Short Term Energy Monitoring: What Does This Information Mean to the Facility Energy Manager?

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ABSTRACT

Engineers at the Energy Systems Laboratory at Texas A&M University have completed short term energy metering studies at a complex of offices in northern Texas and several buildings on the Texas A&M University campus during the past 18 months. These studies typically consisted of installing electrical metering at the whole building level and included sub-metering of selected circuits when possible. Personnel would go through the entire facility ensuring that all lighting, fan, and mechanical systems were active and on. After a period of approximately 10 minutes, a selected areas of the building would be "turned off." This sequence was repeated for all areas of interest in the facility. At the end of the lighting test, air handlers, then chilling and pumping equipment was turned off (if applicable) and a final ten minutes of electrical use data taken.

In each of these facilities, lighting system load verification was the primary goal and the data provided a very good accounting for all buildings studied. The northern Texas office buildings in particular, were interested in these data for comparison with a recently hired performance contractor. The A&M study was a follow-up to an earlier lighting study that had been conducted by the campus energy office. Base electrical load data was also determined from these tests. This paper presents results of these studies and suggests that the method is attractive to both contractors and facility energy managers as well.

INTRODUCTION

The short-term energy metering test (STEM) is a systematic approach to define the energy use of a building's connected electrical loads. The test is based on the measured difference of energy consumed between the operating (on) and disconnected (off) electrical load. Depending upon the building-use circumstances, this "snap-shot" can provide the fractional electrical demand level for lighting, plug loads, air conditioning equipment, etc.

Over the last 20 years, hospitals, schools, office complexes, hotels, industrial and military facilities have been reducing their energy use by utilizing energy services performance contracts (ESPCs) [Munson, 1998 and SmartBase, 1998]. ESPCs provide private and government agencies the capitol investment needed for energy conservation that is paid back from energy savings over a defined period. A popular form of these contracts is the "guaranteed" savings type that derive cash flow from the energy savings that are described in audit reports generated by energy consultants or performance contractors. The audit reports typically contain energy conservation retrofit measurements (ECRMs) that use technological improvements, upgrades, or replacements in lighting, heating, building envelope, air conditioning, and energy management control systems to reduce current and future energy consumption and associated costs. Energy consumption is often calculated from equipment specifications, nameplate data on building blueprints or "rule of thumb" assumptions. Unfortunately, energy saving calculations are often imprecise or, at best, inaccurate. The STEM test provides a short-term, measurable way to verify the energy savings calculated in these energy audits.

STEM tests can also provide facility owner/operators with important information concerning the amount of energy used in a building. Specifically, the magnitude of electrical demand is determined for various building electrical loads. This type of information can be used to help determine improvements needed in building operations. Additionally, if data is collected for a few weeks, the daily electrical use profiles and lighting profiles can be determined for the facility.

EQUIPMENT REQUIRED FOR A STEM TEST

Since the STEM test is based on a measured energy difference, some electrical instrumentation is needed. The equipment falls into two categories: instrumentation to measure the electrical systems and instrumentation to record the electrical data.

Ideally, a facility should meter the building's total electrical consumption. This can be achieved either through sharing a kWh output from the utility meter (simple) or by installing meters on the primary electrical service into the building (complex). In order to share the utility meter signal, the utility company would be required to install some type of signal splitting device from their pulse initiator. This digital pulse signal can then scaled to reflect the actual electrical usage at the building service entrance. Monitoring the building's primary electrical service can be more complicated because power (kW) is determined by metering electrical current (Amps) and voltage (Volts) for each of three phases. Current is measured through the installation of current transducers (CTs). CTs can be installed directly on the building's primary electrical service conductors or on the secondary-side of primary service panel CTs. With either primary or secondary CT metering, voltage is measured with the installation of a potential transducer (PT). The PT and CT need to be in phase with each other and referenced to the same transformer. Proper phasing of the CT and PT is probably the most common error made when installing power metering equipment. Power can be calculated with either a dedicated watt-hour transducer that produces a digital pulse output to a data logger, or the CT and PT can terminate directly into a data acquisition system (DAS). As with all electrical metering, correct scale factors and proper installation is extremely important for good data quality.

The current, voltage, or watt-hour transducer digital signal is wired directly into the DAS where the information is recorded and the data are stored. Most data acquisition systems can accept three types of signals: milliVolts (mV), milliAmps (mA), digital pulses or some combination of these signals. The equipment mentioned above produces outputs that fall into those categories. Often, facilities will have an energy management system (EMS) installed that has the capability to "trend" data. If an EMS is used, the software must be configured to record STEM test data and the facility control operator should know how to do this. With any type of data collecting system, the recording time will need to be in small increments, i.e., one-minute data.

Monitoring the whole building electric consumption is the basis for the STEM test because this measurement provides data to determine the connected electrical loads in a building. However, other building electrical loads can be included in the monitoring plan for information on power consumption and daily usage profiles. An example of this might be the electrical monitoring of the lighting on a floor with many offices and occupants. Sometimes it is helpful to take power measurements with hand-held meters while the equipment is operating. This provides quantitative data from the building components that contribute to the whole building electrical load and provides a quick check on the validity of the data being gathered at the DAS.

PROCEDURE

As with any type of electrical metering, the more that is known about the building, the better. One of the best ways to learn about building operation is to talk with the facility engineer and arrange a building tour with the facility maintenance personnel. These people probably know the most about the operational details of a building. They will know pump sizes, air handling unit (AHU) fan horsepower, the times of day people are in the office and what types of light bulbs are used. Before a building is toured, the ECRM report (if there is one) should be read in order to obtain the list of building components or mechanical equipment that were used to calculate energy savings. As the building is toured, notes should be taken on the specific equipment listed in the report for example, equipment nameplate data. In addition, the location of light switches, mechanical rooms, secured areas, elevators, stairwells, etc., should be noted. The main service entrance electrical distribution switchgear should be studied to determine how the whole building electric consumption is to be monitored. Most of the time, specific questions need to be asked as to the exact loads served by an electrical distribution system. THIS SHOULD BE VERIFIED, if possible, through building plans and/or physically tracing the electrical system.

After the metering instrumentation and DAS have been installed, a timetable or test chronology must be established. The STEM test should be performed at a time when connected building electrical loads can be shut down without disturbing normal operations. If the EMS is going to be used, the system will need to be programmed to support the test chronology. Since the STEM test is an independent verification of connected load energy, the systems included in the ECRM report should also be the systems included in the STEM test (lighting, AHUs, etc.).

The following steps describe a typical STEM test:

1. The data logger or EMS is programmed to collect data at a pre-determined interval (one minute intervals work well)
2. At least two people are needed: one at the data logger to take notes and one to operate the building's electrical systems
3. All electrical systems are turned on in the building
4. The first electrical load is turned off (for example, 10th floor lights)
5. The time and electrical load level is noted by the person at the data logger
6. Wait for an adequate interval to develop a steady electrical use level. The Energy Systems Laboratory uses a 10 minute interval for the DAS to collect data
7. The next electrical load is turned off
8. The time and electrical load is noted by the person at the data logger
9. Eventually, all electrical systems are turned off in the building
10. Wait a final time interval (10 minutes)
11. Test Complete.

STEM TEST EXAMPLE

The following section presents results for STEM tests that were conducted by researchers of the Energy Systems Laboratory (ESL) at a county service complex located in north Texas and at two buildings at the Texas A&M University main campus. The county complex, encompassing about 320,000 square feet, was divided into two buildings, a north and south tower, that were primarily used as offices and various county services. The facility engineer of the complex contacted the ESL after a performance contractor had conducted an energy audit. Concerned about the validity of savings calculated in the ECRM report, the engineer was interested in connected load verification before they signed a performance contract. The ESL received a copy of the ECRM report to review and scheduled a building tour. The proposed retrofits in the report included lighting, chillers and air handling units. The buildings at Texas A&M University included two combined office/classroom buildings and a laboratory building. The physical plant energy engineers were interested in the connected lighting load levels and determining the weekday and weekend light profiles. This information was to be used to evaluate a proposed lighting system upgrade and retrofit.

<u>STEM Test Example – Procedure: County Buildings</u>

ESL personnel conducted a walk-through of the county service complex during a weekday morning. Notes were taken about the building schedules, equipment locations, and personnel contacts. Fortunately, the ESL already had energy monitoring equipment installed in this complex under a previous contract. The energy metering included whole building electric (for both towers) and mechanical systems (chillers, pumps, AHUs). Lighting information was derived by subtracting the mechanical load data from the whole building electrical load. On that evening, the STEM test was performed beginning about 9 p.m. and finishing about 5:15 a.m. the next morning.

After arriving at the site, the ESL team connected a laptop computer to the DAS and set the data collection interval to one minute. Then, with the aid of county personnel, all floors of all sections of the complex were toured to confirm that all lights and air handling units were operating.

The STEM test followed these steps in sequence:

1. Turned off all lights floor-by-floor in the building
2. Waited 10 minutes for the logger to collect steady-state data for each floor before beginning next step
3. Turned off all mechanical systems in the entire complex
4. Waited 10 minutes for the logger to collect data before beginning next step
5. Test Complete

<u>STEM Test Example - Data Analysis</u>

Figure 1 provides a graphical representation of the results of the STEM test for the North tower and Figure 2 represents the data for the South tower. In each figure, the kW demand is shown versus the TSR number. The data points are plotted showing the progression of the test as the AHUs and then the lights are turned off. The data are "jumpy" due to the discrete number of pulses from the utility meter that were then converted using energy and time conversion factors to arrive at an average demand level.

<u>STEM Test Example - Connected Loads Determination</u>

Table 1 shows the demand level from each of the steps from the STEM test data. The AHUs for the North Tower were found to have a demand of about 67 kW. The chiller plant and penthouse electrical services had been sub-metered under a previous contract. The 67 kW demand was obtained by taking the average demand before the AHUs were turned off (125 kW) and subtracting the remainder (58 kW). Notes from the walk-through showed that the remaining equipment consisted of several large exhaust fans and a chilled water circulating pump.

The value given in the ECRM report was approximately 30 kW in a section that calculated savings based on the use of an EMS to control start-stop of air handlers and pumps.

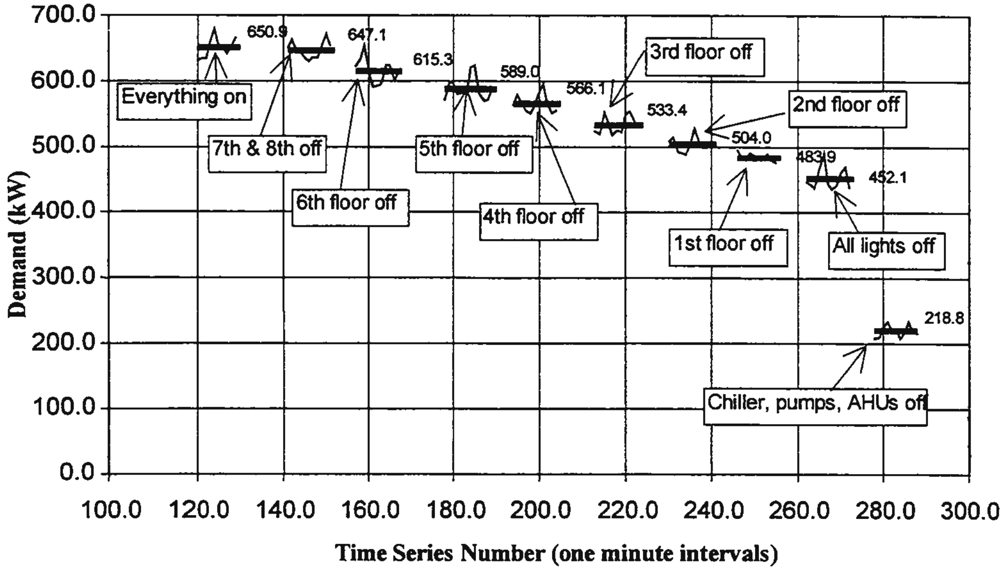

Figure 1. Results of North Tower STEM Test

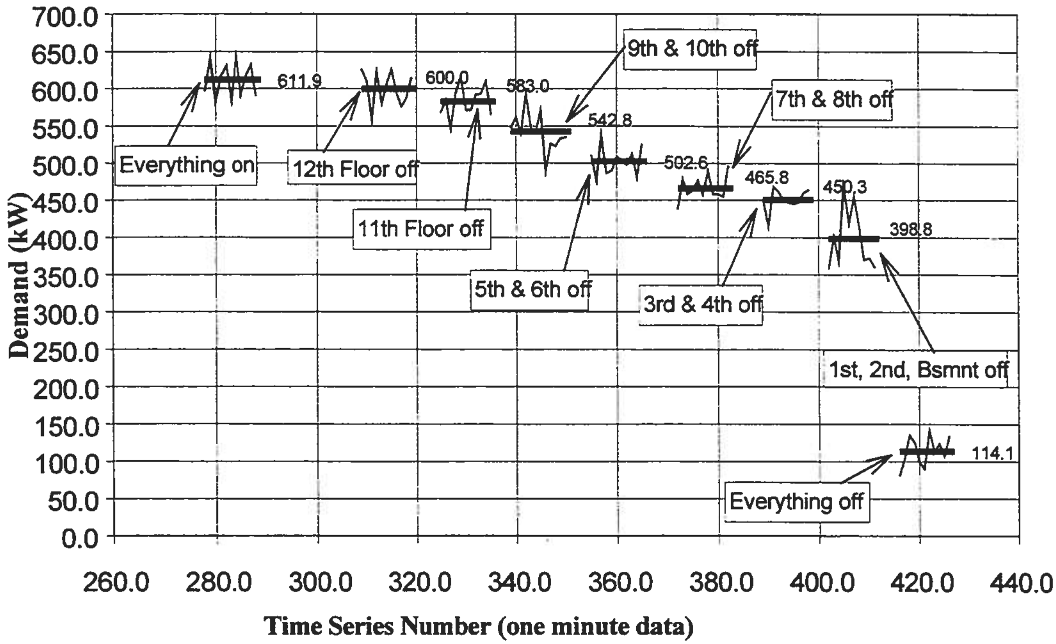

Figure 2. Results of South Tower STEM Test

A direct comparison between the measured STEM test data and the ECRM report was difficult. According to County Complex personnel, the 150 hp motors in the penthouse mechanical room could be operated with one motor running while the other was "free wheeling." This might help to explain the discrepancy between the ESL data showing about 67 kW and the ECRM reported value of 224 kW. If, during the STEM test, one motor was idle and the other was lightly loaded (implied poor power factor), then the data were acceptable. It appears then, that the ECRM savings calculations were based upon both motors running at full load and that is not always the case.

As with the North Tower, the data show about 70 kW for the multizone AHUs in the South tower. There was good agreement between the STEM test data and the ECRM report. The data of the ECRM report showed approximately 64 kW for the South Tower AHUs. Again, it seemed that ECRM report assumed that all the motors were fully loaded for their calculations.

Table 1. April 2-3, 1998 STEM Test Data Results

Step	Demand Level (kW)	Difference (kW)	Cumulative Difference (kW)
All on - North tower	650		
7th & 8th floor lights off (1*)	647	3	3
6th floor lights off	615	32	35
5th floor lights off	589	26	61
4th floor lights off	566	23	84
3rd floor lights off	533	33	117
2nd floor lights off	503	30	147
1st floor lights off	483	20	167
All lights off (2*)	452	31	198
Turn off chiller, pumps, and AHUs	218	234	432
All on - South tower	611		
12th floor lights off (3*)	600	11	11
11th floor lights off	583	17	28
9th & 10th floor lights off	543	40	68
7th & 8th floor lights off	503	40	108
5th & 6th floor lights off	466	37	145
3rd & 4th floor lights off	450	16	161
1st, 2nd, and Basement floor lights off (4*)	399	51	212
Turn off chiller, pumps, and AHUs	114	285	497

(*Notes): 1. Difference is level of demand for that floor's lights
2. 198 kW demand for North tower lighting
3. Difference is level of demand for that floor's lights
4. 212 kW demand for South tower lighting

The power drawn by the lighting in the North Tower during the STEM test was determined by noting the drop in demand level as each floor of lighting was turned off. The summation of these differences yielded a total lighting demand level of approximately 410 kW. The first two columns of Table 2 were extracted from the ECRM report and the third column is the demand consumption (kW) which is the result of multiplying the quantity of fixtures by the watts/fixture. The total demand found by this analysis was 731.5 kW. The ECRM value was about 42% above the lighting kW level found during the STEM test (410 kW vs. 731.5 kW). Emergency lighting and outdoor lighting were not turned off during the STEM test.

Table 2. Current Lighting Demand (ECRM Report)

Fixture Quantity	Watt/Fixture	Total kW
4218	164	637.4
52	82	7.9
167	82	12.6
182	82	13.8
39	82	3
119	43	4.7
161	82	12.2
38	140	4.9
16	26	0.4
89	20	1.6
46	82	3.5
108	41	4.1
117	90	9.7
12	246	2.7
172	82	13
	Total	731.5 kW

STEM Test Example - Baseload Demand

The North Towers Building baseload, after all the lights and AHUs were turned off, was found to be about 332 kW by the STEM test. The remaining baseload probably included the following:

1 Miscellaneous exhaust fans, pumps, soft drink machines, refrigerators and freezers, and small air handlers.
2. Emergency lighting.
3. The large number of computers, printers, monitors, copiers, and other office equipment left on overnight.

During the test, ESL engineers did not quantify the amount and type of equipment in the offices, but it was very noticeable that a considerable percentage of the office equipment in place was left running after hours.

ESL engineers made the following recommendations to the building owners after analysis of the STEM test.

1. Determine the composition of the 332 kW "baseload" found during the STEM test.
   a. Survey the building over several nights to determine the quantity of lights left on after the cleaning crew is finished.
   b. Survey the building over several nights to determine the types of office equipment left running, and associated demand
2. Initiate a program to encourage employees to turn off office equipment as they leave at the end of the day. Monitor success and follow-through.
3. Determine the nature of the weekend energy usage beginning at about 9:00 am and continuing through the rest of the day.

TEXAS A&M STEM

A STEM test was conducted at the Engineering Physics Building (EPB) on the main Campus of Texas A&M University to determine demand levels for lighting and potential savings for a proposed lighting retrofit. The electrical demand due to lighting was determined by collecting energy data for one week from which load fractions were calculated. EPB is divided into two buildings, the teaching side and the office side. The teaching side includes graduate student offices, laboratories and a lecture hall. The office side is primarily offices and conference rooms.

Under a previous contract with Texas A&M physical plant, a permanent building energy data logger had been installed by the ESL to monitor the whole building electric and thermal energy use of the EPB. In the fall of 1998, Texas A&M Physical Plant personnel contracted with the ESL to conduct tests to help determine lighting profiles in selected buildings. The Engineering Physics Building was the first building tested. Before the STEM test, the ESL team installed three additional temporary data loggers to monitor the energy use for lighting circuits on the office side, lighting circuits on the teaching side, and the office third floor lighting circuits.

After arriving at the site, the ESL team, with the aid of physical plant personnel, turned on all lighting and air handling units (AHUs) in both teaching and office sides of the EPB. As with the previous metering test, data were collected for ten minutes (steady state) as desired loads were turned off.

Major results for this test were:

Lighting: The total demand level of all lighting was found to be about 277 kW. The lighting energy used during a typical academic workweek in the Engineering Physics Building-Office side was determined to be 6,700 kilowatt-hours and the measured lighting load fraction was 59%. The lighting energy used during a typical academic workweek in the Engineering Physics Building-Teaching side was about 12,365 kilowatt-hours while the measured lighting load fraction was 40%.

Miscellaneous: An unidentified demand baseload of about 25 kW in the Engineering Physics Building Office wing exists when the lights, AHUs and pumps are turned off. This value was 100 kW for the EPB Teaching wing under the same conditions. As with the County buildings, office equipment that was left running overnight may be contributing to the majority this baseload.

Table 3 shows the energy savings for lighting in EPB using new T-8 lighting fixtures with the number of new bulbs and ballast the same number as those currently installed in EPB. The number of operating hours, based on the LLF, are shown for one week. The kilowatt-hours were calculated by multiplying the connected lighting load by the number of operating hours in one week. The kilowatt-hours were calculated for the current lighting energy used. The kilowatt-hours were also calculated as if the T-8 lighting fixtures were installed. The difference between the lighting fixtures is shown as the weekly savings in kWh. The yearly savings calculation is based on 48 weeks in the calendar year. Four weeks were discounted for holiday breaks during the year. There is approximately a 15% reduction in energy.

Table 3. Kilowatt-hours used during a typical academic workweek

	Energy Use During One Week (kWh)	Connected Lighting Load (kW)	Hours During Test (hr)	Lighting Load Fraction
Office Side Lighting	6700	67.4	168	59%

Tables 4 and 5 shows the energy savings for lighting in EPB using new T-8 lighting fixtures. The number of new bulbs and ballast shown is less than the number of bulbs and ballast currently installed in EPB. The three-bulb/two ballast fixtures are replaced with the three-bulb/one ballast fixtures. The number of operating hours, based on the LLF, are shown for one week. The kilowatt-hours were calculated by multiplying the connected lighting load by the number of operating hours in one week.

Table 4. Scenario 1: Fixtures Replaced with the same number of T-8 Fixtures and Ballast.

Current Lighting Load (kW)	New T-8 Fixtures (kW)	Operational Hours (One Week)	Current Weekly Usage (kWh)	New T-8 Weekly usage (kWh)	Weekly Savings (kWh)	Yearly Savings (kWh)
71.9	61.7	99.1	7125	6115	1011	48,528

The kilowatt-hours were calculated for the current lighting energy used. The kilowatt-hours were also calculated as if the T-8 lighting fixtures were installed. The difference between the lighting fixtures is shown as the weekly savings in kWh. The yearly savings calculation is based on 48 weeks in the calendar year. Four weeks were discounted for holiday breaks during the year. There is approximately a 10% reduction in energy.

Table 5. Scenario 2: Fixtures Replaced with Single T-8 Fixtures and Ballast

Current Lighting Load (kW)	New T-8 Fixtures Lighting Load (kW)	Operational Hours (One Week)	Current Week usage (kWh)	New T-8 Week usage (kWh)	Weekly Savings In (kWh)	Yearly Savings (kWh)
71.9	66.6	99.1	7125	6600	525	25,200

DISCUSSION

The STEM test was successful in determining the connected energy loads, lighting and mechanical for the Dallas county complex building and at the Engineering Physics Building at Texas A&M. The lighting load was clearly established for each floor of both complexes. Figures 1 and 2 clearly show energy load drops, or "steps", as lighting, AHUs and mechanical systems were sequentially shut down. With each step, the magnitude of the lighting loads for each floor of the respective building could be established with a high degree of confidence. Unfortunately, there were some discrepancies between the lighting loads of the STEM test and the performance contract report for the county buildings. However, the multizone AHU energy load in the South Tower 70 kW compared very well to 64 kW as calculated by the performance contractor. The county engineer's goal was achieved because the STEM test provided a "before retrofit" magnitude of demand energy (kW) for the connected electrical loads in the county complex building.

With the STEM information, the county engineer negotiated/discussed discrepancies with the performance contractor. Since the STEM test had been performed by an impartial third party, there was less friction and mistrust between the engineer and the performance contractor. From the test data, the contractor was able to determine that their lighting subcontractor had miscounted the number of lights in the building which explained the discrepancy in the lighting load. Conversely, the STEM test verified the contractor's report for the AHU energy loads. After the problems were resolved there was confidence in the proposed energy conservation retrofits. The STEM test provided unambiguous data that formed a solid base for communication between contractor and owner and helped develop trust between the parties.

The STEM test performed in the Engineering Physics Building established the electrical demand level for each floor's lighting load (Figure 3). EPB teaching side has a higher demand, 210 kW than the EPB office side at 67 kW. After the lights, AHUs and pumps were shut off in the building, a baseload of 100 kW and 25 kW were found for the teaching and office sides respectively. This residual load could be attributed to electrical systems that were not turned off during the STEM test. These could include emergency lighting, refrigerators, vending machines, computers, and miscellaneous exhaust fans. For example, the electrical drawings for this building show a total load of approximately 10.9 kW for all of the EPB.

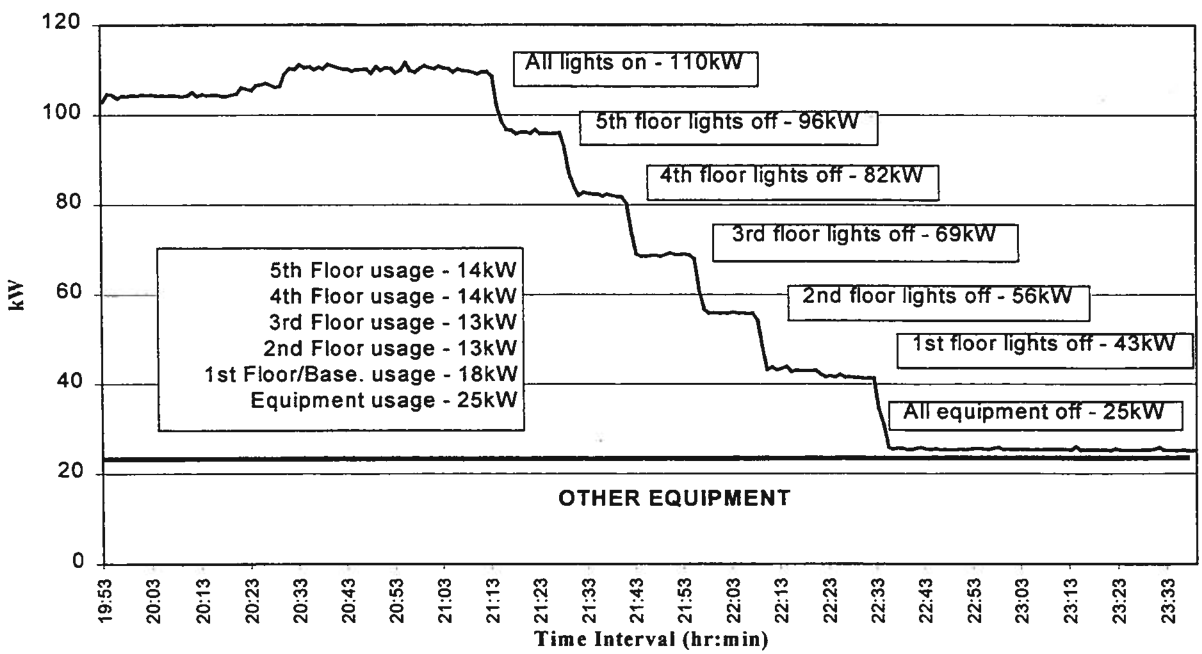

Figure 3. Results of Engineering Physics Building Office Side Blink Test.

From the weekly data profiles, Figures 4 and 5, the total amount of lighting energy used, in kilowatt-hours, was calculated. The total amount of energy, in kilowatt-hours, was calculated based on the assumption that all of the lighting was operating. The lighting load fraction is the percentage of energy used for lighting to the total connected load available to the lighting. This definition of the lighting load fraction accounts for diversity of lighting use. This fraction can be useful in estimating the savings from alternative lighting technologies. The lighting load fractions were found to be higher in the office side than the teaching side. Based strictly on the manufacturer's energy specifications, replacing EPB's lighting fixtures with T-8 bulbs and electronic ballast would decrease lighting energy by 10-15%.

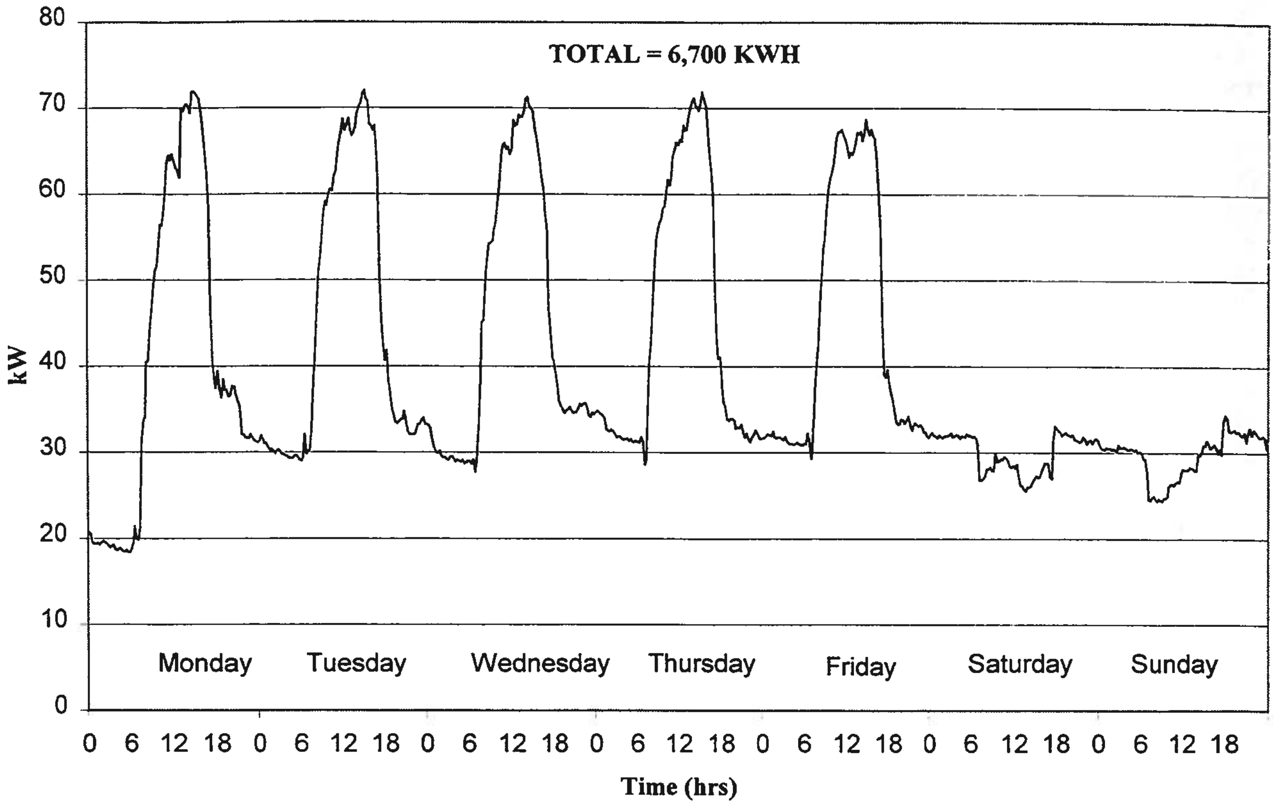

Figure 4. Weekly Lighting Load Profile for Engineering Physics Building, Office Side

An unexpected result of the STEM test was the magnitude of the baseload discovered in all of the county buildings and in the Texas A&M building. The baseload describes the magnitude of energy being consumed by electrical loads that were not turned off during the STEM test (computer CPUs, computer monitors, refrigerators, copiers, etc.). With the STEM test results, the county engineers had the data needed to justify the implementation of an energy awareness program for the county complex employees. The Energy System Lab has done subsequent STEM tests on other county buildings in the North Texas area. Interestingly, these buildings too have had high, unexplained baseline electrical loads similar to the county service complex.

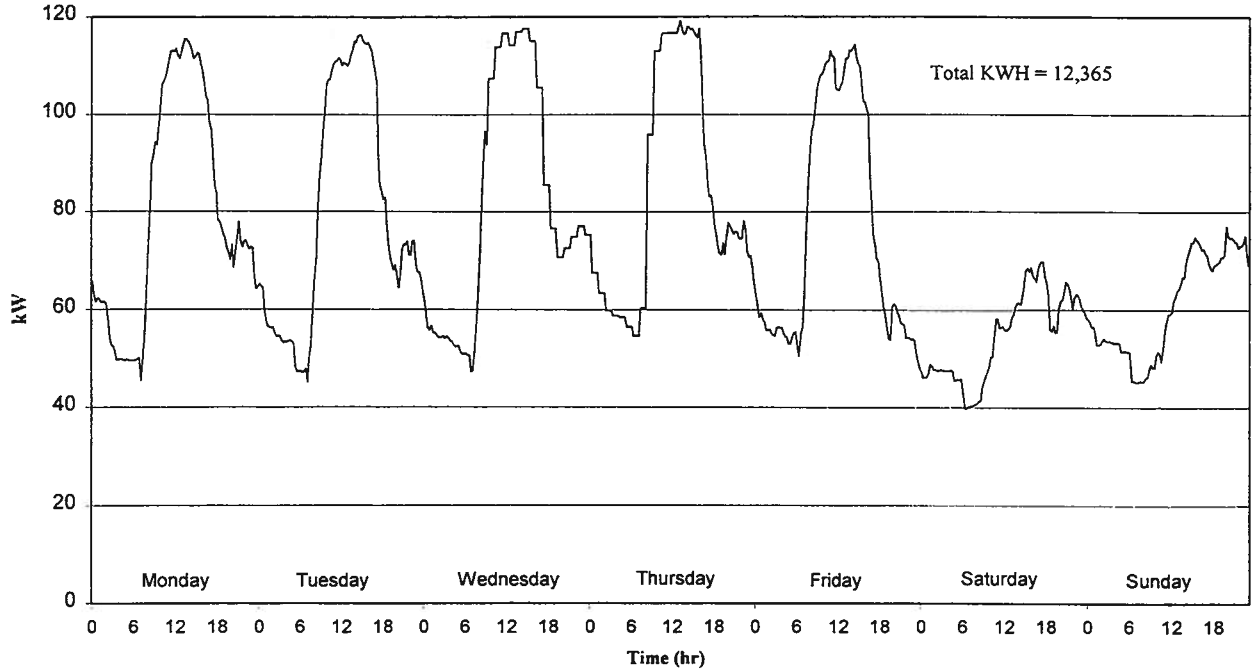

Figure 5. Weekly Electrical Lighting Profile for Engineering Physics Building, Teaching Side

The Texas A&M physical plant is evaluating the results of the STEM test on the EPB complex. The unidentified baseload is a concern and steps are being taken to identify possible sources and ways to reduce the magnitude of the load. The A&M system has recently contracted with the ESL to conduct STEM tests on several additional buildings on the main campus.

The STEM test can provide valuable information on connected electrical energy loads in a building. Whether used for verification of performance contract reports or general energy use information, the STEM test can be useful in determining demand energy loads and the magnitude of baseline electrical loads. These results can be used to find ways to improve energy usage and improve energy conservation.

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