UTILITY COST ANALYSIS

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ABSTRACT

One of the first steps in setting up an energy management program in a commercial building is determining operating costs per energy consuming system through a utility cost analysis. This paper illustrates utility cost analysis methods used to determine estimated energy costs by function in a sample commercial facility. Two approaches are used to determine energy utilization and to project calculated energy consumption. Additional analysis of the utility rate structure is necessary before an estimate of operating costs per energy consuming system can be made. With this, it is possible to identify energy conservation opportunities and develop strategies to control energy waste.

INTRODUCTION

Annual energy use in a 400,000 square foot computer and office facility is estimated using both a top-down approach and a bottom-up approach. The top-down approach involves making an analysis of measured energy consumption, including utility bills and meter printouts, and prorating it to the elements causing that consumption. The bottom-up approach uses calculated loads and the rated capacity of energy-using equipment in conjunction with estimated hours of use to project calculated energy consumption. Combining the two approaches yields an estimate of the breakdown of energy use in the building for each function. This breakdown is then applied to the utility rate structure to determine the dollars spent for each function. The conclusions include estimates of energy costs by function, helping to prioritize further energy conservation study.

BUILDING AND OPERATING CHARACTERISTICS

The complex is comprised of two major buildings: the original structure with 211,650 square feet, built in 1966 as a manufacturing facility for electronic assembly and a four-story annex building with 153,000 square feet added in 1979.

BUILDING SYSTEMS

The systems studied were central heating, ventilation and air conditioning systems (HVAC) serving the original building and the four-story annex building, the automatic temperature control systems, lighting systems, computers and associated power conditioning and emergency power systems, and Liebert HVAC for the computer areas.

Central HVAC Systems

The central plant serves both the original and annex buildings. Two Carrier centrifugal refrigeration machines provide chilled water to coils in air handlers. These machines normally supply a single circulating loop to both buildings when piped in parallel. By adjusting manual valves, the 750-ton machine may serve the original building, and the 400-ton machine may serve a separate circulating loop to the annex building.

Normal operation provides for a single circulating loop to each building. The chillers are brought on-line manually according to outside air temperature. Typically, the 400-ton machine is operated when outside air temperature is from 65 to 75 degrees Fahrenheit. When the temperature goes above 75 degrees Fahrenheit, the 750 ton machine is brought on-line and the 400-ton unit shuts down until the set point for supply chilled water can no longer be maintained. Both chillers are then operated.

Two Compak water tube boilers provide low-pressure steam to hot water converters for both the building domestic hot water and heating hot water with only one of the two 526 HP boilers in operation at a time. In the original building, hot water is circulated to two systems: Reheat coils located in the supply air ducts and the perimeter radiation heating system.

Low pressure steam is piped to the annex building, where a converter provides hot water to perimeter radiation. These circulating systems are operated manually on an as-needed basis, with the circulating hot water temperature adjusted manually according to outside air temperature.

Air Handling Units

Fifteen air handlers in the original building provide a constant volume of air to most of the conditioned spaces. In addition, 2 roof-top units with DX compressors and electric heat condition approximately 8200 square feet. Motor horsepower ranges from 3 to 50 HP with a total of 318 HP.

Each of these air handlers has the capability of providing 100 percent outside air for free cooling. This cycle is operated manually according to outside temperature and the requirement for cooling the occupied space. Ventilation is provided by leakage through the outside air dampers. This leakage ranges from 10 to 20 percent of total air volume.

Occupied space temperature is controlled on these systems by means of the discharge air setpoint in the cooling season and hot water circulating temperature in the heating season.

The annex building is served by two rooftop variable air volume (VAV) air handling units with chilled water coils only. These VAV air handlers serve shut-off boxes in the space. A problem exists in supplying an adequate volume of air without blowing the ductwork apart; it is believed this situation in caused either by poor installation of the fiberglass ductwork or lack of a return air fan in the system. Capability exists to provide outside air for free cooling; this sequence is presently controlled by a pneumatic enthalpy logic center.

Lighting Systems

Office lighting is provided by Watt-Miser fluorescent bulbs; each four-tube fixture has been delamped to two tubes and one ballast has been disconnected. Approximately 2.1 watts per square foot (including ballast) provide 30 to 70 foot candles at horizontal work spaces. In the original building, substantial illumination is lost to the yellowed egg-crate type diffusers. All lighting is manually controlled by the plant operators. Parking lot lights are automatically controlled by a 7-day time clock.

Computers, UPS System and Emergency Generators

Seven IBM central processing units (CPU) are located in the basement and first floor of the annex building. Power to these CPU's is provided by uninterruptable power source (UPS) that filters the utility supplied voltage and frequency and provides battery backup in the event of power interruption. These UPS systems are designed to protect CPU memory until three 1000 kW diesel generators automatically come on-line. Approximately 528 CRT's are interconnected to the mainframe computers; these are distributed throughout the complex. They are left operating continuously by recommendation of the manufacturer.

Computer and Switchgear HVAC

Twenty Liebert down-flow packaged systems with pressurized under-floor air distribution provide 400 tons of cooling to the computer rooms. These self-contained systems are designed to provide both temperature and humidity control through use of re-heat and humidification cycles. At the present time, all electric re-heat is manually switched off. In addition to these air systems, 5 Liebert chillers supply 76 tons of cooling water directly to the CPU's. Three DX systems with economizer cycles provide a total of 96 tons of mechanical cooling to switchgear and UPS equipment rooms.

ENERGY UTILIZATION ANALYSIS - TOP-DOWN APPROACH

Through on-site kW readings of individual loads, observation of operating procedures and interviewing building operating personnel, it is possible to establish the electrical demand profile of the facility. Demand figures accurately reflecting normal operating conditions for each piece of equipment can be calculated from two sets of absolute data: monthly peak demand figures recorded on the utility bills and total peak demand possible for each piece of equipment.

MONTHLY PEAK DEMAND FIGURES

Peak kW for each month of the year 1983 is shown in Table 1 under the column labeled "PEAK KW/KVA." The measured monthly peak kW was 3,574 kW during the summer and 2,686 kW during the winter.

TOTAL PEAK DEMAND POSSIBLE

Table 2 contains the total peak possible for each piece of equipment, as published by the manufacturer. The grand total, which is an absolute maximum peak kW, will not occur during normal operations because of diversity and seasonal variations.

OPERATING KW BY SEASON

Table 3 summarizes the estimated seasonal kW peaks of operating loads which actually occur.

KWH BALANCE

Using 30-minute demand data for the previous 12 months supplied by the utility company, a kWh consumption profile has been developed for both a winter and summer month. KW used to develop this kWh profile is less than the peak kW shown in Table 2. This is due to the fact that it is an average kW during on- and off-peak hours. The kWh balance is shown in Table 4. The estimated annual energy consumption by category is depicted in Figure 1.

TABLE 1: STANDARD AUDIT ANALYSIS

MONTH	kWh	BILL DAYS	kWh/ DAY	PEAK kW/kVa	WATTS/ FT2	LOAD FACTOR	ELECTRIC $	CCF	BILL DAYS	CCF/ DAY	NATURAL GAS $	TOTAL DOLLARS
JAN	1,627,000	32	50,843	2,686	7.36	0.78	$ 99,408	14,130	32	441	$ 9,652	$ 109,060
FEB	1,422,000	28	50,785	2,646	7.25	0.79	$ 90,761	13,530	28	483	$ 9,242	$ 100,003
MAR	1,562,000	31	50,387	2,674	7.33	0.78	$ 96,885	9,210	31	297	$ 6,295	$ 103,180
APR	1,498,000	29	51,655	3,032	8.31	0.70	$ 90,070	6,510	29	224	$ 4,451	$ 94,521
MAY	1,702,000	32	53,187	3,200	8.77	0.69	$ 98,431	2,280	32	71	$ 1,566	$ 99,997
JUN	1,800,000	30	60,000	3,574	9.80	0.69	$ 109,966	2,040	31	65	$ 1,402	$ 111,368
JUL	1,791,000	29	61,758	3,541	9.71	0.72	$ 108,963	1,730	28	61	$ 1,191	$ 110,154
AUG	2,022,000	33	61,272	3,546	9.72	0.71	$ 117,527	2,060	33	62	$ 1,415	$ 118,942
SEP	1,699,000	30	56,633	3,518	9.64	0.67	$ 105,125	1,900	30	63	$ 1,327	$ 106,452
OCT	1,601,000	31	51,645	3,445	9.44	0.62	$ 97,894	3,680	31	118	$ 2,559	$ 100,453
NOV	1,457,000	30	48,566	2,645	7.25	0.76	$ 87,135	6,830	30	227	$ 4,741	$ 91,876
DEC	1,474,000	30	49,166	2,610	7.15	0.78	$ 92,293	15,540	30	518	$10,774	$ 103,067
Tot.	19,656,000						$1,194,458	79,440			$54,615	$1,249,073

Total kWh 19,656,000 X 3413 BTU/KWH = 67,085,928,000 BTU'S = 183,973 BTU'S PER SQUARE FOOT PER YEAR

Total Natural Gas 79,440 X 100000 BTU/CCF = 7,944,000,000 BTU'S = 21,785 BTU'S PER SQUARE FOOT PER YEAR

Totals = 75,029,928,000 BTU'S = 205,758 BTU'S PER SQUARE FOOT PER YEAR

TABLE 2: OPERATING CONNECTED kW

	kW
Computers & Computer HVAC	
Computers	933
Liebert Units	676
CRT's	100
Subtotal	1,709
HVAC System	
VAV AHU's	112
AHU's	240
Pumps	168
Chillers	876
Subtotal	1,396
Lights and Miscellaneous	
Lights	706
Elevators	15
Kitchen	50
Subtotal	771
Grand Total	3,876

TABLE 3: OPERATING kW BY SEASON

	SUMMER kW	SPRING/FALL kW	WINTER kW
Computers & Computer HVAC			
Computers	933	933	933
Liebert Units	567	567	567
CRT's	100	100	100
Subtotal	1,600	1,600	1,600
HVAC System			
VAV AHU's	100	100	100
AHU's	189	189	189
Pumps	75	75	45
Chillers	858	606	0
Subtotal	1,222	970	334
Lights and Miscellaneous			
Lights	706	706	706
Elevators	11	11	11
Kitchen	35	35	35
Subtotal	752	752	752
Grand Total	3,574	3,322	2,686

TABLE 4: kWh BALANCE

WINTER

LOAD	OFF PEAK kW	X	hrs	=	KWH	ON PEAK KW	X	hrs	=	KWH	TOTAL
CRT'S	100		480		48,000	100		250		25,000	73,000
LIEBERT AHU'S	50		480		24,000	50		250		12,500	36,500
VAV AHU'S	60		480		28,800	60		250		15,000	43,800
AHU'S	85		480		40,800	189		250		47,250	88,050
PUMPS (HEAT)	45		480		21,600	45		250		11,250	32,850
ELEVATORS	11		480		5,280	11		250		2,750	8,030
COMPUTERS	933		480		447,840	933		250		233,250	681,090
LIGHTS	260		480		124,800	706		250		176,500	301,300
LIEBERT COMPR.	318		480		152,640	318		250		79,500	232,140
KITCHEN	0		0		0	35		200		7,000	7,000
Totals	1,862				893,760	2,447				610,000	1,503,760

SUMMER

LOAD	OFF PEAK kW	X	HRS	=	kWh	ON PEAK kW	X	HRS	=	kWh	TOTAL
CRT'S	100		480		48,000	100		250		25,000	73,000
LIEBERT AHU'S	50		480		24,000	50		250		12,500	36,500
VAV AHU'S	70		480		33,600	100		250		25,000	58,600
AHU'S	189		480		90,720	189		250		47,250	137,970
CHW PUMPS	75		480		36,000	75		250		18,750	54,750
ELEVATORS	11		480		5,280	11		250		2,750	8,030
COMPUTERS	933		480		447,840	933		250		233,250	681,090
LIGHTS	260		480		124,800	706		250		176,500	301,300
LIEBERT COMPR.	318		480		152,640	318		250		79,500	232,140
KITCHEN	0		0		0	35		200		7,000	7,000
CHILLERS	250		480		120,000	609		250		152,250	272,250
Totals	2,256				1,082,880	3,126				779,750	1,862,630

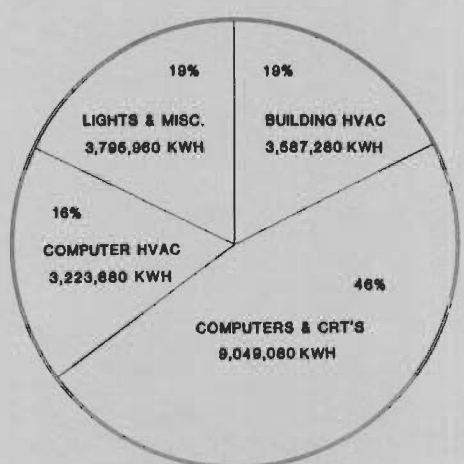


FIGURE 1

ANNUAL ENERGY USAGE-KWH

ENERGY UTILIZATION ANALYSIS - BOTTOM-UP APPROACH

Load calculations were developed at heating and cooling design conditions for the thermodynamic characteristics of the facility including:

- o transmission through walls, windows and roof
- o infiltration - sensible and latent heat
- o ventilation air - sensible and latent heat
- o internal heat gain - people and process
- o solar load
- o miscellaneous electric consumption

Partial load characteristics were input for occupancy, miscellaneous electric consumption and reduced ventilation air over a 24-hour period. These 24-hour profiles were developed for three day types: weekday, Saturday and Sunday.

Calculated design loads were then run on a computer program using ASHRAE Standard Reference Year hourly weather data for the purpose of generating a model of the buildings' energy consumption for comparison to actual utility bills.

The results of the modeling program and actual 1983 natural gas and electric consumption are graphed in Figures 2 and 3. The results indicate a good understanding of the heating requirements of the facility as demonstrated by the close fit of the two curves defining actual and modeled natural gas usage.

Examination of the graph showing modeled electric consumption versus actual 1983 data, illustrates an understanding of electrical energy requirements during all but peak cooling months. Further investigation of actual cooling requirements during these months will be used to tune the model. For purposes of this paper, the model demonstrates an understanding of electric

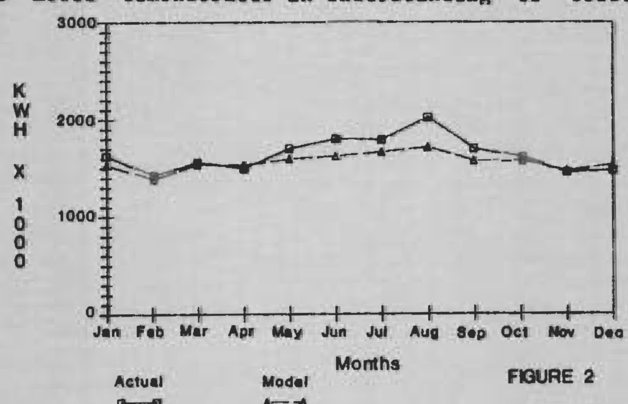


Figure 2 Monthly KWH Consumption

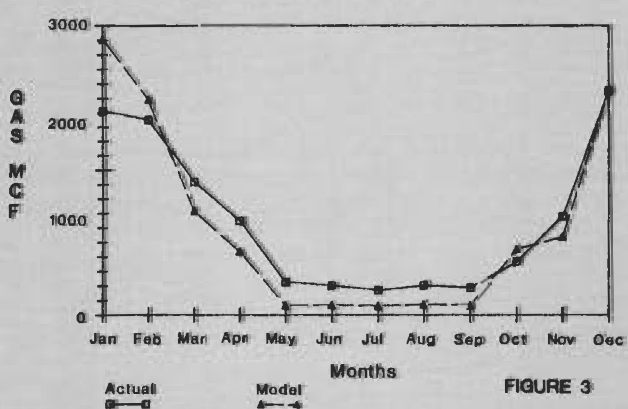


Figure 3 Monthly Gas Consumption

energy requirements for all except the centrifugal chillers.

UTILITY RATE STRUCTURE ANALYSIS

ELECTRIC SERVICE

Philadelphia Electric Company services the facility under rate schedule HT (High Tension Power). The utility company provides untransformed 33,000 volt electric service from their standard high-tension lines. All transforming and switching equipment is owned by the facility.

Rate Structure

Several detailed elements add to the complexity of the rate structure. The rate structure is designed to assess demand charges and includes a ratchet clause. Registered demand is based on the highest rate of electricity used in a 30-minute period for that month. The ratchet clause further stipulates the demand charge during October through May will not be less than 80 percent of the highest billing demand charged during the preceding months of June through September. Therefore, the maximum rate at which electricity is used affects the cost more than one would normally expect. Rate Schedule HT uses the following data to calculate monthly electric bills.

Billing Demand. Computed to the nearest kilowatt of registered demand adjusted to 95 percent power factor. During October through May, billing demand will not be less than 80 percent of the highest billing demand in the preceding months of June through September.

Registered Demand. Metered actual kW demand during the 30-minute period of greatest use for that month.

Power Factor. Metered kVaRH used to compute power factor at time of registered demand peak.

Billed/Registered Kilowatt Hours. Metered total kilowatt hours for the billing period.

On-Peak Kilowatt Hours. Defined as the hours between 8:00 a.m. and 8:00 p.m., daily except Saturdays, Sundays and holidays; except that on-peak hours end at 4:00 p.m. on Fridays.

Off-Peak Kilowatt Hours. The hours other than those specified as on-peak hours.

High Voltage Discount. $0.07 per registered kW of demand.

Sample Rate Calculations

The following sample illustrates all aspects of the rate structure and includes the methods and data for calculating the facility's electric bills.

Customer Charge: .... $ 248.98

Capacity Charge: $4.18 per kW X 3230 (billing demand) = ... 13,501.40

In this case, the billing demand is 80 percent of 4,038 kW, the peak billing demand of June through September. The registered demand adjusted for power factor would have been:

$$\frac{\text{Registered kW}}{\text{Registered P.F.}} \times 95 = \text{Billing Demand or,}$$

$$\frac{2609.6}{81.2} \times 95 = 3053 \text{ kW}$$

Since the 80 percent ratchet exceeds this kW, the greater of the two is used to compute billing kW.

Energy Charge:
$0.0704 per kWh for the first 150 hours billing demand
$0.0544 per kWh for the next 150 hours
$0.0387 per kWh for additional use or,

$0.0704 X 3230 X 150 = ... $34,108.80
$0.0544 X 3230 X 150 = ... $26,356.80
$0.0387 X 506,000 kWh = ... $19,582.20

Time-Of-Use Adjustment:
Off-Peak Credit = $0.0026 per kWh or,
$0.0026 X 894,105 = ... <$ 2,324.67>

On-Peak Charge = $0.0024 per kWh or,
$0.0024 X 580,895 = ... $ 1,394.14

High Voltage Discount:
$0.07 per registered kW or,
$0.07 X 2610 kW = ... <$ 182.70>

SUBTOTAL $92,684.95

Pennsylvania State Tax Adjustment Clause:
5.54 % of $92,684.95 = ... $ 5,134.75

Electric Fuel Credit:
$0.007289 per kWh .... <$10,751.28>

SUBTOTAL $87,068.42

Pennsylvania 6 % Sales Tax:
6 % of $87,068.42 = ... $ 5,224.11

GRAND TOTAL $92,292.53

Rate Structure Observations

1. The effective dollar cost per kW is the total of several elements:

Capacity Charge .... $ 4.18/kW
Energy Charge ($0.0705 X 150) less ($0.0387 X 150) =
($0.0544 X 150) less ($0.0387 X 150) = ... $ 2.355/kW

This holds true since in all cases, 300 times the billing demand is less than the total billed kWh.

High Voltage Discount .... <$ 0.07/kW>

SUBTOTAL $11.22/kW

PA Tax Adjustment & Sales Tax (5.54 % + 6 %) X $11.22 =

GRAND TOTAL $12.51/kW

Therefore, the total dollar cost avoidance for each kW reduction in billing demand will be $12.51 per kW.

2. Elements of the rate structure that have an impact on the effective dollar cost per kWh are:

Marginal kWh Energy Charge .... $ 0.0387
On-Peak Charge - $0.0024
Off-Peak Credit - <$0.0026>
PA Tax Adjustment (5.54 % X $0.0387)... $ 0.002143
Electric Fuel Credit .... <$ 0.007289>
Subtotal .... $ 0.033554

PA Sales Tax (6 % X $0.033554) .... $ 0.0020132

Grand Total .... $ 0.0355672/kW

Therefore, $0.0355672 will be the dollar cost avoidance for each kWh saved. In addition, it is important to note that off-peak savings will be decreased by $0.0029086/kWh to $0.0326586/kWh and on-peak will be increased by $0.0026848 to $0.038252/kWh, including state taxes.

The total component of the dollar demand for this particular utility bill is $40,407.30, or approximately 44 percent.

GAS SAVINGS

Natural gas is supplied to the facility by Philadelphia Electric Company under rate GC General Service. The rate structure is straightforward as opposed to the electric rate structure. The following illustrates the components used to calculate the gas bill.

Customer Charge $10.00
Commodity Charge .... $ 6.133/MCF
State Tax Adjustment .... 3.19 %
Gas Cost Rate (present) .... $ 0.02053/CCF

UTILITY COST ANALYSIS

By applying our understanding of the electric rate structure to the energy utilization at the facility we can see how dollars are being spent for electrical energy.

The dollar allocation for the load categories charged during a typical summer month (see Table 5 for June) can be compared to those during a winter month (see Table 6 for December).

From the sample months depicted, the amount of energy used fluctuated by season for the building HVAC computer, HVAC, and lights. To annualize the kW and kWh costs, we subtracted the constant loads from the total energy used which indicated the kWh and peak kW use by the building HVAC. This gave a clear picture of where electric dollars are being spent. (See Table 7 and Figure 4.)

To compare energy usage to that of an office building without computers, we subtracted the estimated kWh consumed by the computers and associated HVAC from per square foot of the total 183,973 Btu's per square foot consumed in one year. The remaining 69,104 Btu's per square foot used puts this building in a normal electrical consumption range.

TABLE 5: SUMMER (JUNE) ELECTRICITY COST ANALYSIS

Computer & Computer HVAC	kW	X	$12.51=$	kWh	X	AVG$/kWh $0.0354=$	TOTAL $
Computers	933		11,672	681,090		24,111	35,783
Liebert Compr.	517		6,468	232,140		8,218	14,686
Liebert AHU's	50		626	36,500		1,292	1,918
CRT's	100		1,251	73,000		2,584	3,835
Subtotal	1,600		20,017	1,022,730		36,205	56,222
HVAC System							
VAV AHU's	100		1,251	58,600		2,074	3,325
AHU's	189		2,364	137,970		4,884	7,248
CHW Pump	75		938	54,750		1,938	2,876
Chillers	858		10,734	272,250		9,638	20,372
Subtotal	1,222		15,287	523,570		18,534	33,821
Lights & Miscellaneous							
Lights	706		8,832	301,300		10,666	19,498
Elevators	11		138	8,030		284	422
Kitchen	35		438	7,000		248	686
Subtotal	752		9,408	316,330		11,198	20,606
Total	3,574		$44,712	1,862,630		$65,937	$110,649

PLUS POWER FACTOR PENALTY OF: 464 X $12.51 = 5,805

Grand Total = $116,454

TABLE 6: WINTER (DECEMBER) ELECTRICITY COST ANALYSIS

	KW	X	$12.51=$	KWH	X	AVG $/KWH $0.0354=$	TOTAL $
Computer & Computer HVAC							
Computers	933		11,672	681,090		24,111	35,783
Liebert Compr.	517		6,468	232,140		8,218	14,686
Liebert AHU's	50		626	36,500		1,292	1,918
CRT's	100		1,251	73,000		2,584	3,835
Subtotal	1,600		20,016	1,022,730		36,205	56,221
HVAC System							
VAV AHU's	100		1,251	43,800		1,551	2,802
AHU's	189		2,364	88,050		3,117	5,481
Pumps	45		563	32,850		1,263	1,726
Subtotal	334		4,178	164,700		5,830	10,008
Lights & Miscellaneous							
Lights	706		8,832	301,300		10,666	19,498
Elevators	11		138	8,030		284	422
Kitchen	35		438	7,000		248	686
Subtotal	752		9,408	316,330		11,198	20,606
Total	2,686		$33,602	1,503,760		$53,233	$ 86,835

PLUS RATCHET PENALTY OF: 473 KW X $12.51 = 5,917

Grand Total = $ 92,752

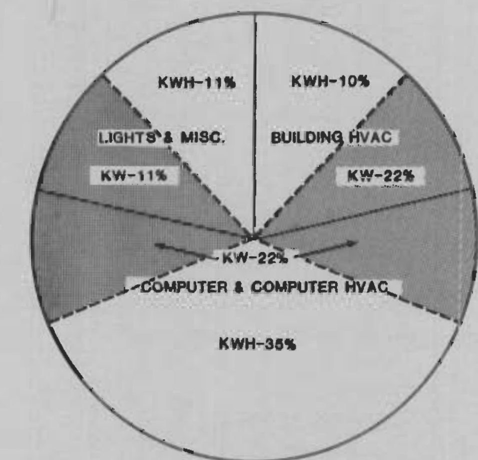
TABLE 7: ANNUAL ELECTRICITY COST ANALYSIS

	kW	X	$12.51=$	kWh	X	AVG $/kWh $0.0354=$	TOTAL $
Computer & Computer HVAC	19,200		$240,192	12,272,730		$434,456	$ 674,648
Lights and Miscellaneous	9,024		$112,890	3,795,960		$134,377	$ 247,267
HVAC	8,893		$111,251	3,587,280		$126,990	$ 238,241
Total	37,117		$464,334	19,656,000		$695,822	$1,160,156

PLUS POWER FACTOR & RATCHET PENALTIES OF:

5856 kW X $12.51 = 73,259

Grand Total = $1,233,415



TOTAL $KW: $537,593. (44%)

TOTAL $KWH: $695,822. (56%)

FIGURE 4

WHERE THE ELECTRIC $'s GO

CONCLUSIONS

Measured energy consumption gathered during on-site auditing of the facility, in conjunction with utility billing history and utility meter printouts can effectively be used to develop load profiles of various energy consuming systems.

The load profiles developed through use of the top-down energy utilization analysis provides a convenient input of estimated hours of use to the bottom-up technique of computer modeling. The computer model may be used as a verification of the understanding of energy consumption in various systems. In this format, enhancements of the model based upon further data gathering are readily implemented. In addition, proposed changes to energy consuming systems for conservation or other purposes may be readily modeled to project energy consumption as a result of any changes.

Analysis of the utility rate structure clarifies the utility costs associated with each billing element. This understanding is necessary to accurate projection of costs associated with a particular energy consuming system.

Once the determination of energy cost by function has been made, practical applications of this understanding are varied. For example, more accurate allocations may be made for cost accounting purposes, budgets for typical systems' operating costs may be readily prepared, or prioritizing further study of energy conservation measures according to system operating costs.■