EDITOR'S NOTE: This is the first of a two-part article which introduces a new energy auditing concept: the ***"Energy Balance."*** *It is a practical, comprehensive way of improving the accuracy of audits that must be made quickly. I would like to thank the authors for sharing the procedures they perfected in the process of making hundreds of energy audits.*

Analyzing Facility Energy Use: A Balancing Act

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ABSTRACT—PART I

When you do an energy audit, you must have a good understanding of how the energy is used by a facility to make sure that your energy efficiency recommendations are accurate and appropriate. You must know what equipment uses energy, how much energy it uses and how much energy it uses as a proportion of the total energy used at the facility. You can do this by monitoring the energy use of all the major pieces of equipment, but this is quite expensive and time-consuming. In this article, Part I, we discuss an alternative way for you to estimate the energy use by developing an *ENERGY BALANCE*. This method is particularly helpful if you have limited time to gather the energy use data.

At the University of Florida Industrial Assessment Center we devised the "Energy Balance" method of energy analysis because we realized that we had sometimes overestimated the energy savings available to a facility. This happened when we did not have a clear idea of how much energy was used by each group of equipment such as motors, lighting, air compressors, air conditioning, etc. Therefore, we developed a spreadsheet where we entered the energy use data gathered at the facility and compared it to the actual energy use as shown in the utility bills.

We then refined our assumptions with respect to load factors and hours of usage if our preliminary results were out of line with the actual total energy use by the facility. Our result is an approximation of the energy used by the major electric equipment systems in the facility. We perform separate energy balances for each type of energy source (electric, natural gas, propane, etc.).

Performing an energy balance gives you several benefits. You can see which equipment systems contribute the most to the energy costs and can spend your time analyzing recommendations for those systems. Because the equipment data is already available in the energy balance spreadsheet, you can easily export portions of the data to the recommendation analysis spreadsheets to calculate energy cost savings. You can check the credibility of your energy savings recommendations by making sure that a recommendation does not save more energy than a given equipment system uses.

Finally, you can show the facility how its energy use and energy dollars are apportioned among the various systems.

In this article we describe the spreadsheet we developed to estimate an energy balance along with several sample energy balances. We explain how to reconcile the preliminary results to achieve a reasonably realistic energy balance. We also provide examples of recommendations that we had to reanalyze and basic assumptions that we needed to revise for consistency with the energy balance.

PART II

The second part of this report, in our next issue, will show you how to use the Energy Balance data you have collected to make sound financial and capital investment decisions.

INTRODUCTION

To improve the efficiency of energy use at a facility, the analyst must have a good understanding of what that energy use is. Energy use data can be gathered by metering and monitoring equipment, but this method is expensive and time-consuming. Often, the energy analyst can spend only a day gathering data, and this sometimes makes getting an accurate picture of the facility's energy use difficult.

At the University of Florida Industrial Assessment Center, we were faced with the task of gathering sufficient data in a one-day plant visit to analyze the existing energy use and make recommendations for changes. We developed an energy balance approach to simulating facility energy use to help with our analysis.

This article will demonstrate the usefulness of constructing an energy balance as an alternative to more costly methods of measuring energy use. We will detail the major steps of creating and using an energy balance. We start with data collection, explain the method used to reconcile the simulated use with the historical use patterns, and discuss use of the energy balance for making recommendations.

WHAT IS AN ENERGY BALANCE?

We modeled our energy balance after the traditional mass and heat balance approach of physics and thermodynamics. We realized that it was not sufficient to look at each energy use system at a facility in isolation because we sometimes found situations where the whole did not equal the sum of its parts. That is, the total metered kWh (and/or kW) use was lower (or higher) than the sum of the estimated uses by each system within the facility. Therefore, we developed a model for estimating the energy uses of each system as a part of the whole system, and we call our model the **energy balance**.[1]

CONSTRUCTING A DETAILED ENERGY BALANCE SPREADSHEET

Before making the facility site visit, you must gather the historical energy use data either from the facility or from the utility supplying the energy. This data must be collected both to prepare for an audit and to start understanding the energy use of a facility. At the facility site visit, you should collect data on all energy-consuming equipment (electricity, gas, or any other form of energy). The equipment-energy use data should be entered in the energy balance spreadsheet. Next, you calculate demand and energy use for the facility based on that data, and adjust the equipment energy use parameters until the predicted use matches the historical use within a given tolerance factor. Only then should you start the data analysis necessary to make energy efficiency recommendations.

Collecting Historical Energy Use Data

To analyze a facility's historical energy use, gather at least 12 months of energy bills. For each type of energy source, find the average demand and energy uses and charges for the past year or business cycle. Do not forget to factor in the various taxes and tariffs. For electricity, demand charges are based on the peak recorded each month, while the energy charge is typically based on the number of kilowatt-hours used each month.

At the University of Florida Industrial Assessment Center (UF IAC), we used an Excel spreadsheet for organizing monthly use and costs. Once the data has been entered, you can quickly produce useful bar graphs of demand and energy use as well as costs trended by the month. These graphs give a quick picture of historical energy use.

For example, you may find a bi-level peak pattern that may indicate a business with different seasonal usages, or you may see a continually increasing pattern. This type of picture will help the auditor understand the processes and business of the client and may prompt questions that plant personnel can answer during the plant visit.

For example, can a bi-level pattern of demand and energy be explained by different operating schedules during different seasons? Or, why is the use continually increasing? Perhaps increased production accounts for the increase, but maybe it is poor maintenance practices and aging equipment.

In addition to the bar graphs, we used pie charts to illustrate the relative energy use between different energy sources. For example, if a plant uses both natural gas and electric energy, then a pie chart makes it easy to see the relative usage between gas and electricity. If the analysis shows insignificant gas use (less than 10% or so), then you know that you should focus your major analytical efforts on the electrical equipment. You will also use this historical use data with your energy balance calculations in order to validate your data collection and assumptions.

Collecting Equipment Energy Use Data

We utilized the following basic method to collect data:

- Meet with plant personnel, someone like the plant manager, to discuss the processes at the plant as well as major energy-consuming equipment and safety concerns. We placed an emphasis on the plant process, since these processes are how the plant makes money. Any energy savings recommendation that causes the plant to lose money in other areas is sure to be rejected.
- Conduct a plant walk-through with plant personnel, again focusing on processes with the emphasis on major energy-consuming equipment and safety concerns. We generally followed the path that the raw material would take as the plant transforms it to a completed product.
- Perform a detailed data collection of energy-consuming equipment. If plant maintenance personnel will help with this task, their services are invaluable.

You will need the following basic data from all types of energy-consuming equipment to compile the energy balance:

- From the discussion with plant personnel, climate conditions, and personal observation, you can estimate the annual use in hours per year (h/yr) and assign a utilization factor for each piece of equipment. We chose the number of hours a year that a piece of equipment should be available for operation as the annual use number. For example, we often used the operating hours for the facility for the annual use hours. Then we modified this annual use number with a utilization factor (uf) to account for the actual time of use of that equipment. For equipment in constant use, the utilization factor could be 0.9 to account for 10% downtime due to maintenance. The utilization factor for equipment in less than constant use is assigned a value according to the percent of use time estimated by plant personnel. This parameter can be adjusted, if necessary, when refining the energy balance.

- From the name plate of the equipment, you should collect and record the following data if available:
  — The power rating in kilowatts (kW), horsepower (Hp), tons, or similar information. For example, if neither kW nor Hp is available, collect the amperage, voltage, power type, and power factor. By power type, we mean alternating current (AC) single-phase or three-phase, or direct current (DC). With this additional information, you can estimate the power rating.
  — Any efficiency values that may be available. For cooling equipment, you should record the energy efficiency ratio (EER) or coefficient of performance (COP). Motor efficiency values can be found on the nameplate or from tables in the DOE MotorMaster program.[2]
  — If no data are available, try to get the manufacturer's name, model and serial numbers, and contact the manufacturer for data.

- Since a motor rarely runs at its rated power level, you need to determine the motor load factor (lf) to calculate the actual power used. You can take a current measurement or a speed measurement of a major motor to get an approximate load factor. You could use a clamp-on ammeter or a tachometer and compare the measurement to the amperage rating or the speed drop characteristics curve to estimate its load factor. However, you must remember even this type of measurement is just a one time sample. The only way to get an accurate measure would be to measure load over a relatively long period. To get this accurate measurement, you could use a strip chart recorder, a monitor connected to a computer, a data logger, or part of an energy management system. If you have not measured the load factor, you will have to estimate one. We have found that typical motor load factors are between 0.35 and 0.60. However, some motors such as fans and air compressors generally have higher load factors of 0.8 to 0.9.

- To adjust the total power use, we also assign a diversity factor (df) to each piece of equipment. We use this to account for similar pieces of equipment that are not run concurrently. For example, if the plant has two condensate pumps but only one can be run at any given time and the second is used in a backup mode, you should account for this fact with a diversity factor of 0.5. Most equipment that operates a large number of hours during the plant's peak use shift will have a diversity factor of 1. (For a more complete explanation of load factor and diversity factor, see Capehart[3]. Also see, Capehart[1].)

It is not feasible to collect data on every piece of equipment at a facility. However, you should try to collect detailed information on the larger pieces of equipment that use 90% of the energy. We used a miscellaneous category to account for the last 10% of energy use by the large number of small energy users.

You should collect data on the following pieces of equipment:

- Motors: These are the largest single energy consumer category in most manufacturing facilities. Generally, you should concentrate on motors over five horsepower. However, depending on the size and type of facility, you may want to increase or decrease this threshold. Furthermore, you may want to treat a large number of similar small-size motors as a group. For example, some facilities may have a large number of conveyor belt motors of similar size and with similar usage patterns. See the motor section of **Figure 1: Energy Balance—Electrical Equipment.**

- Heating, ventilating, and air conditioning (HVAC): Locate all the heating, cooling and ventilating equipment. Exhaust fans should be included in the motor list. Sizes of equipment (in kW, tons or other units) together with EERs or COPs must be found and recorded. From this EER or COP data, we can find the kW/ton power consumption and the total kW by knowing the size in tons of each unit. The energy consumption is then found by multiplying the full-load kW by a factor called the Full Load Equivalent Operating Hours (FLEOH) of the compressor unit. The FLEOH is dependent on the geographical area where the facility is located, and can usually be found from the local utility or from the State Energy Office for the area. (Note that you need to use the compressor operating hours, not the hours that the facility is air-conditioned, for your air conditioning equipment operating hours.) See the HVAC section of **Figure 1: Energy Balance—Electrical Equipment.**

- Air Compressors: We placed air compressors in a separate category from other motors because the efficiency recommendations are often quite different and we wanted to isolate the air compressor system's energy use. The hp size of each compressor should be recorded. When you examine the air compressor system, also look for auxiliary equipment, such as air dryers. See the air compressor section of **Figure 1: Energy Balance—Electrical Equipment.**

- Lights: Note the usage patterns of the lights as well as the usage patterns of the lighted areas. Then find the total wattage of the facility's lighting system. Purely resistive lighting loads, such as incandescent lights, will have a ballast-energy use factor of one. You will have to take into account the ballast factor for fluorescent lights and HID lamps. If you cannot obtain information that is more accurate, you can estimate the ballast-energy use factor to be 1.15 to 1.20, meaning that the ballast consumes 15% to 20% energy in addition to the rated power of the lamp. See the lighting section of **Figure 1: Energy Balance—Electrical Equipment.**

- Specific process equipment: Sometimes the facility process will have specialized equipment that should be examined carefully to make sure all energy data is gathered. For example, a plastic-products facility may have injection molding machines. These machines will have motors, which should be included in the motor section with appropriate load factors. They will generally have heaters that heat the plastic before it enters the injection process, and they may have some type of chilling (typically chilled water) to cool the final product. All these energy-using components of the injection molding process must be recorded in the data collection process. They can be entered in a separate injection molding process equipment section of the energy balance if desired.

- Gas and oil powered equipment: Nameplate ratings in Btu/hr, efficiencies, and load factors must be obtained. You should also verify the maintenance schedule for possible tuning opportunities.

- Miscellaneous equipment: You will not need to collect detailed data on small energy consumers such as office equipment or other plug loads at a manufacturing facility. We typically consider the miscellaneous uses to account for 10% of the actual kW and kWh use in a facility. That number goes into our energy balance as part

Figure 1. Electrical Equipment

(Sample Audit—Sawmill and Office Building)

Lighting

Location and Equipment name	W	Fixtures	Lamps per Fixture	Est. hours per year lights used	Est. hours per year area used
Lighting					
Office					
Lighting line item					
Conference room, 8' fluorescent	60	2	2	2,025	500
Lobby and hallway, 8' fluorescent	60	4	2	2,025	2,025
Office lighting sub-total:					
Saw Mill					
Saw mill, 8' fluorescent	95	7	2	2,025	2,025
Saw shack, incandescent	100	1	1	2,025	2,025
Head saw, halogen spotlight	95	1	2	2,025	2,025
Saw mill, HPS	150	8	1	2,025	2,025
Saw mill lighting sub-total:					
LIGHTING TOTALS:					

Motors

Location and Equipment Name	HP (rated)	units	hours per year	lf	uf
Saw Mill					
Motor line item					
Chipping edger	75	2	2,025	0.4	0.6
Head saw	100	1	2,025	0.4	0.6
Log trimmer	15	1	2,025	0.4	0.6
Conveyor	5	2	2,025	0.4	0.8
Saw mill motors sub-total:					

and Energy Balance

A/C (Y/N)	Estimated ballast factor		kW	kWh	Estimated Annual Cost ($/yr)
			=kW/lamp x Number of Fixtures x Number of Lamps per fixture x (Ballast factor + 1)	=total kW x Estimated hours per year	= kW x $/kW/month x 12 months/yr + kWh x $/kWh
Y	1.15		0.28	559	54
Y	1.15		0.55	1,118	108
			0.8	***1,677***	***162***
N	1.15		1.53	3,097	251
Y	1.00		0.10	203	16
N	1.00		0.19	385	31
N	1.15		1.38	2,795	226
			3.2	***6,479***	***524***
			4	**8,156**	**687**

df	Est. Efficiency	Number of Belts	kW	kWh	Estimated Annual Cost ($/yr)
			= (Hp/unit x number of units x lf x 0.746 x df)/ Efficiency	= kW x hours per year x uf / df	= kW x $/kW/month x 12 months/yr + kWh x $/kWh
0.9	0.94	8	42.81	57,793	5,701
0.9	0.95	4	28.42	38,366	3,785
0.9	0.91	-	4.43	5,976	590
1.0	0.88	-	3.41	5,525	496
			79	***107,660***	***10,571***

(*Continued*)

Figure 1. Continued—Electrical Equipment

Miscellaneous					
Drying room fans	2	8	8,760	0.9	0.6
Drying room fans	7.5	6	8,760	0.8	0.6
Miscellaneous motors sub-total:					
MOTORS TOTALS:					

Air-Conditioning

Location and Equipment name	Tons	units	SEER	df	hours per year
A/C line item					
Scragger booth, window unit	1	3	8	1.0	2,000
A/C sub-total:	**3.0**		**8.0**		
Average COP:			**2.3**		
A/C TOTALS:					

Air Compressors

Location and Equipment Name	HP (rated)	units	hours per year	lf	uf
Air Compressors line item					
Maintenance shop	15	1	2,025	0.4	0.8
Saw mill	20	2	2,025	0.4	0.8
AIR COMPRESSOR TOTALS					

The Energy

	CALCULATED FIGURES
	ESTIMATED MISCELLANEOUS
	TOTALS
	MIN ACTUAL kW
	MAX ACTUAL kW
	ACTUAL kWh | Cost
	ERROR IN kWh | Cost

and Energy Balance (Sawmill and Office)

1	0.84	1	12.79	67,217	4,465
1	0.90	1	30.01	157,715	10,478
			43	*224,932*	*14,943*
			122	**332,592**	**25,514**

			kW	kWh	Estimated Annual Cost ($/yr)
			= tons/unit x number of units x 12 x df / SEER	= kW x CDD / df	= kW x $/kW/month x 12 months/yr + kWh x $/kWh
			4.50	9,000	733
			4.5	**9000**	**9,005**

df	Estimated Efficiency	Number of Belts	kW	kWh	Estimated Annual Cost ($/yr)
			= (Hp x number of units x lf x 0.746 x df)/ Efficiency	= kW x hours per year x uf / df	= kW x $/kW/month x 12 months/yr + kWh x $/kWh
1.0	0.91		4.92	7,968	869
1.0	0.91	3	13.12	21,249	1,908
			18	**29,217**	**2,777**

Balance

			148	378,964	37,983
0.1			14.8	37,896	3,798
			163	**416,861**	**41,781**
			145		
			165		
				416,900	41,700
			-1.1%	-0.01%	0.19%

of the total facility energy use. However, in a commercial facility or office building, the computers, fax, and copy machines may account for a substantial energy use, and do need to be recorded.

Data Compilation

After collecting the data for the energy-using equipment, you need to record and organize the data and simulate the operations of this equipment to develop an estimated energy use to compare to the historical energy use. At the UF IAC, we used an Excel spreadsheet to organize the data in preparation for data analysis. We started with a spreadsheet template that already contained the basic layout and equations. To prevent inadvertent altering of the equations, we locked the fields containing equations.

We typically organized the data in one of four ways:

- By type of equipment;
- By building or location;
- By process;
- By utility meter or other energy use measuring device.

These different organizational methods are not mutually exclusive. Often, we used a combination of these methods to help us focus on the energy-using equipment. For example, if we organized by building, we would have a sub-organization by type of equipment. We might also organize by utility meters where the facility had more than one meter, then by equipment on that meter. No matter how you decide to organize your data, you should sub-total the energy use, demand, and cost of each area. You will find these sub-totals useful in latter analysis. **Figure 1: Energy Balance—Electrical Equipment** contains the formulas used in each section of the energy balance and shows a sample layout of the sections of an energy balance.

By Equipment

Our fundamental organization is always by type of equipment. For example, we typically start by listing lighting, process motors, heating ventilation and air-conditioning equipment, air compressors, and specialized process equipment. We list any non-electric power equipment, such as natural gas or oil-fired boilers, separately. (Natural gas-fired equipment will also be separated by meter.) Then, we assign the power ratings, hours of use, and initial load, utilization, and diversity factors to each piece or group of equipment. Figure 1 illustrates this basic layout for the electric portion of an energy balance.

By Building or Location

You may also find it useful to further separate the equipment by building or location. One obvious example would be to separate lighting by office, parking lot, and manufacturing area because the lighting is used differently in each area. The office may only be operated from eight to five, while the manufacturing area operates 24 hours a day. The parking lot lighting should only operate at night. We found that this type of separation can help identify energy-saving opportunities. For example, if the parking lot lights were operating more than the nighttime hours, then it might be profitable to install photo-sensors. The lighting section of figure 1 illustrates the office and a saw mill.

By Process

For a facility that has multiple processes or multiple lines performing similar processes, you may find it useful to further separate equipment by process. Different processes may have different operation schedules, and their separation makes it easier to understand how energy is used in each. For example, a lumberyard may cut lumber eight hours a day, but it may take 60 days to dry the lumber, and the drying processes may operate 24 hours a day. Once the data is organized in this manner, opportunities for improvement may become obvious. Does the lumberyard need a better method for drying wood to keep up with the cutting operations? In another example, we visited a plant that had multiple lines performing similar processes. After we had organized the equipment by lines and analyzed the diversity factor, we found that their peak load could be lowered by managing the maintenance and line changeover schedule.

It is very helpful to consider the whole process when you are checking to see if your equipment list is complete. For example, if the facility spray-painted items that went on a conveyor line and through a drying oven, you would check to see if you had recorded an air compressor (for spray painting), conveyor motors, and heating elements.

By Meter

The more meters a facility has, the more accurately you can simulate the energy use at that facility. If a facility has multiple meters, develop a separate energy balance for each meter. Then, at the end, aggregate the values to get the total facility usage. For example, the office areas may have a different electric meter from the manufacturing plant. You may find it useful to first separate by meter, since each meter will have a different bill. Of course, you must separate gas-metered equipment from electric-metered equipment in any case. In addition, you will find it necessary to separate equipment related to each different type of energy sources: oil, coal, wood, propane, etc. Figure 1 shows only the electric use section of the energy balance. We use the same energy balance template for other meters or energy types by using a similar section with the appropriate equations and units for that energy source and that equipment.

VALIDATING ENERGY BALANCE WITH HISTORICAL USAGE PATTERNS

Once you have collected and organized the data and entered it into the energy balance spreadsheet, you start by totaling the demand and energy use from each equipment sector to get a total for the facility. Then you must compare it to the historical totals. If you have separated the equipment by meters, you should perform this balance for each meter and then aggregate each part at the end.

If your data collection and utility measurements are accurate, you should have a reasonably good estimate of the energy use by equipment sector. If the energy balance values are fairly close to the historical usage, you can fine-tune the energy balance values using the steps described below (see Fine-tuning the Energy Balance). However, if the values are more than a few percentage points apart, you should check the following areas before you start trying to adjust the energy balance.

- Was equipment missed during the site visit?
- Did you fully understand how the equipment is used?
- Did you fully understand equipment diversity?

- Did you fully understand the motor load factors?
- Did you fully understand the utility bills? Did you record them correctly?
- Was the energy demand and use metered correctly by the utility?

Comparing Energy Balance to Historical Energy Bills

The past use of energy and power is a good indicator of how a plant may be currently using their energy-consuming equipment. However, you must be aware of any changes in operation between the past and present. For example, you must consider if the plant has added any equipment or changed production schedules when you use the historical energy bills. Again, the goal is to specifically account for 90 percent of the historical energy use, and a demand between the actual minimum and maximum demand values achieved during the last business cycle. If a large piece of equipment has been added or removed during the period for which you are analyzing the bills, you must adjust the hours of use for that equipment for the appropriate period.

Sources of Problems with Reconciling the Energy Balance to Historical Energy Bills

You will find that at times you have trouble reconciling your predicted use with the historical use. In these cases, we have found a number of reasons for this inability to satisfactorily complete the energy balance. An advantage of performing the energy balance in the manner we describe is that this process may uncover a problem either of your understanding how a plant uses energy or a problem that must be addressed by the plant or the utility company.

Missing Equipment from the Plant Audit

Perhaps during the plant visit, you missed collecting data on some large energy-consuming equipment. The best way to approach this issue is to verify with plant personnel that you covered all primary and secondary processes at the plant. Sometimes it is easy to miss some of the less significant processes at a plant. The plant may produce a by-product from its processes that are almost an afterthought for plant personnel. For example, they may not have realized that processing scrap requires energy use at the plant. Equipment required for processing scrap may include shredders, compactors, cyclone separators, etc. Maybe you made the plant visit in the winter and the company uses portable coolers or a large number of personal fans in the summer for employee comfort.

Faulty Understanding of Equipment Usage

Possibly, during the plant visit, you did not properly find out how or when equipment is used because plant personnel may not understand its use. Equipment run primarily during off peak business hours may be a prime suspect. For example, plant personnel may give you faulty information about how personnel on shifts, other than his shift, actually use the energy-consuming equipment. Maybe, plant personnel who are on site during the day do not know when outdoor lights are used. To approach this issue, you could interview plant personnel or make follow-up visits during various times to get a better understanding how the equipment operates. For example, we came across one plant that we estimated a higher energy use than the historical numbers showed was possible. We over-estimated the energy use because initially the auditor misunderstood use of the plant-electric heaters. All the heaters combined to account for a large power use. Initially, the auditor assumed a use factor that was too high. Actually, the heaters were only used on the coldest nights of winter and then they would cycle with only a portion being energized at any given time. The exercise of creating the energy balance helped the auditor understand how the plant used their heaters.

Faulty Understanding of Equipment Diversity

A one-day visit to a plant is a small sample. The day of the visit may not have been a typical day. Observing that two identical pieces of equipment do not operate at the same time may be an aberration. Unless there is control equipment that prevents the operation at the same time, you cannot be sure. To approach this issue, you should interview plant personnel about the interactions between the equipment, so you can estimate the diversity of equipment operations. Again, you could also make periodic visits to observe how the equipment actually operates even if these visits are on the same day during your audit visit.

Faulty Understanding of Load Factors

You need a good understanding of the basic ideas of typical equipment design (or over-design). To approach this issue, you could take some sample measurements of equipment for large energy-consuming equipment to get an idea of the load factors.

Faulty Understanding of Utility Bills

Sometimes, some of the equipment will be separately metered, and you did not receive the bills for these meters. If you check the bills with the utility representative, you may understand the utility billing structures better than the plant personnel may. An alternative would be to interview the plant employee who pays the bills to make sure you have them all.

Faulty Measurement of Energy Use by the Utility Meter

Sometimes with the merger and divestiture of companies, a plant may be sold to two different parties. We found one such case where the plant meters were not properly divided. Therefore, one plant was unknowingly giving electricity away to another plant with a different owner. Sometimes meters are not working properly or meter readers have read them wrong. These problems need to be brought to the attention of company management and the utility company, so the problem can be solved.

FINE-TUNING THE ENERGY BALANCE

If the estimated demand and energy use do not match the historical demand and energy use within two percent, including miscellaneous, you must begin revising your assumptions to reconcile the collected data on energy-using equipment with the historical data. Often we were able to match historical energy use to within fractions of a percent. Once you have complete confidence in the data you have collected, then the only parameters that you can adjust or "tweak" are the load, utilization, and diversity factors. Again, the goal is to account for 90 percent of the historical demand and energy consumption for every type of energy. The other 10 percent you can consider caused by miscellaneous loads. By adjusting these three factors, you can develop a fairly accurate balance of the energy and demand use at a manufacturing plant.

How to Adjust the Energy Balance

There are eight possible mismatches between the total calculated facility demand (kWc) and energy use (kWhC) and the historical demand (kWh) and energy use (kWhH). You must adjust the load, utilization or diversity factors depending on which situation you have. As you adjust one of the parameters, you may find that you then have to adjust another to fine-tune your results. Table 1 shows the adjustment to make for each the situation.

Adjusting the Load Factor

As previously mentioned, we have found that most process motors have a load factor between 0.35 and 0.6. We generally start at 0.4. Some motors such as the air compressors and fans will have higher load factors typically from 0.8 to 0.9. If your total kW and kWh are a little too low (or too high), then increase (or decrease) the motor load factor slightly for the lightly loaded motors. However, if the total kW is significantly higher or lower than the historical demand, then you will have to look for some other reason (see **Validating Energy Balance with Historical Use** above). To change the energy and power use for a motor on the energy balance, you can change the load factor.

Adjusting the Utilization Factor

As discussed previously, we chose the annual hours of use for a piece of equipment as the operating hours for the plant or department. Then, we used the utilization factor to account for cycling of equipment, maintenance downtime etc. If your kWh is too low or too high, you can adjust the utilization factor to help reconcile the difference. You might want to adjust it for specific pieces of equipment rather than an across-the-board adjustment on all equipment. Changing the utilization factor changes only the estimated annual energy use for a piece of equipment.

Adjusting the Diversity Factor

We used the diversity factor to calculate the average demand when two (or more) similar pieces of equipment are highly unlikely to run at the same time. For example, if a plant had two pumps, but when one was running, the other was in standby mode, then the diversity factor for each pump would be 0.5. Another example would be a plant that has a large number of fans, but the probability of a fan running at the time of the peak was 75%. Thus, the diversity factor of each of the fans would

Table 1. Adjusting the Load, Utilization, and Diversity Factors

Situation	*Demand*	*Energy*	*Adjustments*
1	$kW_c < kW_H$	$kWh_c < kWh_H$	Increase the load factor on some of the motors.
2	$kW_c > kW_H$	$kWh_c > kWh_H$	Decrease the load factor on some of the motors.
3	$kW_c = kW_H$	$kWh_c < kWh_H$	Increase the utilization factor on some of the equipment.
4	$kW_c = kW_H$	$kWh_c > kWh_H$	Decrease the utilization factor on some of the equipment.
5	$kW_c < kW_H$	$kWh_c = kWh_H$	Increase the diversity factor on some of the equipment.
6	$kW_c > kW_H$	$kWh_c = kWh_H$	Decrease the diversity factor on some of the equipment.
7	$kW_c > kW_H$	$kWh_c<kWh_H$	Decrease the diversity factor and increase the utilization factor on some of the equipment.
8	$kW_c < kW_H$	$kWh_c > kWh_H$	Increase the diversity factor and decrease the utilization factor on some of the equipment.

be 0.75. Changing the diversity factor changes only the estimated annual demand for a line item on the energy balance for a piece of equipment.

Data Analysis

Once you are comfortable that your data represents the actual energy use (i.e., your calculated demand and energy use accounts for 90 percent, excluding miscellaneous, of the historical use), you can use the energy balance spreadsheet to produce several useful graphs that show the relative energy use of each set of equipment (lighting, motors, etc.), the relative energy use of groups of equipment by each separately metered area, and so forth. We used a pie chart to show the relative usage and cost of each type of electrical equipment. This pie chart gave us a good indication of the areas with the greatest opportunity for energy savings. It also allowed us to show the plant personnel where their energy was being used. In addition, viewing the pie charts helped UF IAC auditors with less experience gain a better feel for the areas to concentrate upon during subsequent audits for similar plants. See Figure 2 for a sample pie chart based on our sample energy balance.

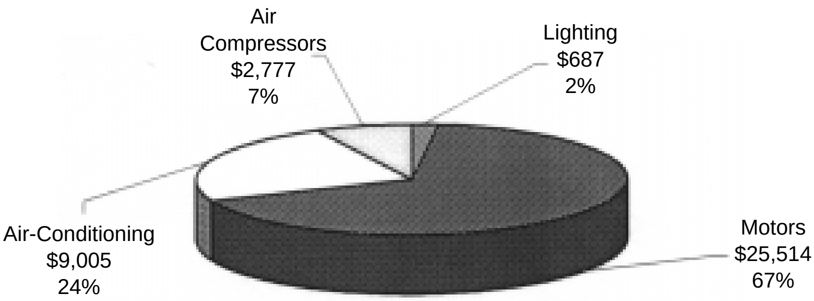

Figure 2. Estimated cost of operation by type of electric device.

EXAMPLES OF BENEFITS RECEIVED USING AN ENERGY BALANCE

At the UF IAC, we have had many instances when the energy balance method described here in Part I has aided us with understanding the energy use of a facility and with recommendation ideas. Here are three examples of these instances.

Interactions between Recommendations

During the analysis of recommendations for a client, we made a series of interrelated recommendations including high-efficiency motors, demand shifting, and synchronous v-belts. Separately, these recommendations showed a total energy savings of about 50%, which seemed highly unlikely. After reviewing our energy balance, we realized that these recommendations were not mutually exclusive. A before-and-after

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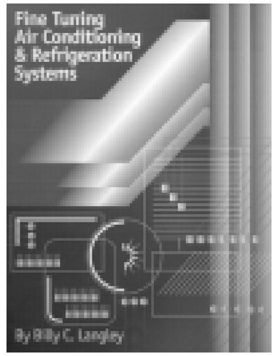

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energy balance showed that the actual savings from the combined measures was much less than 50%.

In another case, we prepared a series of lighting recommendations: T-8 lighting, occupancy sensors, photo-sensors, compact fluorescent lighting, and lower wattage halogen lamps. However, the combined savings would have saved more than the energy balance predicted that the lighting system used in total. Again, using the before-and-after energy balance pointed out the result of double-counting the savings.

Our most memorable example of the need for an energy balance was in our early audits when we used an initial motor load factor of 80% for a facility and calculated a savings in demand and energy that was higher than the total historical demand and energy use for the facility. At this point, we realized that we needed a tool for better analysis, and this gave rise to the development of our energy balance method of energy and demand analysis.

CONCLUSION

Before you can save money through the efficient use of energy, you must understand how that energy is used. One strategy would be to monitor equipment with an energy management system or some other monitoring method. Monitoring takes a period of observation and is costly. Even if the expense of this costly monitoring is undertaken, it is unclear if you will benefit from it without significant additional analysis. With the method we describe in this article, you can gain many of the benefits of the more costly methods with less cost. Maybe, after performing this method, you will find that installing an energy management system will yield appropriate benefits, or maybe you will find that the more costly methods will not yield an acceptable return on investment. Therefore, depending on the situation, the energy balance method may provide a relatively low-cost and reasonably accurate alternative to understanding the energy use at a facility.

NEXT STEP: MAKING FINANCIAL DECISIONS

An energy product salesperson tries to sell you their services to install some high efficient equipment. This salesperson tells that this equipment will save your facility lots of money. You have your most recently updated energy balance available. How can you use this energy balance to confirm or refute the claims of the salesperson? Upon a short analysis you find that the project will reduce the facility energy use; however, how do you know if this energy saving project is the best investment available to you? How does this project compare to other projects that compete for the scarce resource of capital? How long will it take to recover the money spent on this project? Will this project increase the bottom line?

In our next article, "Using Energy Balance Data to Make Financial and Capital Investment Decisions," we will explore the proper engineering analysis to apply, so you may answer such questions with some degree of confidence. Watch for "Using Energy Balance Data to Make Financial and Capital Investment Decisions" in the next issue.

References

1. Capehart, Barney L. and Capehart, Lynne C. "Improving Industrial Energy Audit Analyses," Proceedings of the ACEEE Energy Efficiency in Industry Conference, Grand Island NY, Summer 1995.
2. MotorMaster and the Motor Challenge, http://mm3.energy.wsu.edu/mmplus
3. Capehart, Barney, "Equipment Load Factors, Use Factors and Diversity Factors as well as a General Discussion of Energy Audit Procedures," http://www.ise.ufl.edu/capehart/papers/diversity.doc, 2000.

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