Extended Industrial Energy Assessments Supported by Monitoring[1]

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ABSTRACT

One week of monitored demand, temperature or on-off data has been used in studies of 11 industrial plants to provide substantiation for energy conservation projects and to study demand control. Both centrally located loggers for monitoring electrical phase information from remote sensors and individual, self-contained sensor-logger combination units with generally simpler output have been used.

Extended assessments involving about two additional days in each of seven plants are discussed in detail in this paper. The additional days provided more time to study plant energy consuming equipment, waste management, and productivity issues. More time was available to interview plant personnel about related concerns and possible solutions, thus leading to identification of more projects to study. This led to about two more recommended projects in each final report (a 25% increase). Recent average savings are $13,000 per year per recommended project. A program day costs about $6,000, so the payback for up to two additional days is less than one-half year.

Data was obtained that led to the identification of several equipment turn off projects. Accurate data on duty factors (and in the case of the centrally located loggers demand factors) also result to support energy conservation calculations. However, the projects were small in terms of annual cost savings. They are not cost effective when compared to the program cost of the additional time and effort to install and remove the loggers, having a simple payback in excess of two years.

No demand control projects in the form of demand reduction or demand shifting were identified, supporting the conclusion that small and medium-sized industry is not a good candidate for demand control.

Introduction

Texas A&M University (TAMU) has operated an Industrial Assessment Center (formerly known as an Energy Analysis and Diagnostic Center) supported by the U.S. Department of Energy since 1986. Major goals of the Industrial Assessment Center (IAC)

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program include providing practical educational opportunities for university students and serving the needs of small and medium-sized manufacturers. IAC's are located strategically around the nation in order to involve universities and manufacturers over a large area. Manufacturers are served by plant assessment visits made by students supervised by engineering faculty members or other qualified university staff. After each visit, a formal, technical report written in terms of projects recommended for implementation is supplied to the manufacturer. Manufacturers must be classified within standard industrial classification (SIC) major group 20 through 39. With the advent of U.S. DOE's Industries of the Future (IOF) program, the IAC program now focuses on IOF plants, suppliers and customers.

The Texas A&M IAC has involved 180 students and served almost 400 manufacturers, recommending 3000 projects and $16.5 million per year of cost savings. Each manufacturer is surveyed within a year of receiving their report to determine what resulted in the plant. Based on 373 surveys, manufacturers have implemented 62% of the projects recommended and have achieved 57% of the potential cost savings. Nationally the fractions are about the same (Office of Industrial Productivity and Energy Analysis 2001).

The Houston-Gulf Coast area, with a major concentration of manufacturing plants and large-scale energy consumption, is the main area served by TAMU. Texas spent $5.35 billion in 1992 for manufacturing electricity and fuels (12% more than California, the next largest consumer state), and consumed over 76 million MWh of electricity for manufacturing, the most of any state (Bureau of the Census 1992). Houston (90 miles from TAMU) has long been one of the most energy-intensive manufacturing areas in the nation (Bureau of the Census 1982). The Houston area has both small and medium-size IOF plants and large IOF manufacturers such as chemical and petroleum refining plants. A recent advertisement for a directory of manufacturers lists 4,074 plants in the city of Houston—only Chicago had more plants (Manufacturers' News Inc. 2000). Approximately 95% fall within the program criteria for small and medium-size manufacturers and many are IOF plants. There are about 100 large IOF plants in the area that are too large for the program criteria but that TAMU may be able to serve under special arrangement (Bureau of Business Research 1999).

Approximately 20% of TAMU past assessments have been to IOF industries and that number will rise as more attention is given IOF industries, suppliers and customers. Most assessment visits take one day away from the campus, but in January 2000, the TAMU IAC spent three days at a fiberglass plant in one of the first IAC visits to a large ($216 million in gross annual sales and $8.3 million in annual energy costs) IOF manufacturer.

In addition to interest in IOF assessments, the TAMU IAC has experimented with extended assessments and in-plant monitoring for a number of years. Monitoring in seven plants before the IAC visit was designed to provide backup for assessment recommendations in reports (Farouz et al. 1999; Heffington et al. 1998).[2] Monitoring of three other plants was for the main purpose of studying demand control and related issues, and occurred in plants identified as candidates during an IAC visit (Dooley & Heffington 1998; Dorhofer & Heffington 1994; Heffington, Dorhofer & Lewis, 1996; Lewis, Dorhofer & Heffington 1995).

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[2] One plant (377) was monitored by equipment installed by the IAC team during the formal plant visit.

Extended Assessments

Texas A&M University has accomplished a total of seven assessments (plants 330, 331, 332, 354, 355, 357, and 376) supported by monitoring equipment placed in the plant and removed before the formal plant visit. The data was intended to support demand control and energy conservation projects, giving insights into investigation and data gathering that might be made during the formal plant visit by the full assessment team (usually two staff members and about six students). Results from plants 330, 331 and 332 were published previously (Farouz et al. 1999; Heffington et al. 1998).

The earlier results are noteworthy because they were obtained with portable data loggers centrally located near electrical control centers, using sensors (e.g. current transducers) on electrical circuits connected to the loggers via wiring runs as long as 600 ft (Dorhofer & Heffington 1994). Phase current and voltage signals were measured and were available directly from the loggers. However, the loggers can convert current and voltage data to supply power (real, apparent and reactive), power factor and energy consumption information when downloaded. Demand time histories of real and apparent power generally were most useful. Such time histories reveal duty factor (on-off) information and can be integrated to yield energy use. Monitoring three-phase electrical equipment requires at least two sensors, two wires from the sensors to the logger, and two recording channels in the logger. The cost of the equipment and supplies (installation and data analysis costs not included) in one plant was estimated to be $8,000 (Dorhofer & Heffington 1994). The loggers used in these studies generally were able to monitor up to eight items of electrical equipment. Lack of channels, difficulty and safety of installation, and wiring run distance to the loggers all are considerations and sometimes obstacles in selecting equipment to be monitored.

Monitoring in the first three plants contrasts with the last four plants where data was obtained with more easily installed, self-contained, sensor-logger units needing neither wiring nor a central data logger. More time and skilled technical assistance are needed to install the central data logger and its sensors.

Results from Centrally Located Loggers

Table 1 summarizes plant data regarding three plants monitored with centrally located loggers and remote sensors. The energy consumption data is from utility bills. In each case, at least one visit was made to the plant to install the logger and another visit was made to retrieve the logger about one week later so that the data would be available for review before the formal assessment visit. Installation and removal time was always two days or more. In each plant one week of 15-minute data, including weekend work or shut down was obtained. An Energy Systems Laboratory staff member, an electrician and at least one student made each visit to install or remove systems. Production and personnel safety always are important issues. In order not to interfere with production, no circuits (usually 480 volt) were deactivated for sensor installation or removal.

Table 1. Summary of Product and Energy Consumption Data for Plants 330, 331, and 332

Visit Number	Main Product	Annual Energy Consumption			
		Electricity (kWh)	Monthly Demand (kW)	Natural Gas (MCF)	Total Cost ($)
330	Aluminum extrusions	2,300,000	500	16,000	270,000
331	Paper products	3,600,000	650	1,000	190,000
332	Centrifugal castings	5,000,000	2,000	41,000	540,000

Plant 330 produces extrusions such as storefronts and window frames. It has two extrusion press lines with 200-hp electric drive motors capable of handling 6-inch diameter aluminum billets. The demand time-history of six systems associated with extrusion press 2 was monitored with a centrally located logger (the on-off status of two lighting circuits was monitored by self-contained loggers). The total electrical feed for press 2 was monitored and included the main 200-hp motor, a 40-hp auxiliary motor, a 25-hp stretcher motor on a work-hardening operation associated with the press, billet heater fans, and other equipment such as electric resistance die heaters. In addition, the main 200-hp drive motor, 25-hp stretcher motor, and 25-hp billet heater exhaust fan were monitored separately. A bank of 24, 1-hp cooling fans and a 25-hp cutoff saw were also monitored. All motors were alternating current. Review of the total circuit data for press 2 and of the data for the larger motor revealed only normal operation. Two small projects involving turning motors off when not in use were identified for two of the 25-hp motors and a similar lighting turn-off project was identified from one of the self-contained loggers. Figure 1 shows a sample of the demand time-history data that can be obtained from the relatively sophisticated central loggers. Such data can be integrated over time to give accurate energy savings. It can also be expanded to show more detail. Figures such as Figure 1 from all the monitored channels were included as an additional section in the final assessment report sent to the manufacturers. Total savings were estimated to be 22,500 kWh per year and $1,000 per year (Heffington et al. 1998).

One unique feature of this visit involved the bank of cooling fans. Monitored data showed that some fans inappropriately were turned off when product cooling was desired. This data was reviewed during the plant visit and management personnel immediately suspected this condition to be a possible cause of recent quality control problems. The suspicion led in turn to employee education efforts. However, savings could not be quantified.

Plant 331 has three production areas producing pressure-sensitive labels, adding machine rolls, and impact and thermal transfer ribbons. Environment is important to product handling and the plant is air-conditioned with nine, 30-ton roof top units (RTU). Due to environmental needs, the RTU's did not appear to be good candidates for such projects as short cycling for demand control, and there was not logger capacity to monitor all of them.

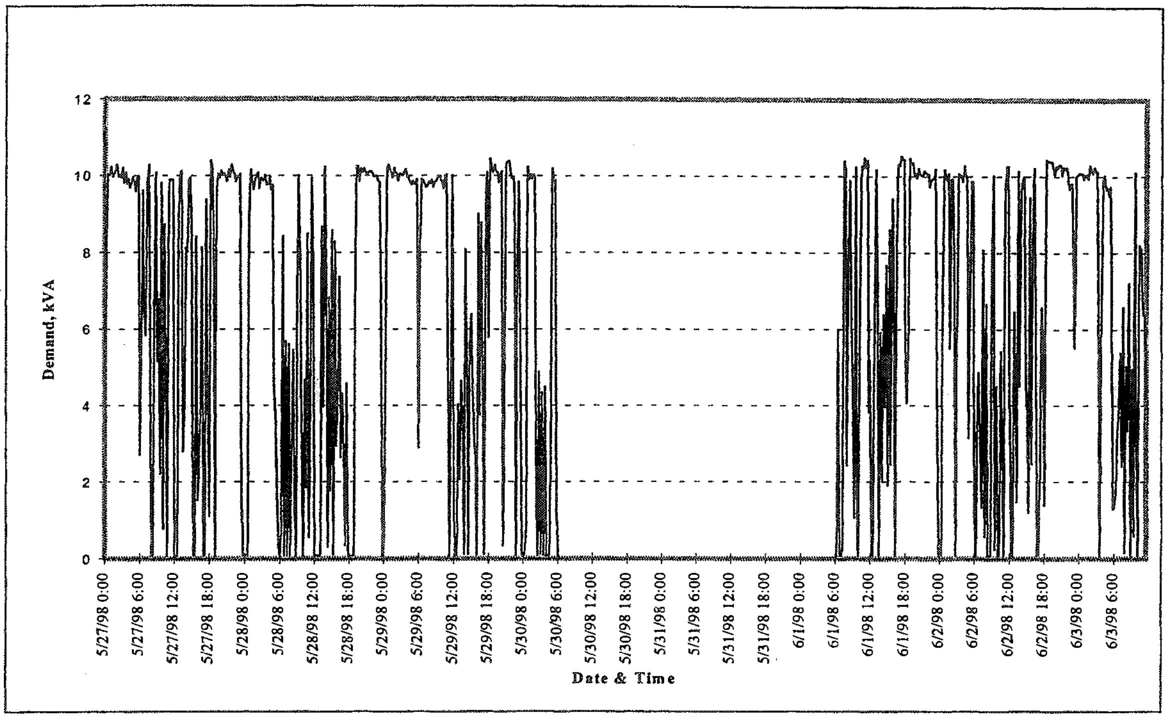

Figure 1. Demand Time History for 25-hp Stretcher Motor

An RTU in the warehouse could be turned off occasionally and was monitored. Other than the compressed air and air-conditioning systems, the largest motors were 30 hp or less. Seven systems were monitored: lighting circuit, 30-ton warehouse RTU, adding machine roll machine (30-hp), cyclone vacuum system (30 hp), large label press (25 hp), printing press (25 hp), and small label press (20 hp). Some systems have several subsystems and the largest motor's size is given in parenthesis. Two recommendations resulted from the warehouse lighting data. One involved light turn-off when not in use and a more complicated project involved pulling material from the warehouse on Fridays for weekend operations so that the lighting could be off on Saturdays. Data from the label presses identified times when both could be turned off. The cyclone vacuum system was also left on needlessly. Total savings were estimated at 75,600 kWh per year and $2,650 per year (Farouz et al. 1999).

Plant 332 produces steel, brass or bronze centrifugal castings. Main production equipment is 10 electric arc furnaces and 14 spinners with motors up to 100 hp. The furnaces and spinner motors are central to production and did not appear to be likely candidates for energy conservation. Their operation is obvious and closely monitored, and so they are not left on needlessly. Deferred operation of this essential production equipment for demand control appeared unlikely. In addition, there was insufficient logger capacity to monitor them all. Eight systems were monitored: four cutoff saws ranging from 20 to 30 hp and two dust collectors of 15 hp each were individually monitored, as were a 25-hp shot blaster and a 3-hp ladle heat blower fan. No projects were identified from the monitored data in this plant (Farouz et al. 1999).

Extra visits were made to observe the plants' energy consumption, waste management, and production processes and equipment; select equipment for monitoring; and install and remove the monitoring equipment. During this extra time in the plants, projects are initially identified and sometimes eliminated before assignment to students for detailed study. In the course of detailed study, others are eliminated as economically or technically infeasible before being recommended to the manufacturer in the final report. Results for the first three plants are shown in Table 2, along with a summary of conservation data supported by logged data (Farouz et al. 1999).

Table 2. Summary of Projects and Centrally Located Logger Results

Plant	Number of Projects				Potential Annual Savings			
					Total		Logged Data Support	
	Initial	Assigned	Recom-mended	Logged Data Support	Energy (kWh)	Cost ($)	Energy (kWh)	Cost ($)
330	23	19	15	3	36,000	1,500	22,500	1,000
331	16	14	13	4	147,000	5,200	75,600	2,650
332	17	14	10	0	124,000	3,500	0	0

Results from Self-Contained Units

Four plants have been monitored with individually self-contained sensor-logger units. These are small (about 2 inch by 1 inch by 1 inch), battery-powered systems costing on the order of $100 per unit that internally record either event data (such as on-off) or data at intervals from 0.5 second to 9 hours. They can be initialized or "launched" and downloaded directly with a desktop computer. The type used in these studies provide motor on-off data (sensing vibrations), light on-off data (sensing light output and requiring the setting of a threshold level so that background light such as sunlight does not interfere), or thermocouple data.

Visits must be made to the plant to install the units and to retrieve them. Typically, they are launched a few hours before leaving campus for the visit and then simply attached where monitoring appears productive. No active circuits in the plant are involved and so safety considerations are different compared to the centrally located logger systems. Interrupting plant operations for safety reasons typically is not a consideration. Installation time requirements are reduced. All four initial visits for installation of self-contained loggers required less than seven hours in the plants to interview plant personnel, select systems to be logged and install loggers. Similarly, logger removal is much simpler, requiring less than three hours for each of the plants monitored. With travel and analysis, this amounted to about two days of effort.

Table 3 summarizes data from the four plants monitored by self-contained loggers. The energy consumption data is from utility bills. In each case, a week or more of data (event or 5 or 10-minute interval) was obtained.

Table 3. Summary of Product and Energy Consumption Data for Plants 354, 355, 357 and 376

Visit Number	Main Product	Annual Energy Consumption			
		Electricity (kWh)	Monthly Demand (kW)	Natural Gas (MCF)	Total Cost ($)
354	Centrifugal castings	3,300,000	2,000	24,000	420,000
355	Oilfield pumps	6,800,000	2,400	14,000	500,000
357	Plumbing supplies	4,200,000	930	12,000	290,000
376	Oil drilling bits	21,000,000	3,100	30,000	940,000

Plant 354 centrifugally casts heavy-wall stainless steel using nine electric arc furnaces and 11 spinners with motors ranging in size from 7.5 to 20 hp. Although monitoring on-off condition with the self-contained loggers is possible, the furnaces and spinner motors again were not selected for monitoring for similar reasons given for plant 332. Plant 355 manufactures subsurface pumps and accessories for the oil industry in a metal fabrication operation capable of highly accurate work on material up to eight inches in diameter. The main manufacturing area is fully air-conditioned. Other than air compressors and chillers, most of the equipment is rated at 40 hp or less. Plant 357 supplies brass tubular plumbing supplies for non-commercial repairs. The main operations are cutting, bending and plating of brass tubular stock. The plant is partially air-conditioned and other than air compressors and air conditioners, most of the equipment is rated at 50 hp or less. Plant 376 makes drilling bits for the oil industry and in addition to the 3,100 kW of demand shown in Table 3, has two, 1,000 hp mud pumps operated on a different rate schedule than the rest of the plant. There is a set contractual demand of 325 kW for the mud pumps and by contract terms they are only operated during off peak times.

Table 4 summarizes the logging activity at plants 354, 355, 357 and 376. At plant 354, the on-off unit 5 on the sand blaster showed that it runs intermittently during the day. Unit 6 indicates that the associated dust collector is left on even when the sand blaster is off. Furthermore, even though unit 8 provided no useful data, observation during three visits indicated the lighting in the sand blaster area is never off during the day, so this became the subject of a project. Total savings from the two projects are 18,900 kWh/year and $700 per year. At plant 355, units 2 and 3 showed that the compressor air intake was coming from an area about 20 °F hotter than the compressor room in the summer. Unit 4 demonstrated the possibility of intake from outdoors through an exterior wall. Thus a recommendation was made saving 14,200 kWh per year and $540 per year to install a damper system so that intake air could be taken from a different area during the summer. In addition, unit 8 showed that the carpentry room lighting was on when not needed. Total savings based on logged data at plant 355 are 23,800 kWh per year and $900 per year. For plant 357, two lighting turn off projects save 30,200 kWh per year and $800 per year. At plant 376, three equipment turn off projects are identified saving 107,700 kWh per year and $2,900 per year. Energy conservation savings supported by logged data at the four plants are summarized in Table 5 and may be compared to the total energy savings reported for the plants.

Table 4. Systems Monitored with Self-Contained Units

Visit #	System #	System Designation	Monitored Item	Supports Projects
354	1	Roof fan (20 hp)	Temp. (on-off)	
354	2	Air compressor #1 (20 hp)	Temp. (on-off)	
354	3	Cooling tower #1 water flow line	Temperature	
354	4	Cooling tower #3 water flow line	Temperature	
354	5	Sand blaster barrel tank	Motor on-off	2
354	6	Dust collector motor (15 hp)	Motor on-off	1 (with #5)
354	7	Air compressor #2 (25 hp)	Motor on-off	
354	8	Sand blast room lighting	Light on-off	No data
354	9	Ladle heater area lighting	Light on-off	No data
354	10	Sand blast room special light	Light on-off	No data
355	1	South air compressor (125 hp)	Temp. (on-off)	
355	2	Air compressor room	Temperature	1 (with 3,4)
355	3	Air compressor roof air intake	Temperature	1 (with 2,4)
355	4	Ext. wall (possible intake loc'n.)	Temperature	1 (with 2,3)
355	5	North air compressor (125 hp)	Motor on-off	
355	6	Dust collector (45 hp)	Motor on-off	
355	7	Cooling tower (25 hp)	Motor on-off	
355	8	Carpentry room lighting	Light on-off	1
355	9	Receiving area lighting	Light on-off	
355	10	Interior office lighting	Light on-off	
357	1	Air compressor roof air exhaust	Temperature	
357	2	Air compressor room air intake	Temperature	
357	3	Main air compressor (200 hp)	Motor on-off	
357	4	Standby air compressor (200 hp)	Motor on-off	
357	5	Shipping area lighting	Light on-off	1
357	6	Breakroom lighting	Light on-off	1
357	7	Boiler fan motor	Motor on-off	No data
357	8	Conveyor motor	Motor on-off	No data
357	9	Pack area lighting	Light on-off	No data
376	1	Core storage building	Temperature	
376	2	Wheelabrator #1	Motor on-off	
376	3	Wheelabrator #2	Motor on-off	No data
376	4	Dust collector	Motor on-off	No data
376	5	Furnace cooling pump (7.5 hp)	Motor on-off	1
376	6	Heater cooling pump #2 (7.5 hp)	Motor on-off	
376	7	Sandblaster	Motor on-off	
376	8	Warehouse	Light on-off	1
376	9	Mud pump canopy	Light on-off	No data
376	10	Powerhouse	Light on-off	1

Table 5. Summary of Projects and Self-Contained Unit Results

Plant	Number of Projects				Potential Annual Savings			
	Initial	Assigned	Recom-mended	Logged Data Support	Total		Logged Data Support	
					Energy (kWh)	Cost ($)	Energy (kWh)	Cost ($)
354	19	13	10	2	63,000	2,900	18,900	700
355	17	12	9	2	124,000	4,700	23,800	900
357	19	15	9	2	182,000	4,700	30,200	800
376	19	13	8	4	2,850,000	76,900	107,700	2,900

The extra visits to the plants again allowed more projects to be identified. Table 5 summarizes the number of projects initially considered, assigned to students for detailed study, and recommended to the manufacturer for the plants described in Table 3, along with energy conservation data.

Data from the self-contained units generally is not so sophisticated as that from the centrally located loggers that monitor phases and are able to yield time histories of demand from which on-off data can be obtained such as that in Figure 1. The temperature units used in Table 4 do produce time histories of temperature, but the motor on-off and lighting on-off sensors simply produce on-off data as in Figure 2.

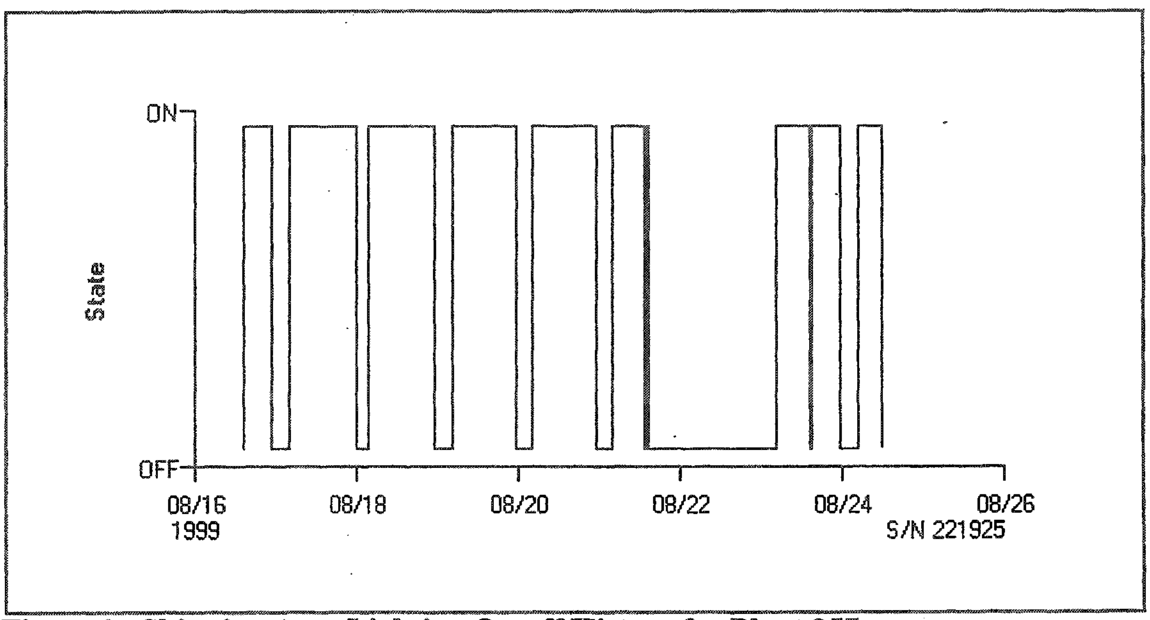

Figure 2. Shipping Area Lighting On-off History for Plant 357

In one other plant (377) five motor on-off and one lighting on-off self-contained units were installed during the formal assessment visit to gain more information about the plant for the report. One possible lighting project was identified, resulting in a recommendation to save 8,600 kWh per year and $500 per year. This study only required one extra day in the plant, for retrieving the loggers after one week of data gathering.

Industrial Demand Control

A major goal for the monitored data was to support demand control projects by identifying equipment whose operation could be deferred during times of peak demand. None were identified in the work described in this paper or in three other plants where monitoring was installed subsequent to IAC assessment visits. In those plants, goals were to control demand and provide more information to the production manager (plant 178—Heffington, Dorhofer & Lewis, 1996) or to measure demand and duty factors (plants 298 and 302—Dooley & Heffington 1998).

A recent review of literature indicates that, compared to the commercial and institutional building area, little has been done in industry (Liu 2001). This may be attributed to a number of conditions: lack of deferrable demand in manufacturing plants, lack of possibilities for reduced quality of some condition in order to reduce demand (e.g. short cycling environmental control equipment practiced in the building energy conservation area), lack of energy storage (e.g. thermal storage also used in building area), complicated rate schedules not well understood by the end user, and energy that is inexpensive compared to other costs. With regard to the latter two conditions, IAC personnel spend a significant effort in each assessment explaining rate schedules and particularly demand and power factor, which are not well understood by most plant personnel encountered. Energy costs are a small fraction—on average about 2 or 3%—of gross annual sales. Materials, labor and overhead, for example, are much more significant. Deferrable demand in industry appears to be either significant, obvious projects not needing sophisticated monitoring (such as the 1000-hp mud pumps at plant 376) or relatively insignificant projects.

Discussion of Results

A significant benefit from the extra time spent in the plants is more projects recommended in the final reports. A review of 24 reports immediately preceding that for plant 330 showed averages of 10.4 projects assigned to students for detailed study upon leaving the plant and 8.5 projects recommended to each manufacturer in the final technical report (Heffington et al. 1998). A similar review of 24 more recent reports (for non-extended assessments preceding plant 388) showed averages of 10.7 assigned and 8.3 recommended projects. The averages for the seven plants described here are 14.7 and 10.6, respectively. This is a 25% increase in recommended projects. Average savings for each project recommended by the Texas A&M University IAC in its last 50 assessments are $13,000 per year. An assessment day has long been worth about $6,000 in terms of IAC program costs at the university level; presently each day is worth $6,100. Assuming that recommended savings increase linearly with the additional projects, an average of two more projects is worth a total of $26,000 per year. This results in a rapid payback of slightly less than one-half year when compared to the program sponsor's cost (about $12,000 at $6,000 per day for two days) of the additional time spent in the plant. However, the optimum time required to obtain the extra projects has not been determined—perhaps less than two days would provide two additional projects. The additional time in the plant also allowed some of the projects initially considered to be eliminated before being assigned to students for formal study, thus allowing them additional time on more suitable projects. Tables 2 and 5 show that about four projects in each plant are eliminated before assignment to students.

The monitored data from the seven plants is used to support energy conservation projects to turn off equipment. Some of those projects probably would have been identified without the use of the monitored data. Tables 2 and 5 show that these projects are relatively small and reveal that the largest savings in any one plant that is based on logged data is $2,900 per year.[3] Considering that installing and removing monitoring equipment (of either type) takes at least two days, the payback based on program expenditures is more than four years.

The centrally located logger systems give much more data than the self-contained loggers. For motors, the centrally located logger data can be used directly to obtain demand and on-off data from which duty factors can be deduced. Other useful parameters, such as power factor, are also available. The self-contained units give only on-off data and such things as demand (load) factors must then be obtained in some other manner for energy conservation calculations.

Several of the monitoring systems in Table 4 gave no useful data. In the case of the lighting sensors, a lighting threshold level must be set to indicate when lights come on and this can be difficult to do in the field.

Conclusions

The extra time (about two days before a one-day assessment visit by the full team) spent in the plants while installing monitoring systems provides the advantage of more familiarity with the plant and increases the number of recommended projects by two (25%). Such recommended projects are estimated to have average savings of $13,000 annually and with program costs near $6,000 per day, the additional days are paid for in less than one-half year, which is a cost-effective expenditure of program resources.

Accurate on-off and demand data can be obtained by monitoring appropriate equipment. However, monitoring tests in small and medium-sized plants have supported only relatively small, energy saving equipment turn-off projects. Comparing the annual savings of those projects to the investment in program funds at the university level to pay for the extra effort in the plant does not favor monitoring, having a payback of more than four years. Seeking significant demand control projects in small and medium-sized industry based on monitoring has been fruitless.

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[3] Total electrical energy savings in all cases but one in Tables 2 and 5 are also less than $6,100. These energy savings do not include demand, natural gas, waste, or productivity savings. The minimum total savings from all recommended projects are $21,500 per year for plant 332 so that the payback for the program cost of that assessment is less than 0.3 year. Average annual savings at all seven plants are $113,000 per plant.

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