DEMAND CONTROL UTILIZING ENERGY MANAGEMENT SYSTEMS - REPORT OF FIELD TESTS

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ABSTRACT

Energy Management systems and particularly demand controllers are becoming more popular as commercial and light industrial operations attempt to reduce their electrical usage and demand. Numerous techniques are used to control energy use and demand and many manufacturers are offering equipment. This study attempts to characterize and quantify the effects of various control philosophies used in these equipments. Monitoring and control equipment has been installed in commercial facilities with results used in this study. Individual loads have been characterized by their demand contribution and run times. Load profiles and demand histories for various facilities have been used to analyze several energy control philosophies. The results from pre and post control situations are herein presented by using the collected field data. It has been found that facilities which appear quite similar may vary in load characteristics such that the same control philosophies may not produce the same result in demand limiting or energy savings. Specifically, the proper energy management philosophy depends not only on the operation of the facility, but also on the characteristics of the individual loads which may be controlled. This paper gives comments concerning scheduling control concepts and demand limiting philosophy. Special recommendations are made regarding demand control techniques.

INTRODUCTION

With the proliferation of low cost energy management systems (EMS), small commercial and light industrial operations are constantly faced with the decision of "Should an energy management system be installed?" and, "If so, which one?" Often the facility operators turn to energy management firms or hire a consultant competent in the area of energy management to make specific recommendations based upon the facility's needs. Just as often, the energy expert is faced with making recommendations based upon limited data, subjective descriptions of past experience or even instinctive guesses.

To supplement the data available to a consultant, various types of instrumentation can be installed to provide additional data when desired. In many cases, the data obtained from these measurements is in such a crude form that it becomes difficult and time consuming to accurately evaluate a facility's operations and the potential effects of a control device on the facility. Further, recommendations that are based on this type of data may be implemented but never closely checked against the data gathered during the energy audit.

A specific area of energy management that suffers greatly from the lack of data or the lack of concise data is demand limiting. To provide some insight into this problem, MICON Engineering began several years ago establishing a technique for obtaining data from facilities for use in evaluating EMS equipment and the potential for demand limiting. After selecting data analysis techniques, field installations were made to verify the validity of the techniques as well as to determine the effectiveness of various demand limiting algorithms.

The work presented in this paper is the result of five years of effort in energy consulting, auditing, research, and control applications. During the course of investigations involving energy audits, it became apparent that the issue of demand limiting, while simple in concept, presented difficult problems. In practice, selecting a good demand limit and determining the impact of the controller on the facility are significant problems. To help solve this problem, a data acquisition system was developed that would aid in the evaluation of demand limiting potential. This device was microprocessor-based and portable to allow installation at several facilities. The data gathered by this system and its subsequent analysis indicated that a statistical approach to determining a facility's demand limiting potential might be possible. To prove feasibility of such an approach, it was necessary to implement several demand limiting algorithms and closely monitor their effectiveness as a demand limiter, as well as their effect on the facility.

This paper presents a chronological overview to the implementation of a data acquisition system developed to aid in setting demand limits. In addition, it provides information on analysis of the data received, use of statistical data to establish a demand limit, and field implementation of several algorithms. Some problems normally encountered with standard demand limiting algorithms are discussed and conclusions reached from the work to date are presented.

DATA ACQUISITION

The most difficult problem associated with specifying and subsequently establishing the performance of energy management systems is the lack of adequate data. Preinstallation data is difficult to obtain. Therefore, many consultants and operators make no attempt to characterize their particular control problem prior to installation of an energy management system. A typical approach is to install the equipment and hope for the best.

An equally difficult problem is attempting to charac-

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terize the performance and resulting savings of an energy management system following the installation of equipment. In many cases, the lack of a "base case" makes quantitative performance comparisons evaluations impossible. It has further been established that the so called base case studies which come from general facility evaluations and climatic data are virtually useless with respect to predicting and evaluating demand control performance.

As a result, a data acquisition system is necessary such that a true evaluation of an energy management system using pre and post installation data can be accomplished.

Before constructing the data acquisition system, it was determined that a system capable of collecting large quantities of data would be necessary. It was anticipated that only a subset of the data collected would be used for selecting a demand limit. The data acquisition system specifications called for the unit to be capable of the following tasks.

* Logging of facility power levels.
* Monitoring of individual load run times.
* Maintaining the time of day with respect to all activities.
* Storing at least one week of data.
* Maintaining flexibility as to the type of equipment that could be monitored.

The resulting microprocessor-based system is shown in block diagram form in Figure 1. The building energy use was measured utilizing a watt transducer which produced a signal proportional to the instantaneous power use. This signal was digitized, stored in the microprocessor, and later transferred to the cassette tape.

The loads were monitored via several techniques, primarily either current sensing devices or voltage sensing devices which were capable of giving an indication whether the equipment was on or off. The microprocessor stored the time at which each piece of equipment went off or on and transferred this information to the cassette tape along with the building power data. The data stored on the cassette tape was later brought back to an analysis computer capable of reading the data and doing a variety of calculations.

DATA ANALYSIS TECHNIQUE

After the data acquisition system was installed in a facility, data was gathered at approximately one-week intervals. Cassette tapes from the data acquisition system were obtained from the facility and analyzed on a general purpose microprocessor system. Special analysis programs were written to interpret the data and give various forms of output. The process of determining which data was important was accomplished in an iterative fashion as analysis proceeded. A cross section of the type of data obtained is shown in Figure 2. The first group of data concerns the installation parameters and provides a record for the test. Also, by recording the readings from the facility utility meter, it was possible to check calibration of the data acquisition system against the utility meter and vice versa.

The second group of data shown in Figure 2, Equipment Use Summary, provides information on individual loads showing duty cycles, energy use, and energy use as a percent of the total energy used by the facility. The rated power for each load was obtained either from nameplate data or by measurements taken during installation. From this information, various characteristics of each load can be seen. The Maximum, Minimum and Average Duration section also provides information about operating characteristics of each load as related to the on-times and off-times of each load. For purposes of demand limiting, it is

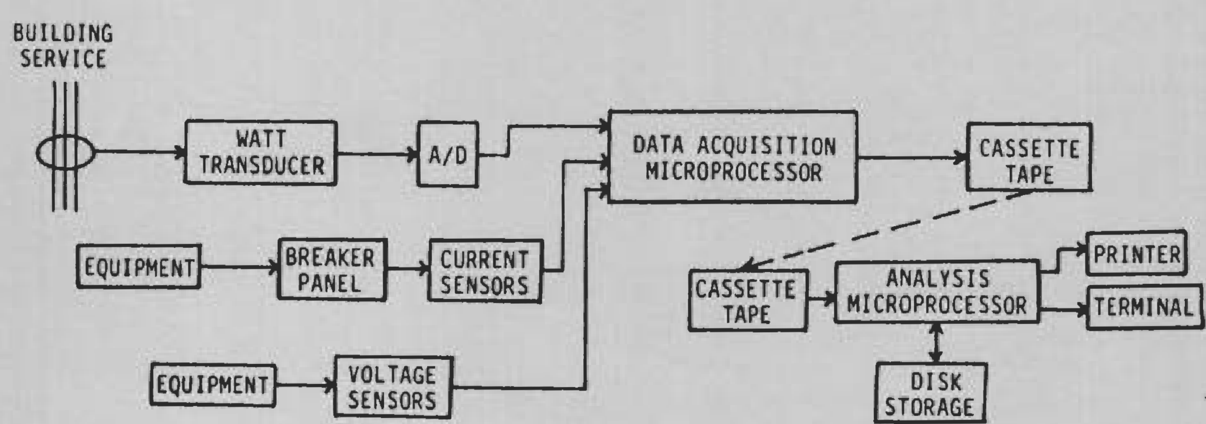

Figure 1: DATA ACQUISITION SYSTEM

INSTALLATION DATA

The recording duration was 5 days, 13 hours, 5 minutes. The watt transducer was configured with a PT ratio of 3:2 and a CT ratio of 900:5 for a full scale reading equal to 405.0 kw. The maximum integrated demand recorded was 183.2 kw at 17:07 on Friday. The energy measured in the interval monitored totaled 13731 KWH. The utility meter measured 13402 KWH in this period.

EQUIPMENT USE SUMMARY

	RATED POWER (KW)	DUTY CYCLE (%)	ENERGY USE (KWH)	ENERGY USE (%)
Pattie grill	11.00	1.6	23.55	.17
Soup kettle	10.80	1.3	23.55	.17
East fryer	5.30	9.5	67.28	.49
West fryer	5.30	19.75	139.33	1.05
Steam booster	23.10	5.03	154.79	1.27
Outside lights	12.40	52.89	872.90	6.35
Dishwasher booster	30.00	24.08	961.47	7.00
Oven	15.50	9.53	196.76	1.43
Center A/C(prim)	27.60	40.05	1471.19	10.71
East A/C(prim)	18.40	36.96	905.34	6.59
Center A/C(sec)	27.60	1.50	55.31	.40
East A/C(sec)	18.40	26.95	660.15	4.80
Base load	27.60	100.00	3673.33	26.75

MAXIMUM, MINIMUM, AND AVERAGE DURATIONS

	ON DURATION			OFF DURATION	
	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM	MINIMUM
Pattie grill	0:49	0:03	0:18	31:23:37	0:22
Soup kettle	9:02	0:01	0:27	39:22:02	0:05
East fryer	10:20	0:05	0:49	7:29:33	0:02
West fryer	15:12	0:04	1:59	10:21:58	0:03
Steam booster	3:11	0:01	0:04	1:10:07	0:01
Outside lights	12:46:33	7:45:39	11:43:57	11:30:42	6:31:56
Dishwasher booster	5:14:51	0:34	13:10	10:10:18	0:55
Oven	22:47	0:07	3:13	14:30:22	0:03
Center A/C(prim)	12:36:33	0:05	12:24	1:13:55	0:12
East A/C (prim)	12:25:52	0:02	49:12	3:50:37	0:08
Center A/C(sec)	1:08:40	0:01	1:29	3:27:39	4:56
East A/C(sec)	13:01:41	0:02	2:14:33	52:05:11	33:44

DEMAND PEAK CONTRIBUTIONS (PERCENT OF RATED POWER)

	SUN	MON	TUE	WED	THU	FRI	SAT
Pattie grill	2.4	0.0	0.0	0.0	0.0	0.0	0.0
Soup kettle	4.2	0.0	0.0	3.3	0.0	0.0	0.0
East fryer	7.1	9.9	12.0	9.0	11.3	7.7	4.2
West fryer	59.2	30.0	33.2	77.3	45.4	10.1	22.5
Steam Booster	46.7	36.6	4.0	3.5	5.3	2.9	7.7
Outside lights	0.0	100.0	100.0	0.0	100.0	100.0	100.0
Dishwasher booster	100.0	94.5	100.0	100.0	0.0	100.0	100.0
Oven	0.0	94.8	0.0	0.0	83.3	55.9	66.2
Center A/C(prim)	100.0	100.0	0.1	100.0	100.0	100.0	0.0
East A/C(prim)	100.0	95.2	0.0	100.0	100.0	97.0	0.0
Center A/C(sec)	100.0	0.0	0.2	0.0	0.0	0.0	0.0
East A/C(sec)	0.0	0.0	0.0	100.0	0.0	97.0	100.0

DAILY DEMAND PEAKS (MEASURED AND ESTIMATED FOR LOADS STUDIED)

		ESTIMATED	MEASURED
09:52:30	SUNDAY	144.44 KW	168.16 KW
21:32:30	MONDAY	136.58 KW	175.55 KW
00:21:00	TUESDAY	79:22 KW	125:03 KW
16:13:00	WEDNESDAY	135.26 KW	165.32 KW
17:25:30	THURSDAY	127:72 KW	157.46 KW
17:07:30	FRIDAY	151:09 KW	183.19 KW
18:54:30	SATURDAY	110:05 KW	159.89 KW

FIGURE 2. Sample Data from Data Acquisition System

important to know information concerning devices whose running times are longer than the 15-minute period used for calculating the facility demand. In addition to demand limiting, this type of information was also able to detect overloaded or malfunctioning equipment, especially in the case of refrigeration compressors.

The Demand Peak Contributions and Daily Demand Peaks sections of Figure 2 directly address the demand problem, showing the percent of time each load was running during the 15-minute period that created the demand peak for each day of the week. This information is very valuable in determining the loads which should be strongly considered for demand limiting. As an additional check on the thoroughness of the study, a demand peak was estimated for each day of the week based solely upon the loads that were running during that 15-minute period. If the estimated demand peak remained lower but changed consistently with the facility peak, then it was assumed that loads being monitored fairly represented the facility's demand. Any large discrepancies in the estimated peak and the measured peak would indicate a major piece of equipment had been ignored or some other factors were affecting the demand peak.

While this data provided extremely useful insight into the characteristics of each load and which loads should be controlled, it proved to be a very tedious data base when used to select the demand limit. In an effort to more concisely present the data, a statistical approach was implemented. The demand profile (probability density function) shown in Figure 3 gives the percent of time the facility demand was at a particular value. From this plot, facility characteristics can be seen indicating the demand at which the facility spent most of its time. This plot indicates the facility spent a great deal of time in the area of 120KW. However, it did spend at least 15 minutes at a demand of 200KW. This small percent of the time at the high demand level established the demand bill for the month.

A different presentation of the same data (cumulative density function) is shown in Figure 4, where the plot represents the percent of time the facility demand stays above a particular value. For the example shown, the percent of the recording time that the facility remained above 150KW was approximately 5%. This particular format for data presentation has proved to be one of the most concise and useful techniques utilized to date.

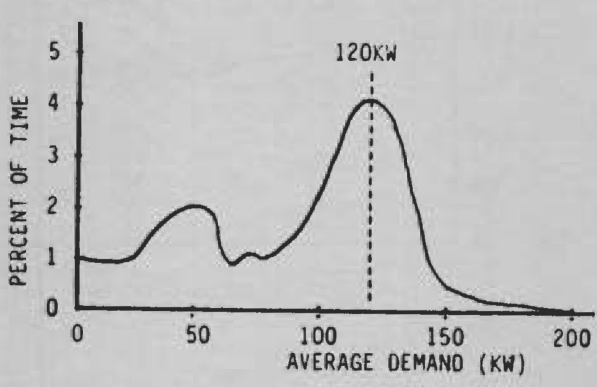

Figure 3: TIME SPENT AT A SPECIFIC DEMAND VALUE

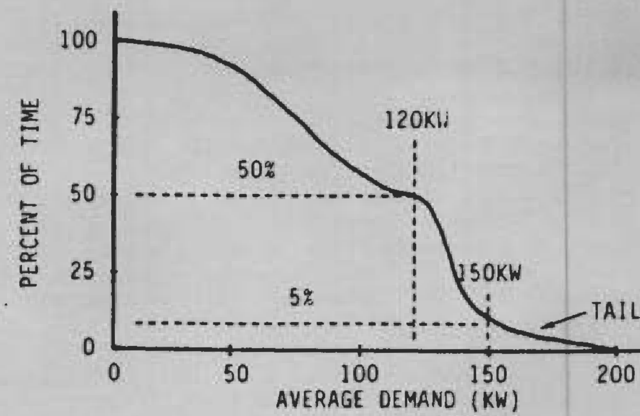

Figure 4: TIME SPENT ABOVE A SPECIFIC DEMAND VALUE

DETERMINATION OF DEMAND LIMITING POTENTIAL

Referring again to Figure 3, it can be observed that only a small fraction of time is spent at the highest demand levels. This would indicate a great potential for demand limiting in this facility.

Figure 4 provides a simple technique to predict the effects of selecting a particular demand limit. For the earlier example, if a demand limit of 150KW was selected, the controller would have to shed loads for a minimum of 5% of the time to maintain the demand below 150KW. If the demand limit was erroneously selected at 120KW, the controller would shed loads approximately 50% of the time. For most facilities, this excessive amount of control is usually unacceptable to the facility operations.

From a plot such as the one in Figure 4, it is possible to determine the maximum demand limiting potential for a facility. The general rule would be that demand limit cannot be set below values located in the steepest section of this curve. In other words, the presence, absence, and/or size of the tail is an indicator of the demand limiting potential. Facilities which do not exhibit a long tail have almost no potential for demand savings without resulting in considerable occupant dissatisfaction. Experience has shown that almost all facilities have some type of tail; however, this tail may range from 5% of the facility demand peaks to 25% of the facility demand peaks.

When using a graph like this one, the first tendency is to select the desired percent of time the controller is to control, and translate this to a demand limiting value. Two conditions may exist that require additional information when interpreting the graph. First, given that the controller is going to control 5% of the time, when and how does this 5% occur? Second, how good is the controller? If the 5% occurs once a day, continuously, this might have the controller turning off air conditioning for as long as an hour and fifteen minutes. It is likely this is not an acceptable situation, at least not to the building occupants. If, on the other hand, the 5% consists of multiple demand excursions of shorter than 5% duration, it is more likely that control can be tolerated.

The second issue preventing easy selection of the demand limit deals with the demand limiting philosophy utilized by the controller. Figure 5 shows a plot of an ideal demand profile along with a demand profile produced by most control algorithms. Note that the ideal demand profile contains no tail while the controller plot contains a small tail. This comparison implies that the specific characteristics of the demand limiting algorithm to be used must be considered when selecting a demand limiting point. For the imperfect control algorithm to maintain a selected demand limit, the actual percentage of time spent controlling will be greater than that derived from the demand profile.

To provide more insight into the two problems stated above, it was concluded field tests would be necessary to determine characteristics of several demand limiting algorithms.

DEMAND LIMITING TESTS

To conduct the algorithm tests and to gather further data, a microprocessor-based control system was developed that could be programmed with many of the features and algorithms available commercially. The main features of this system included:

* Load control outputs.
* Load run indication inputs.
* Temperature input.
* Power usage input.
* Battery backed up data.
* Remote communications.
* Data logging.

The data logging features were particularly important in evaluating the effectiveness of various control algorithms. The building energy use was logged to allow continual monitoring of the building demand profile. In addition, other data such as the total energy used, the number of sheds per load, and the run times for each load were logged. The ability to set a study level to any demand level enabled monitoring of individual demand levels. The control system kept track of the number of demand excursions above the study level, the number of times the study level was exceeded, the average duration above the study level. This data provided the means of determing whether the facility was being over-controlled or under-controlled on a regular basis.

A Simple Demand Limiter

The first algorithm implemented was a simple approach to demand limiting. Whenever the demand went above a specified value, the loads were duty cycled. The duty cycle percentages were preselected to prevent any piece of equipment from being cycled too rapidly. As expected, this algorithm was not able to control the demand limit tightly. By the time the demand limit was recognized, it was often too late to prevent a demand level overshoot. While this could be compensated for by lowering the demand limit, such action would result in unnecessary over-controlling as could be predicted by the demand profile in Figure 4.

A Slope Sensitive Demand Limiter

The next algorithm implemented incorporated slope sensitive demand limiting techniques. By looking at the current instantaneous power trend and projecting future demand, control actions were taken appropriately. Figure 6 shows the control curve utilized for this algorithm. Based upon the current 15 minute average demand and the instantaneous demand, decisions were made as to whether no loads would be shed, loads would be shed conditionally, or loads would be shed unconditionally. Conditional sheds required that each load meet its minimum off-time and minimum on-time to prevent rapid cycling. In addition, loads were selected using a priority scheme based on a scheduled priority, runtime, and temperature information, if applicable. If the average demand ever exceeded the desired demand limit, unconditional shedding would override all minimum on-times and priorities. The result was an algorithm which could more closely hold to a selected demand limit; however, the typical problem associated with slope sensitive

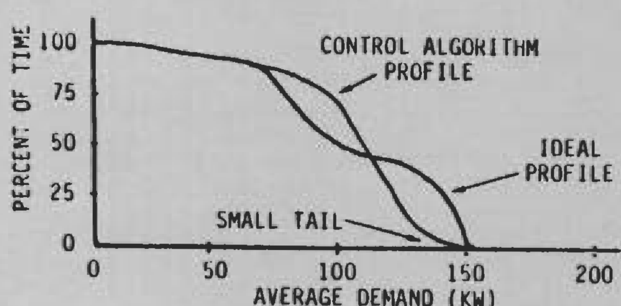

Figure 5: DEMAND PROFILES

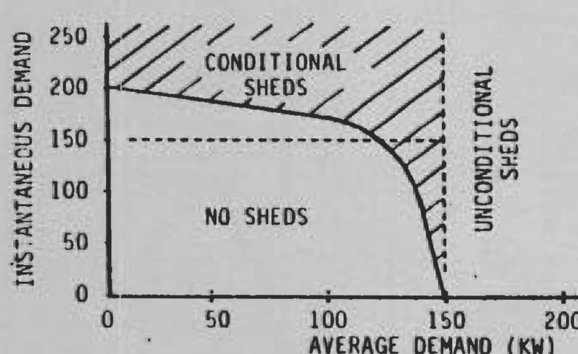

Figure 6: SLOPE SENSITIVE DEMAND ALGORITHM CONTROL CURVE

algorithms began to occur.

Even though the demand profile and study data indicated that only light controlling was in order, the number of sheds indicated that a large number of control actions were being taken. Close inspection of these excess control actions revealed a problem of controlling the demand in a facility which has many loads that have a very high instantaneous power but are on for very short durations. (The data in Figure 2 had forewarned of several loads having these characteristics; however, their impact was not recognized until after the controller was installed. This situation, unfortunately, occurs regularly with many EMS installations.) In this case, cooking equipment such as fryers and steam tables was the cause. It is likely that this problem also occurs in the industrial environment where motors and compressors may run for very short periods. The solution to over-controlling was to de-sensitize the algorithm such that it did not respond as rapidly to the instantaneous peaks created by this type of equipment. The inevitable negative effect of de-sensitization was an inability to institute control actions fast enough when a real demand problem occurred. Allowing an algorithm to control unnecessarily would not allow accurate determination of an appropriate demand limit from the demand profile. Allowing the demand limiter to react too slowly, and therefore permit over-shoots to occur, required that the demand limit be set below its optimum level. Neither of these two possibilities were deemed acceptable.

These findings indicated that the demand limiting algorithms implemented in most available EMS equipment possessed severe shortcomings. The need for an algorithm that would not unnecessarily shed loads, yet would maintain the desired demand limit, was not only necessary to utilize the demand profile technique previously selected, but might also vastly improve state-of-the-art demand controllers for certain facilities.

In addition to the control problem, it was also recognized that a significant problem existed in setting the demand limit to be used on a continuing basis. Seasonal changes dramatically affected the demand profile, thus indicating that the demand limits should be changed on a regular basis to maintain either maximum savings or to prevent significant over-controlling.

CONTINUING WORK

Results of work to date indicate that significant improvements are needed in the more or less "standard" slope sensitive algorithms. A new program has been developed to implement several changes to the slope sensitive algorithm. Some of the features that have been added are:

* Increased time between load sheds when the average demand is low to reduce over-control.

* Decreased time between load sheds when the average demand is high to allow fast response to real demand problems.

* Decreased time to restore loads when the demand is low to prevent loads from being held off unnecessarily.

* Increased time to restore loads when the demand is high to prevent controlled loads from compounding the demand problem.

* Utilization of rated power and run indications to more accurately predict when the controller must shed loads to prevent a demand problem in the future.

Computer simulations incorporating these new concepts have indicated that the new algorithm is much less sensitive to instantaneous demand yet will maintain within a percent or two the selected demand limit. The algorithm has been installed at several facilities, and the data is currently being evaluated to determine the algorithm's effectiveness.

It is felt that a demand limiting algorithm, to be truly effective throughout the year, must be capable of constantly adjusting its own demand limit based upon the information available. Several approaches have been investigated to adjust this demand limit based upon the demand profile. Results of this work are encouraging, but the proprietary nature of the work prevents its presentation at this time.

CONCLUSIONS

Based upon the work performed to date, several conclusions can be drawn regarding the gathering of data for purposes of demand limiting, selecting an appropriate demand limit, and choosing the demand algorithm to be used. The major conclusions are as follows:

* Improved data acquisition equipment is necessary to properly evaluate demand limiting potential. It is preferred that the necessary information be obtained from one central location.

* A statistical demand profile can rapidly and concisely identify demand limiting potential.

* The characteristics of many of the common demand limiting algorithms are in need of improvement.

* Facilities containing loads with high power ratings and short on-durations provide a special problem to demand limiters.

* The automatic adjustment of a demand limit may be accomplished utilizing the demand profile technique.

It is hoped that the discussion and data evaluation presented in this paper show the necessity of adequate data acquisition and evaluation in the performance characterization of energy management systems. It has been shown that it is quite possible, using normal "energy audit" techniques, to draw incorrect conclusions concerning the potential for demand limiting based on the individual operating profile of the facility. It has further been shown that our normal expectations of demand savings can be exaggerated if taken from a data base which consists of equipment ratings and excluding actual equipment duty cycles.

It is specifically important to note that an actual understanding of the duty cycle and demand correlation of all large apparatus is necessary if proper demand control techniques are to be utilized.