A HYBRID MONITORING-MODELING PROCEDURE FOR ANALYZING THE PERFORMANCE OF LARGE CENTRAL CHILLING PLANTS

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ABSTRACT

This paper presents a methodology to effectively model the performance of central chilled water plants in campus or multi-building complexes where detailed modeling of every building served by the plant is out of the question, usually due to budgetary and/or time constraints. The work presented has evolved through years of practical experience in the analysis of central chiller plant performance for the purpose of justifying the economic merit of load-shifting and energy-saving strategies. The proposed method has been used strictly for retrofit applications, but is also applicable to new plants if enough parameters are known. Throughout the years the author has found that this methodology requires significantly less effort than using the more complex building hourly simulation programs, and often allows greater flexibility in addressing conditions which are not within the scope of commercial modeling programs.

The following sections justify the need for this type of approach and provide a detailed description of the procedure using data and results from a real project.

INTRODUCTION

Southeast Texas, U.S.A. is one of the most air-conditioned regions of the world, and as such, an intense user of electric power used to generate and distribute chilled water for process and ambient cooling. Air-conditioning in this region has become a necessity which goes well beyond human comfort. For the thriving semiconductor industry, world-renowned medical centers, and research facilities in the many institutions of higher learning, air-conditioning and dehumidification is not an option, but rather an absolute necessity.

As demands for air-conditioning, and thus power requirements, in the region have increased, utility companies have been faced with limited generating and/or distribution capacities. As a solution, many of the larger power companies have developed a number of incentive programs aimed at reducing peak electrical demand by means of load-leveling strategies. Prior to implementing these strategies and awarding incentives, however, significant time and effort must be spent in quantifying the cost and benefit of each proposed energy conservation and demand control measure.

Experience and common sense have taught us that energy conservation and demand control strategies are most cost-effective where large loads can be controlled at a single location, as is the case in central chilling plants serving large facilities. Therefore, the need to establish a sound and practical methodology to evaluate the performance and cost-effectiveness of central chilling plants. We define a "practical" methodology as one that makes the most of available measured data, is flexible enough to be adapted to different equipment configurations, and does not require the use of detailed hourly simulation programs which are expensive, not particularly easy to use, and often require more input than one can reasonably provide within the limitations of a consulting engineering operation.

One of the major challenges in developing this simplified methodology was that it should be sensitive enough to allow for predicting peak power draw (kilowatts) as well as monthly and annual energy consumption (kilowatt-hours). Further, given the nature of the load-shifting strategies of interest to utilities, the methodology must be able to predict daily electrical load profiles on an hourly basis.

The methodology is described in detail in the following sections. We refer to it as a "hybrid" monitoring-modeling procedure because it relies on a limited amount of effectively utilized monitored data in order to tune and run the model. Where reliable monitored data cannot be obtained, the methodology becomes unreliable and is not recommended unless the analyst feels comfortable making assumptions based on his/her subjective understanding of the facility's operation.

METHODOLOGY

The basic approach taken in this work is that all the loads being served by a central chilling plant can essentially be treated as a "black-box". Understanding the exact nature of fluctuations in loads seen at the plant is not necessary as long as these can be consistently represented in terms of known, measured parameter(s). This approach is particularly useful in very large (often multi-building) facilities, where modeling the performance of each individual building and its energy-using systems represents an impractical (and unnecessary) task, but the methodology is just as convenient to use in smaller plants.

All data presented in this paper to illustrate the methodology applies to a chiller plant serving a medium size (approximately 17.000 square meters of construction) junior high school in southeast Texas, USA, that was analyzed using this procedure and is currently under construction. This facility was selected for illustration purposes even though the chiller plant is relatively small, because the methodology contains all the elements that would be included in a major chilling plant application. The methodology may be easily modified to other installations, and where applicable this is pointed out.

The objective of the analysis conducted for Kingwood Middle School was to evaluate the performance of an existing 400-ton chilled water plant consisting of air-cooled chillers, for possible retrofit with more efficient centrifugal or screw water-cooled machines and/or a thermal energy storage system. The specific tasks to be accomplished by the analysis were; (1) model the existing central plant; (2) model the proposed new plant; (3) conduct an evaluation of the relative operating and installation costs. The emphasis in this paper is on the procedure used to model the chilled water plant, not on the savings potential or the actual systems chosen. Descriptions of the systems analyzed and the steps required to model them are described below as the methodology is developed.

MONITORED DATA

The first step in the modeling process consists of determining the independent parameters that will "drive" the model. In the case of commercial building simulation programs, the building thermodynamic load calculations constitute the basic parameter that drives the central plant simulator. The plant simulator takes these thermodynamic loads and based on equipment characteristics specified, calculates the electrical energy that is required to meet the cooling load on an hourly basis. Calculating these thermodynamic loads, however, is a non-trivial task which depends on a great number of variables, including but not limited to; weather conditions, building construction characteristics, building occupancy, internal loads, ventilation loads, etc. Some of this information is easier to obtain than other, and in most cases there is a fair amount of uncertainty associated with each one of the inputs, and the resulting loads.

The methodology proposed here represents a "short-cut" which bypasses the entire thermodynamic load calculation process with all its uncertainties and goes directly to the plant model. The trick is in identifying key measured parameters which are representative of system behaviour and which are themselves used as inputs in developing the model. These key monitoring parameters are discussed below.

Electrical Demand & Consumption

Standard building simulation programs typically produce electrical demand and consumption data as a program output. When modeling existing plants, if the results don't match actual monitored data, the programmer will typically "adjust" inputs and operating parameters (almost) on a trial-and-error basis until the program output matches the known data. This "fudging" process often results in the manipulation of a large number of variables which may significantly decrease the credibility of the entire simulation.

The methodology proposed here uses the desired output (electrical demand and consumption) as the most important input parameter. The procedure begins by obtaining monitored electrical demand data for as many "representative" days of the year as practical. These representative days are the ones that are used to fine-tune the plant model, and typically include the days with the highest electrical demand, as well as days when it is apparent that central plant equipment does not operate.

Figure 1 shows electrical demand data provided by the electric utility for the day with the highest electrical demand at Kingwood Middle School during 1995. This is typical of data our regional utility companies can provide in either hard copy or diskette for facilities drawing in excess of 400 kilowatts of electrical demand. With this information, the modeler may begin gaining an understanding of the facility's electrical consumption patterns before any real analysis work begins. The following basic information may be obtained upon inspection of data presented in Fig. 1:

- Electrical demand begins increasing at about 3:00 a.m. and increases steadily through noon.
- Facility peak electrical demand was 780 kW at noon on September 25. Load remained fairly even until about 4:00 p.m.
- Facility electrical demand drops sharply between 5 p.m. and 6 p.m. to approximately 240 kilowatts.
- After midnight, electrical demand drops to approximately 110 kilowatts.

Weather Data

The most sophisticated commercial building simulation programs rely on fairly detailed weather data to develop building thermodynamic calculations. Most programs use some kind of "typical-year" data, but some also allow for the use of real monitored weather data. In either case, the amount of weather data fed to the simulators is quite significant and typically includes; dry-bulb temperature, wet-bulb temperature, solar radiation, cloud cover, wind velocities, and ground temperatures. The main drawback of this approach is that the level of uncertainty involved in the process increases when so many variables are involved. When using real monitored data, it is unlikely that all variables will be properly recorded for every hour or the year, yet the end user rarely has knowledge of this. In addition, many of the methodologies used in these programs are inadequate to properly account for the dynamic interaction of the various weather variables.

The methodology presented here uses weather data as an independent parameter which is correlated to building loads. The number and type of weather variables considered may vary from application to application, and one of the steps in this process is to identify the minimal number of known variables that will correlate well to building loads.

Most electric utilities are aware of the strong dependency between outside dry-bulb temperature and load and actually use it as one of their main indicators to forecast load fluctuations. Upon request, these utilities will make this temperature data available to the end-user and/or technical analysts for evaluation of central chilling plant options. Figure 2 shows temperature data provided by the utility overlaid on electrical demand data shown on Figure 1. The overlay makes it quite obvious that electrical power draw at Kingwood Middle School during occupied hours is highly dependent on outdoor dry-bulb temperature. In order to corroborate this dependency we conducted a straight linear regression analysis for September 25, which shows a correlation factor of 0.75, with a standard error of 6.1 and a maximum deviation of 7.7% during occupied hours.

In cases where dry-bulb temperature does not appear to have a strong-enough correlation with electrical demand, we have found that wet-bulb temperature is a useful second-order correlation. The variables that correlate well are used to drive the plant model, as described in the following paragraphs.

Other Monitored Parameters

Under the standard approach to modeling, detailed data must be obtained for all significant energy-using systems so that the program may properly account for their energy consumption. This includes number and type of light fixtures, fan motors, computer equipment, kitchen equipment, etc. Such detailed information is often difficult and very time consuming to obtain, much less model properly.

Under the proposed approach, the analyst arranges to have all central plant equipment turned off and takes a power reading at the main meter with all other systems in operation. Figure 3 shows the result of such an experiment conducted on January 15 of 1996, when we took advantage of low temperatures to shut down all cooling equipment until 3:00 p.m. in order to observe fluctuations in building loads. From Figure 3 we can see that the building base loads during a typical winter day remain fairly constant at approximately 200 kilowatts.

It is important to observe that these base loads exclude ventilation equipment (air handlers). Individual power readings were taken of all major air handling systems using hand-held power meters. Total measured fan motor load is 140 kilowatts, which results in a total load of 140 kW. When this is added to the 200 kilowatts of base load we obtain a non-plant related load of 340 kilowatts.

TUNED MODEL

The second step in the analysis is to develop a base model of the central cooling plant, which is tuned to match monitored data. Table 1 shows a typical model developed for the existing chilled water plant at Kingwood Middle School, using monitored data for September 25 of 1995. A detailed explanation of Table 1 is provided below:

Col. A

Actual monitored dry bulb temperature provided by the local utility company.

Col. B

Hour of the day. For reference only.

Col. C

Percent building cooling load expressed as:

%Load = 2.14 x OAT - 107.58

A 50% reduction factor is used for the hours between 18 and 24, since building is conditioned but occupied by cleaning crews only. A 25% factor is used for start-up loads at 3 a.m. These factors are determined by visual inspection of available data (See explanation for columns T, U, V).

Col. D
Cooling load in kBtuh. Load is expressed in Btuh because efficiency data for the chillers was given in terms of EER, making conversions easier. Cooling load assumes a full-load equal to 360-tons, which is the current operational chiller capacity.

Col. E
Chiller-1 is treated as the lead chiller in the model, and is the first to be loaded-up to either match building load, or operate at full load until it maxes-out.

Cols. F, J, N
Chiller pct. full load is expressed as the ratio of tonnage delivered to full capacity. This value is used to determine chiller part-load EER.

Cols. G, K, O
Chiller EER is obtained by curve-fitting EER vs. % load data provided by manufacturer. This actually underestimates energy use at high temperatures, because manufacturer assumes that part-load coincides with low ambient, which is not necessarily true. We feel, however that this partially compensates for compressor cycling at reduced loads.

Cols. H, L, P
Chiller kW is calculated as the ratio of chiller load (in Btuh) to EER (Btuh/W).

Cols. Q, R, S
Pump power draw is based on measured consumption of 15 kW for one pump and programmed control sequences which enable one pump per chiller

Col. T
Calculated plant kW is the sum of all three chillers and pumps power draw.

Col. U
Metered building kW from utility.

Col. V
Building "Base" kW is load not associated with the central chilled water plant, and includes, lighting, ventilation systems, and miscellaneous. This is obtained as the difference of U - T, and closely matches the sum of building electrical loads (from Fig. 3) plus the known load of 140 kilowatts for air handling systems during occupied hours.

TYPICAL-DAY&MONTHLY MODEL

Once the analyst is satisfied that the tuned model provides an accurate representation of central plant energy consumption, the base model is modified to use weather data for a "typical" day of each month. The data we use is the monthly average temperature for every hour of the day, which we obtain from files prepared for use by the Department Of Energy's building simulation program.

Figure 4 shows total modeled daily kilowatt profile for a typical September day, and the metered data for September 25 of 1995. The close similarity of the profiles gives us confidence that the model will be able to closely simulate building performance.

Typical-day models for each month are used to obtain monthly energy consumption by multiplying daily kilowatt-hour consumption by the total number of occupied days. Likewise, monthly peak demand is calculated by inserting the maximum recorded or anticipated temperature for that month into the model and allowing it to calculate electrical demand.

Figure 5 shows modeled versus actual monthly kilowatt-hour consumption for Kingwood Middle School. Figure 6 shows modeled versus actual demand data. The results are within the accuracy of most sophisticated computer models (18%). Most of the discrepancy is actually during the heating months, and can be accounted for as the additional energy used by boilers and heating pumps. These have little or no effect on the analysis of cooling plant performance however, and were not modeled. If deemed necessary, however, a similar model may be developed for heating loads.

THE MODEL AS AN ANALYSIS TOOL

The tuned model described above for Kingwood Middle School was used as the starting point for the analysis of the benefits to be expected by replacing the chillers with two new water-cooled centrifugal chillers, cooling towers, and variable-volume pumping system.

Table-2 shows a modified central plant model for the same typical September day used in the base model for Kingwood Middle School. Facility loads are slightly different because the plant modifications were modeled after considering electrical and thermal load reductions due to lighting improvements. An explanation of the modified model follows:

Col. A

Outside air temperature for each hour of a "typical" day of the month, obtained from DOE-2 weather files.

Col. B
Time of day. For reference only.

Col. C
Percent building cooling load expressed as a function of outdoor temperature and hour of the day. The same relationship used in the base model is used here, except that loads have been reduced due to implementation of lighting efficiency improvements.

Col. D
Cooling load in tons. This the load the building air handlers see. The total at the bottom of this column represents the load the building sees during the seven-hour On-Peak window (14 to 20).

Col. D1
Storage tank tons. This the load represented by the storage tank. During the hours of 14 to 20 (seven-hour period starting at 1 p.m. and ending at 8 p.m.) the tank represents a negative load (discharge) equal to the building load.

During the hours of 9 p.m. to 2 p.m. the tank is recharged by the chillers at a rate that will achieve full-charge during this period. Charging rate is determined by dividing the total at the bottom of Col. D by the available six hours.

Col. D2
Represents the total load seen by the chillers, which is the sum of the building loads and the tank loads.

Col. E
Chiller-1 is treated as the lead chiller in the model, and is the first to be loaded-up to match total plant load (Col. D2) when less than 200, or meet 50% of load when it exceeds 200. Note that the chiller is off during the On-Peak window.

Col. F
Chiller kW obtained as the product of tonnage and chiller efficiency expressed in kW/ton. These values vary depending on load according to part-load data provided by manufacturer.

Col. G
Chiller-2 is the lag chiller, and meets 50% of the total plant load when load is greater than the capacity of Chiller-1.Chiller remains off during On-Peak window.

Col. H
Same as Col. F

Cols. I through N
Power draw of primary chilled water pumps, condenser water pumps and cooling tower fans. These motors only operate when associated chillers are in operation.

Col. O
Secondary chilled water pump percent speed. It is the same as percent building cooling load (Col. C), except with a minimum value of 30%. If load is zero (0), however, pump is assumed to be off.

Col. P
Secondary chilled water pump power draw (kW) obtained by applying the following:
60 HP x 0.756 kW/HP x (%speed)^3/(drive-motor effic.)
A drive-motor efficiency curve obtained from drive manufacturers is entered into calculation.

Col. Q
Sum of power draw for chillers, primary pumps, condenser pumps, cooling tower fans, and secondary pump.

Col. R
Calculated total building kW at given time and temperature. Obtained as the sum of Plant Calculated kW (Col. Q) and Base kW (Col. S).

Col. S
Building "Base" kW is load not associated with the central chilled water plant, and includes, lighting, ahus, and miscellaneous. Values shown reflect a reduction in lighting power which does not show on Table 1.

Figure 7 shows the daily kilowatt profile for the typical September day after the chiller replacement and the implementation of a thermal energy storage system. This is the type of information that is presented to electric utility companies in order to justify investment in these load-shedding technologies. The figure shows a reduction in central plant energy use of approximately 200 kilowatts on a day with relatively mild temperatures.

CONCLUSIONS

The results presented in this paper illustrate the model's ability to match actual facility energy use profiles with a certain degree of accuracy. This is of academic value only, however, unless the model can be used to analyze the performance of alternative systems. This is where we believe the methodology offers a very distinct advantage over even some of the most elaborate commercially available computer models .

The methodology allows the analyst to effectively analyze the benefits of alternative central plant equipment configurations taking into account the most relevant factors affecting power draw, while allowing the non (less) significant parameters to remain unchanged. The model makes no assumptions based on built-in characteristics of the program. What the analyst enters as equations and data, is what the model uses to compute results.

This procedure has been used to model a large number of system configurations, mostly dealing with the cost-benefit of replacing inefficient chiller plants with more efficient centrifugal chiller machines, water thermal energy storage, and variable-volume chilled water pumping. Plant modifications resulting from analyses done using this methodology have shown that the methodology is as reliable in predicting future use as it is in matching use patterns of existing systems.

Much of the work associated with obtaining monthly and annual energy use and demand values once the model has been tuned is highly repetitive. At this time, all of this is still being done manually, which is time consuming and not very cost-effective. Future work will include the development of "Macro" routines which will conduct linear regressions, automate the transfer of weather data, enter chiller efficiency curves, and report results. Once this is accomplished the procedure will be extremely efficient and easy to use for the analysis of "what-if" scenarios.

The methodology proposed is highly dependent on the availability of reliable monitored demand and weather data. Without these, the method becomes guesswork and is not recommended. In Texas, the State Energy Conservation is sponsoring the installation of monitoring equipment at all sites where energy conservation efforts are being considered. This is to be encouraged as the first step towards understanding how and where energy is being used. It is only with this information that a reasonable analysis may be conducted.

FIGURE 1: PEAK DAY ELECTRICAL LOAD PROFILE

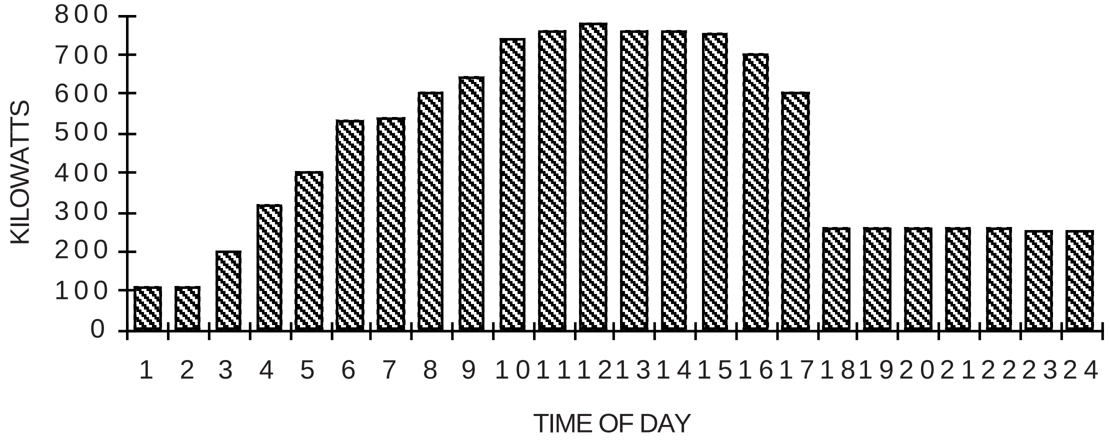

FIGURE 2: PEAK DAY ELECTRICAL/TEMPERATURE PROFILE

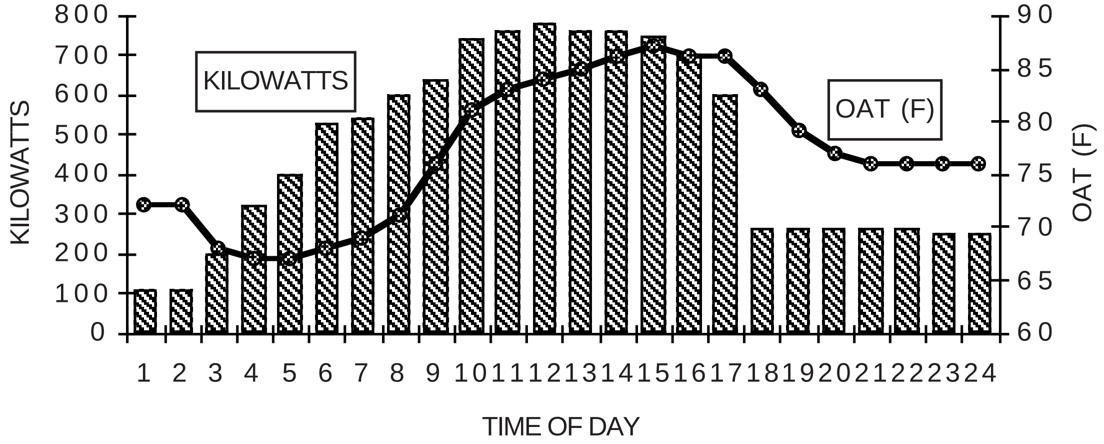

FIGURE 3: BASE DAY ELECTRICAL LOAD PROFILE

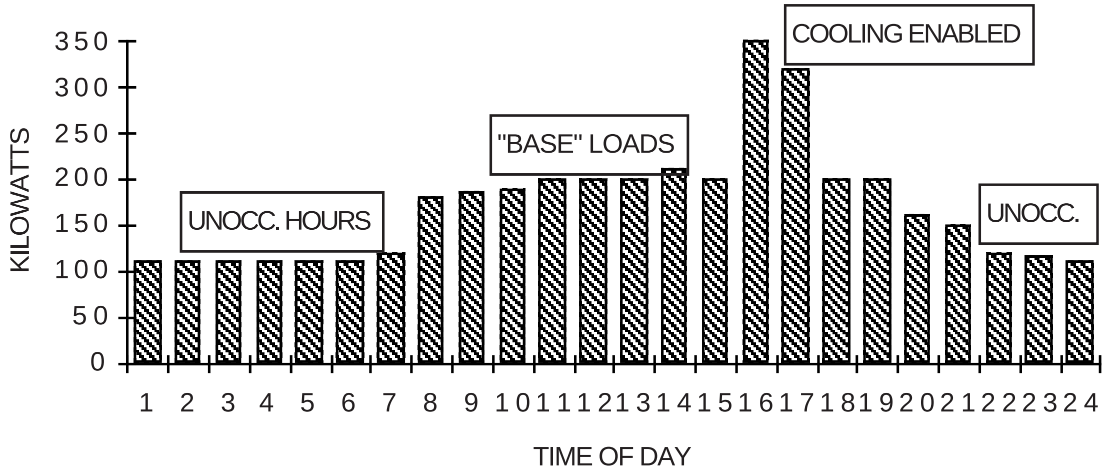

FIGURE 4: ACTUAL & MODELED KW FOR TYPICAL SEPTEMBER DAY

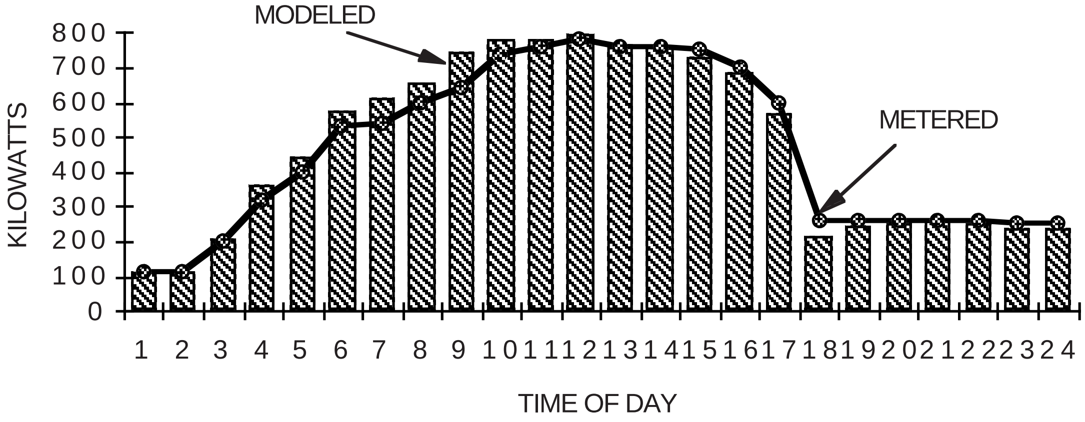

FIGURE 5: ACTUAL VS. MODELED MONTHLY KWH

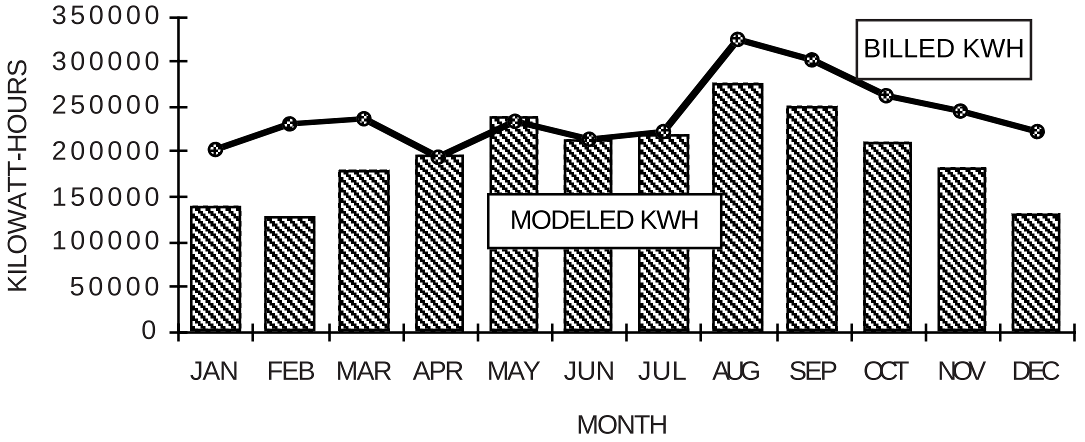

FIGURE 6: ACTUAL VS. MODELED MONTHLY KW

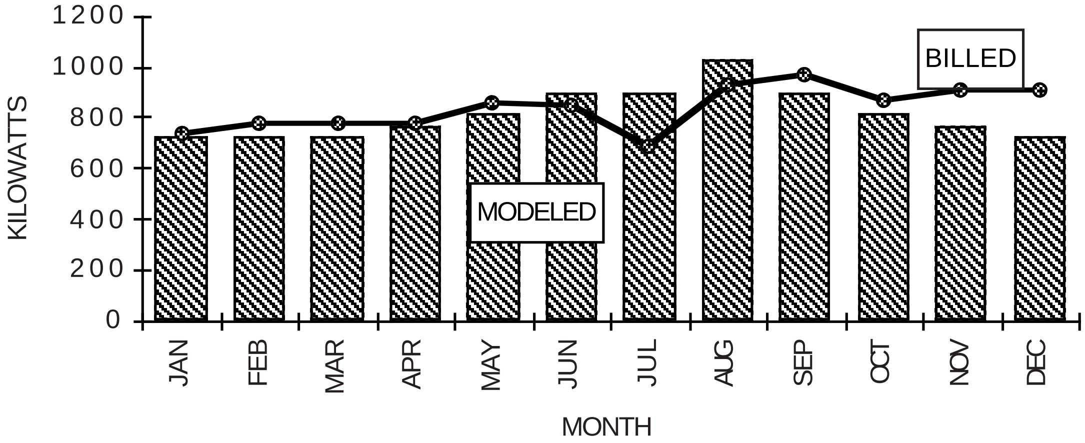

TABLE-1: SEPTEMBER 25 EXISTING PLANT MODEL

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
Temp. Bin	Hour of Day	Pct. Full Load	Cooling Load KBtuh	Chiller 1 Load KBtuh	Chiller 1 Pct. Full Load	Chiller 1 EER Btuh/W	Chiller 1 Kw	Chiller 2 Load KBtuh	Chiller 2 Pct. Full Load	Chiller 2 EER Btuh/W	Chiller 2 Kw	Chiller 3 Load KBtuh	Chiller 3 Pct. Full Load	Chiller 3 EER KBtuh/W	Chiller 3 kW	CHWP-1 kW	CHWP-2 kW	CHWP-3 kW	Plant kW	Metered Bldg. kW	Base Calc. kW
72	1	0.00	0	0	0.00	13.06	0	0	0.00	13.06	0	0	0.00	13.06	0	0	0	0	0	110	110
72	2	0.00	0	0	0.00	13.06	0	0	0.00	13.06	0	0	0.00	13.06	0	0	0	0	0	110	110
68	3	9.49	410	410	28.46	12.04	34	0	0.00	13.06	0	0	0.00	13.06	0	15	0	0	49	200	151
67	4	35.80	1,547	1,440	100.00	8.40	171	107	7.40	12.82	8	0	0.00	13.06	0	15	15	0	210	320	110
67	5	35.80	1,547	1,440	100.00	8.40	171	107	7.40	12.82	8	0	0.00	13.06	0	15	15	0	210	400	190
68	6	37.94	1,639	1,440	100.00	8.40	171	199	13.82	12.60	16	0	0.00	13.06	0	15	15	0	217	530	313
69	7	40.08	1,731	1,440	100.00	8.40	171	291	20.24	12.36	24	0	0.00	13.06	0	15	15	0	225	540	315
71	8	44.36	1,916	1,440	100.00	8.40	171	476	33.08	11.85	40	0	0.00	13.06	0	15	15	0	242	600	358
76	9	55.06	2,379	1,440	100.00	8.40	171	939	65.18	10.36	91	0	0.00	13.06	0	15	15	0	292	640	348
81	10	65.76	2,841	1,440	100.00	8.40	171	1,401	97.28	8.56	164	0	0.00	13.06	0	15	15	0	365	740	375
83	11	70.04	3,026	1,440	100.00	8.40	171	1,440	100.00	8.40	171	146	10.12	12.73	11	15	15	15	399	760	361
84	12	72.18	3,118	1,440	100.00	8.40	171	1,440	100.00	8.40	171	238	16.54	12.50	19	15	15	15	407	780	373
85	13	74.32	3,211	1,440	100.00	8.40	171	1,440	100.00	8.40	171	331	22.96	12.26	27	15	15	15	415	760	345
86	14	76.46	3,303	1,440	100.00	8.40	171	1,440	100.00	8.40	171	423	29.38	12.00	35	15	15	15	423	760	337
87	15	78.60	3,396	1,440	100.00	8.40	171	1,440	100.00	8.40	171	516	35.80	11.74	44	15	15	15	432	750	318
86	16	76.46	3,303	1,440	100.00	8.40	171	1,440	100.00	8.40	171	423	29.38	12.00	35	15	15	15	423	700	277
86	17	76.46	3,303	1,440	100.00	8.40	171	1,440	100.00	8.40	171	423	29.38	12.00	35	15	15	15	423	600	177
83	18	35.02	1,513	1,440	100.00	8.40	171	73	5.06	12.90	6	0	0.00	13.06	0	15	15	0	207	260	53
79	19	30.74	1,328	1,328	92.22	8.87	150	0	0.00	13.06	0	0	0.00	13.06	0	15	0	0	165	260	95
77	20	28.60	1,236	1,236	85.80	9.24	134	0	0.00	13.06	0	0	0.00	13.06	0	15	0	0	149	260	111
76	21	27.53	1,189	1,189	82.59	9.43	126	0	0.00	13.06	0	0	0.00	13.06	0	15	0	0	141	260	119
76	22	27.53	1,189	1,189	82.59	9.43	126	0	0.00	13.06	0	0	0.00	13.06	0	15	0	0	141	260	119
76	23	27.53	1,189	1,189	82.59	9.43	126	0	0.00	13.06	0	0	0.00	13.06	0	15	0	0	141	250	109
76	24	27.53	1,189	1,189	82.59	9.43	126	0	0.00	13.06	0	0	0.00	13.06	0	15	0	0	141	250	109
Year		---					3,394				1,556				207				5,814	11,100	5,286

TABLE 2: PLANT MODEL FOR TYPICAL SEPTEMBER DAY WITH NEW CHILLERS AND TES

A	B	C	D	D1	D2	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
Temp.	Time Of Day	Pct. Full Load	Cooling Load Tons	Storage Tank Tons	Total Plant Tons	NEW Chiller-1 Tons	NEW Chiller-1 kw	NEW Chiller-2 Tons	NEW Chiller-2 kW	CHWP-1 kW	CHWP-2 kW	CWP-1 kW	CWP-2 kW	CTFAN-1 kW	CTFAN-2 kW	Sec. CHWP Pct. Speed	Sec. CHWP Calc. kW	Plant Calc. kW	Total Calc Kw	Base kW
73.2	1	0.00	0	235	235	117.4	50	117.4	50	9	9	13	13	11	11	0	0	166	276	110
72.9	2	0.00	0	235	235	117.4	50	117.4	50	9	9	13	13	11	11	0	0	166	276	110
72.4	3	11.84	47	0	47	47.4	24	0.0	0	9	0	13	0	11	0	30	1	58	209	151
72.1	4	46.71	187	0	187	186.9	104	0.0	0	9	0	13	0	11	0	47	3	140	250	110
72	5	46.50	186	0	186	186.0	103	0.0	0	9	0	13	0	11	0	47	3	139	329	190
72.9	6	48.43	170	0	170	169.7	85	0.0	0	9	0	13	0	11	0	48	4	122	350	228
76.6	7	56.34	201	0	201	100.7	43	100.7	43	9	9	13	13	11	11	56	5	157	387	230
79.7	8	62.98	228	0	228	114.0	48	114.0	48	9	9	13	13	11	11	63	7	170	443	273
82.3	9	68.54	250	0	250	125.1	54	125.1	54	9	9	13	13	11	11	69	9	183	446	263
84.1	10	72.39	266	0	266	132.8	58	132.8	58	9	9	13	13	11	11	72	11	192	482	290
85.2	11	74.75	275	0	275	137.5	61	137.5	61	9	9	13	13	11	11	75	12	199	475	276
85.8	12	76.03	280	0	280	140.1	62	140.1	62	9	9	13	13	11	11	76	12	203	491	288
86.1	13	76.67	283	0	283	141.3	63	141.3	63	9	9	13	13	11	11	77	13	205	465	260
85.9	14	76.25	281	-281	0	0.0	0	0.0	0	0	0	0	0	0	0	76	12	13	265	252
84.9	15	74.11	272	-272	0	0.0	0	0.0	0	0	0	0	0	0	0	74	11	12	245	233
84	16	72.18	265	-265	0	0.0	0	0.0	0	0	0	0	0	0	0	72	11	11	203	192
81.7	17	67.26	245	-245	0	0.0	0	0.0	0	0	0	0	0	0	0	67	9	10	102	92
78.5	18	30.21	121	-121	0	0.0	0	0.0	0	0	0	0	0	0	0	30	1	2	55	53
77.1	19	28.71	115	-115	0	0.0	0	0.0	0	0	0	0	0	0	0	30	1	2	97	95
76	20	27.53	110	-110	0	0.0	0	0.0	0	0	0	0	0	0	0	30	1	2	113	111
75.4	21	26.89	108	235	342	171.2	87	171.2	87	9	9	13	13	11	11	30	1	241	360	119
74.7	22	26.14	105	235	339	169.7	85	169.7	85	9	9	13	13	11	11	30	1	238	357	119
74	23	25.39	102	235	336	168.2	84	168.2	84	9	9	13	13	11	11	30	1	235	344	109
73.8	24	25.18	101	235	336	167.8	84	167.8	84	9	9	13	13	11	11	30	1	234	343	109
		---	1,409	0			807		493									3,100	7,363	4,263

FIGURE 7: TYPICAL DAY WITH NEW CHILLERS AND TES