8:00 am and 5:00 pm, heating load decreased due to the increase in internal gains and outdoor temperature. In addition, during the weekends, the base load was lower than the weekday base load due to the warmer temperature, as mentioned earlier in this paper.

Followup Site Visits

Building 43 was visited again after the data were examined. The building manager confirmed the conjectures above. The building was indeed heated and cooled during the weekends and at night, if the indoor temperature went below the thermostat set-point during the winter months and above the set-point during the summer months.

Using the approach described above, 10 sites were identified to have significant potential for cost-effective energy savings and considered for further investigation for a proposed energy-use sub-metering project. This project will collect more detailed energy end-use measurements of individual building systems, such as lighting and heating, ventilating, and air conditioning (HVAC), to confirm the postulated interactions and conservation potentials prior to design and installation of retrofits. This sub-metering will also permit the effectiveness of the individual measures to be established.

Recommendations for Further Evaluation

After followup visits were made to the sub-set of sites selected for further analysis, five sites were selected for sub-metering. One of the sites chosen, a large office building, was not one of the original 17 sites. This site was selected at the suggestion of a Hanford Energy Management Committee (HEMC) member because of frequent complaints of being too hot in the summer and too cold in the winter. Therefore, occupants in this building were adding portable heaters and fans. The HEMC also wanted to look at the lighting and HVAC profiles to study the relationship between HVAC and lighting loads. Other buildings selected for sub-metering possibilities are Building 11, Building 12, Building 43, and Building 22.

Because the Hanford Site is so large, it is expected that significant temperature variation may occur from building to building. Consequently, it would be advantageous to measure weather information near the buildings that are to be studied in detail. Also, to better understand the heating and cooling load of the buildings, it would be useful to install indoor temperature sensors. For a building with high bays, several interior temperature sensors should be installed vertically to understand temperature stratification.

FINDINGS AND FUTURE DIRECTIONS

This evaluation of electrical power measurements on the Hanford Site reveals that considerable insight can be gained regarding the opportunities

for electrical energy savings with small amounts of building characteristics and climate data. The ability to collect and examine time-series data at hourly intervals at low incremental cost makes such evaluations even more valuable because of the added insights of daily energy use schedules.

Through normalization and comparison of the measurements, several useful performance indicators are established. These include comparisons of power densities, sensitivity to outdoor air temperature, and comparisons of average working day and non-working day energy use profiles by season. The review of these indicators with building managers helps to stimulate and confirm thinking of energy savings opportunities and facilitate the development of projects to further study energy use and implement conservation measures.

With the support of the HEMC and the DOE In-house Energy Management Office, PNL will sub-meter the five most promising sites to further investigate energy use patterns and conservation potentials. This will be accomplished by adding additional power, equipment status, and temperature sensors to the data loggers already in place and by using new portable loggers to make additional measurements for short periods of time.

Following compilation and analysis of this more detailed data, it is envisioned that cost-effective energy saving opportunities will be identified and installed. With the continuing energy use and temperature measurements, it will be possible to empirically derive the energy savings achieved for comparison with the design estimates and simulation model results. Thus, we hope to demonstrate how metering technology is used in a step-wise fashion to target sites for evaluation of energy savings, confirm initial hypotheses of energy use patterns and conservation potentials, assist in the specification of energy saving measures, monitor the performance of conservation measures, improve the understanding of the installed performance of selected measures, and improve the tools and methods to identify, specify, and evaluate energy saving measures.

CONCLUSIONS

Our general observation from this work is that it is a logical and cost-effective application of scientific methods to cultivate energy use data that is collected principally for utility billing purposes. Where metering of previously unmetered sites is being considered, we highly recommend the use of hourly or sub-hourly data recorders collect information on energy use profiles and operation schedules. Although this can significantly increase the costs of metering, we believe that these costs can be offset by savings that result from applying the data to improve building operating practices or system efficiencies.

Collection and examination of concurrent outdoor temperature data is a valuable addition to the metered energy data. With this data, very useful comparison plots of daily energy use versus outdoor temperature can be generated. These plots can be used to differentiate buildings based upon the

size of the apparent base loads, heating loads, and cooling loads. Furthermore, these plots can be used to track the performance of the buildings over time as operational changes or efficiency improvements are made.

ACKNOWLEDGMENT