Part Three of a Series

A Case Study for Energy Auditing Using an Interactive Energy Balance

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ABSTRACT

The two previous articles in this series have described how to create an energy balance (*Analyzing Facility Energy Use: A Balancing Act*) [1], and how to expand the basic energy balance spreadsheet to include a number of economic analysis measures (*Energy Balancing—How to Use the Energy Balance Data You Have Collected to Make Financial Decisions*) [2]. Simultaneously, another article (*An Interactive Energy Balance: A Case Study*) [3] was published which emphasized concepts and improved the ideas of the previous ones through an interactive, user-friendly software.

In this article—the third in the series—we describe this new interactive software that allows the user to perform an energy balance for a facility more easily and efficiently. This new, interactive software provides a graphical user interface, or GUI, to expedite the entry of data, using menus whenever possible. Large amounts of data on facility energy bills, facility equipment, and operating characteristics are still required, but the new interactive software greatly speeds up this data entry process and reduces the chances for data entry errors. In addition, the process of adjusting facility equipment and operating characteristics to match the actual energy consumption is improved and compressed so that this critical task is also performed with less manual effort. All the energy consumption data are displayed in graphs and pie charts. Moreover, calculations of potential energy savings recommendations are performed for each type of equipment considered. The end result is an

energy balance software tool that is much easier to use than any of our previous Excel spreadsheets. This increased ease of use makes it much more likely that other people will use this tool to assist them in their energy auditing studies, making decisions to purchase new equipment, or upgrading less efficient equipment. The article concludes with a case study that provides insight on the faster data entry and balancing process, graphical display, and recommendations, as well as further demonstrating the value of the energy balance approach.

INTRODUCTION

The first article in our series, *Analyzing Facility Energy Use: A Balancing Act*, described the process of developing an energy balance for a facility and showed the use of an Excel spreadsheet [1]. Preparing reliable equipment lists and associated operating characteristics with just a spreadsheet can be a tedious and time-consuming process, and there is a high probability of human error. Furthermore, changes made to the spreadsheet data in one place may require multiple corrections in other spreadsheet locations. This can cause lengthy re-entry of data with many redundancies, and requires a significant amount of unnecessary work. The second article in our series, *Energy Balancing—How to Use the Energy Balance Data You Have Collected to Make Financial Decisions* [2], extended the basic energy balance spreadsheet to compute common economic evaluation measures to assist in energy retrofit project analysis and selection. However, this extended energy balance still required lengthy data entry and tedious manual processes to complete the task. For graphics, additional work needed to be done as for any other data set.

To simplify and speed up this data entry process while providing graphical display of data and making energy conservation recommendations (beyond back-of-the-envelope calculations), we have developed a GUI (graphical user interface)-based energy balance program called the interactive energy balance program (IEB), using Microsoft Access and Visual Basic. Microsoft Access has only limited abilities for designing front-end menus, and because of these limitations of working with the available macros and the restricted structures of Access, we used Visual Basic for a much more flexible and useful approach. With Visual Basic, we created a user front end which shows only the data entry menus, rather than showing any pieces of the actual database. This makes the application more user-friendly and less intimidating to use. Visual Basic also has features that allow for checking the format and range of data entry, and correcting data errors.

The software presented in this article is the result of our experience at the University of Florida Industrial Assessment Center (UF-IAC) in performing audits for more than 340 manufacturing facilities in Florida. The UF-IAC currently provides an energy balance to our clients using a series of Microsoft Excel spreadsheets. We have improved our own productivity by incorporating the Excel spreadsheets into the Access database format. This new software tool, the IEB, integrates all energy bill and energy use data into a single application database and then calculates cost savings for various energy efficiency projects. With the new IEB energy software, the process of entering data and developing recommendations for improving efficiency in operations, production, and equipment has been greatly expedited; typically in a third of the time used for the original spreadsheet approach. Historically, the recommendations made by the IAC have provided potential savings of about 20 to 40 percent of the clients' electric energy consumption. In this article, we will discuss the energy balance for electrical equipment only, although the IEB software can be easily extended to other energy sources (i.e., natural gas, propane, fuel oils, etc.). This extension will be provided in the future.

In the following section, we summarize our energy balance methodology, including definitions and data entry procedures, which start with data entry of the facility energy bills, usually for a twelve-month period. Then equipment data are entered, listing each major piece of equipment in the categories of air conditioning, lighting, refrigeration compressors, air compressors, motors, and others. In the third section, we discuss the importance of determining energy use by equipment sector through an energy balance, and show how this is done using the IEB software. A case study is presented in section four, which includes a demonstration of IEB graphic and predictive capabilities. Finally, we present our conclusions in section five.

METHODOLOGY

As discussed in detail in our previous articles, we collect and record energy use data on all major energy-consuming equipment in the facilities that we audit. One convenient way to organize the inventory data is by general equipment groups such as lighting, motors, heating, ventilating and air conditioning (HVAC), air compressors, and any other specific piece of equipment that consumes electrical energy (chillers, welders, or specific production line equipment). Another way to inventory the equipment is by its plant location, and a plant layout diagram is useful for this type of inventory.

To explain why we gather certain information on the equipment related to its energy consumption, we will define three important parameters: the load factor, the use factor, and the diversity factor. The load factor (LF) for a given piece of equipment is the ratio of the actual electrical power drawn by the equipment to its full load power. The load factor for many motors can be estimated by measuring the actual current being drawn by the motor and comparing that to the motor's rated full load current. (We have found average motor load factors for most facilities range between 0.4 and 0.5 on an annual basis, although higher loads are not uncommon and LFs for specific pieces of equipment can be much higher). The *use factor* (UF) for a piece of equipment is the ratio between the time that a particular piece of equipment is operating and the total time that it is available for use. The *diversity factor* (DF) is defined as the probability that a particular piece of equipment will come online at the time of the facility's peak load. (This factor does not relate to equipment that is kept as a backup for actual running systems. However, two identical pieces of equipment that are interlocked so that they do not come on at the same time would have a diversity factor of 0.5.) These three parameters must be estimated for each piece of equipment in the facility.

Our data collection for individual pieces of equipment is generally limited to the largest energy users or energy use categories. We account for the energy use of small pieces of equipment, such as very small motors, desk lamps, and small numbers of office equipment (e.g., computers and peripherals) with a category we call miscellaneous equipment use. We allocate 10 percent of the total historical energy use to this category of equipment that does not have a major role in the facility energy usage. Using this miscellaneous category greatly reduces the job of collecting data at a typical facility.

The IEB Interactive Database Application

The IEB database uses Microsoft Access. Figure 1 shows the start-up screen. First, the "Run IEB" button is selected, and the main menu window appears as shown in Figure 2. This shows IEB's present capabilities. A simplified data entry flow diagram for the energy database is illustrated in Figure 3. Presently there are six categories of equipment that are most likely to be found in any building, manufacturing, or commercial facility included (more will be included in the future). These six categories are: lighting, air conditioning, motors, air compressors, chillers, and a miscellaneous category called other. A help button for each of

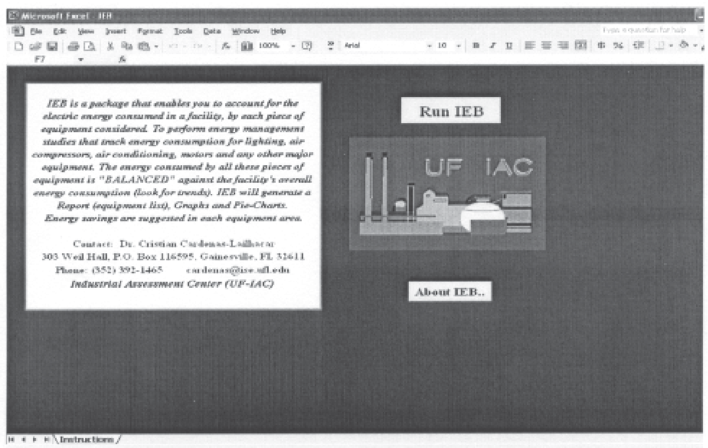

Figure 1. The Interactive Energy Balance (IEB) Starting Screen

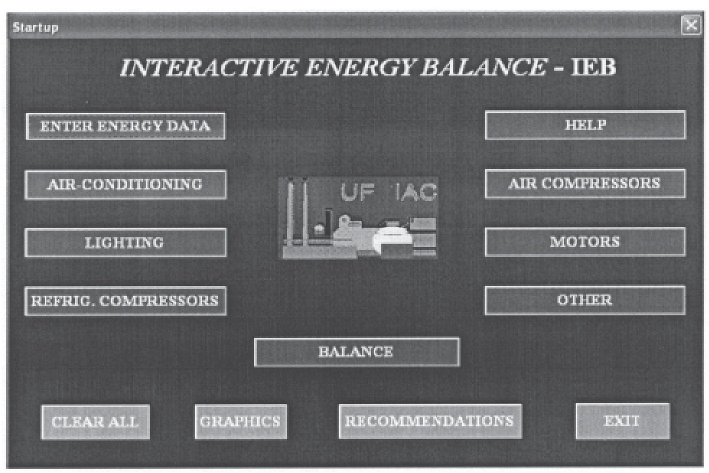

Figure 2. The Interactive Energy Balance (IEB) Main Menu Window.

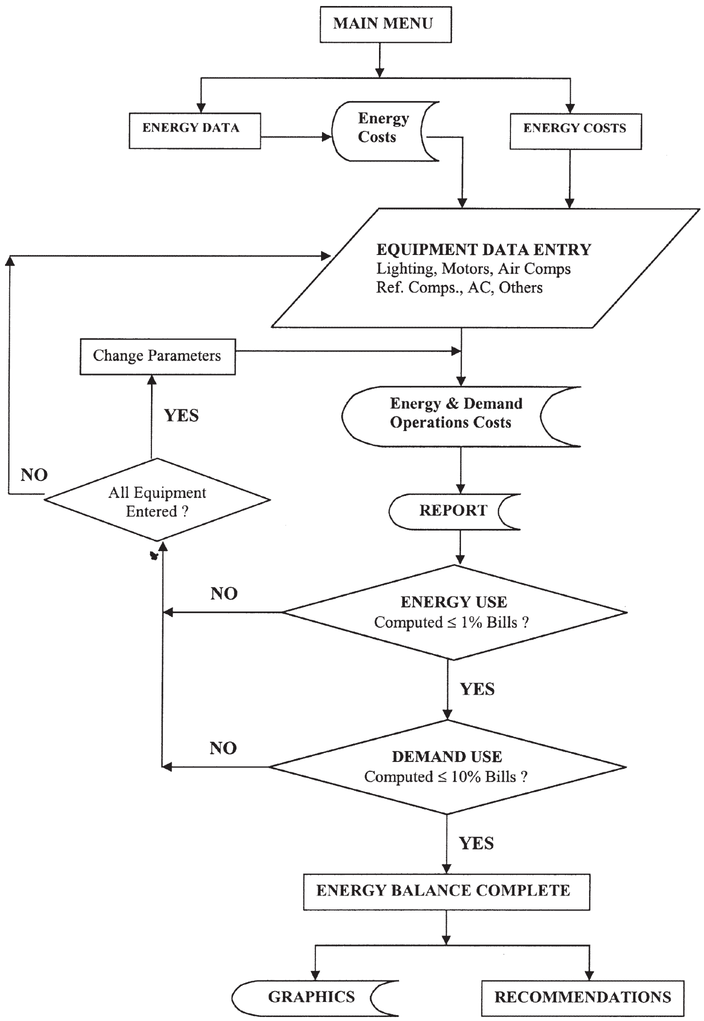

Figure 3. The Interactive Energy Balance (IEB) Simplified Data Flow Diagram.

these six data entry screens is provided, and it displays information about the kind of data that must be entered. Finally, the energy balance decision is shown, after which a spreadsheet is generated from which graphics can be displayed and recommendations for energy savings can be explored.

We start by entering monthly energy bill data by clicking on the

"Enter Energy Data" button. Based on this data, IEB calculates and displays, among other results, the average demand cost, average energy cost with demand, and average energy cost without demand, shown in Figures 4a and 4b. Next, information on the particular pieces of equipment and their operating characteristics are entered. Finally, total energy consumption and average monthly demand of the equipment listed are calculated and compared to the last twelve months' energy bills.

Ten percent of the total energy consumption coming from the energy bills is included as a miscellaneous energy use category. The calculated annual energy use should match the annual energy use from the facility bills within 1-2 percent. Similarly, using a 10 percent miscellaneous demand category, the calculated average demand should be within the minimum and maximum ranges, or match the annual average demand from the facility bills. We also consider as acceptable a demand value that falls in the range between the maximum and minimum monthly demand shown in Figure 4b. If either the calculated energy use or demand are out of range, we examine the data manually to determine the likely source of error and then use the IEB to help us systematically adjust the appropriate parameters and repeat the energy use and demand balance calculation until we are in the correct range.

The interactive energy balance software allows the user to track the energy consumption and peak demand for a facility for a period of twelve months. An interface menu is provided for the entry of monthly energy consumption, monthly peak demand, and costs, as shown in Figure 4a. Once the user clicks on the accept button, a window pops up displaying, among other demand and energy costs, maximum and minimum demand for the period considered, as shown in Figure 4b. In addition, and in parallel, a table is created in Excel format with the same information for the billing period, so the user can manipulate it and post it in his/her report (see Appendix A-1). At this point, the IEB stores the average electrical energy cost without demand, the average demand cost, and the average electrical energy cost with demand, and uses them in all other required parts of the software. For example, the energy costs associated with operating lights, motors, etc. are calculated later by the IEB and automatically recalculated whenever the monthly utility bill data are modified. We consider these data very valuable, as they allow reconciliation between energy bills sent by the utility company with the estimated en-

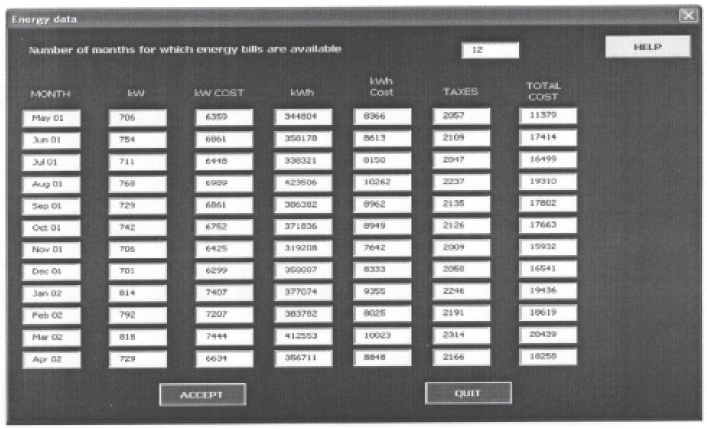

Figure 4a. Energy data screen where historical electrical data are entered.

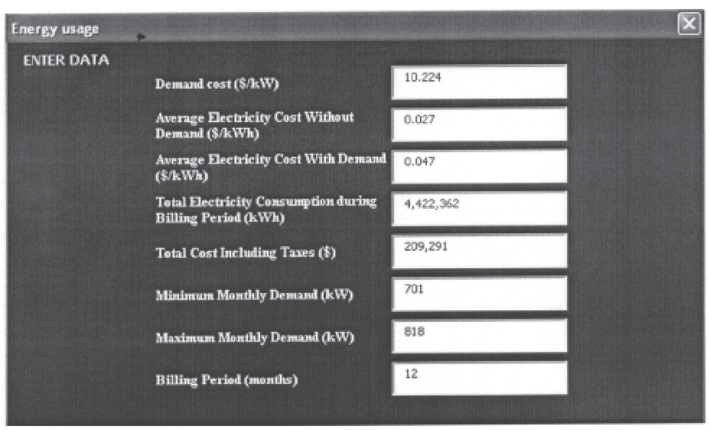

Figure 4b. Energy data window showing energy and demand costs, minimum and maximum demand, and billing period.

ergy being used by the individual pieces of equipment in the facility, along with their operating costs determined in the energy balance section. Additional periods of billing data beyond twelve months will be included in the future (e.g. two to five years of energy bill history), together with other sources of energy commonly used, such as natural gas, propane, fuel oils, diesel, etc.

The operating equipment data entry interface menus (Figures 5, 6, 7, 8, and 9) provide the user with easy-to-use drop-down boxes with pre-programmed, commonly occurring values. For example, the various possible locations, and the types and ratings of standard equipment commonly found in facilities, are available for the user in drop-down boxes and need not be entered manually into the spreadsheet. This menu-based approach is much quicker and less error prone than individual data entry into a spreadsheet. The user completes the entry of all data for a particular type of equipment (lights, motors, etc.) and then adds them to the equipment list by clicking the ADD button.

After all the equipment data are entered, this information is automatically stored in an MS Access database. This relational database identifies each piece of equipment by a unique equipment ID. Various lookups such as operating hours, efficiencies, and load factors are possible. This database is connected to all the interfaces and can be modified by any of them.

Energy Bill Analysis

The opening window of the IEB environment, shown in Figure 1, allows the user to enter data for energy costs, energy use, and equipment found in the facility. Typically, a user will click the "Electric Data" button and enter energy bill data for the last twelve months, as shown in Figure 4a, to determine energy costs. By clicking the "Accept" button, IEB will calculate the demand cost, energy cost without demand, and the energy cost including demand. These energy parameters are of primary importance, as they will be used mainly to compute energy and demand costs of operating each piece of equipment used in the facility. If the user already knows the energy costs, this cost information can be directly entered via the *energy costs* option (see Figure 1). Once the energy use data or energy cost data are entered, the user must enter data for each piece of equipment that is a significant energy consumer. In Figure 2, buttons for *lighting*, *motors*, *air compressors*, *air conditioning*, *chillers*, and *others* are displayed. Use of these buttons is discussed in the following sections.

Lighting

The lighting data entry window is shown in Figure 5. Here is where the user starts entering data for the facility lighting systems. For this purpose, the IEB contains fields that are appropriate for listing the equipment and computing the energy usage and costs associated with that equipment. The pull-down menus for room location and type of light contain typical sites and types of lamps. The number of fixtures, lamps per fixture, hours of usage, and wattage must be entered manually.

After all the information has been entered, the user clicks on the "Add" button and the data are automatically displayed in the table at the bottom of the lighting window, as shown in Figure 5.

As we improve our IEB, we will add data entry points for lighting levels in a specific location. Data on lighting intensity levels provide information about under- and over-illuminated areas of the facility. The IEB will contain IES-recommended lighting levels to allow immediate determination of potential savings. These data will help us decide whether to recommend a complete or partial re-lamping, as well as whether any other suggestions—like installing skylights or physically lowering some fixtures—are appropriate. We also plan to input occupancy rates for specific locations. This will help us determine the feasibility of using occupancy sensors. A good source of information in lighting is suggested in reference [4].

Motors

The United States Department of Energy (DOE) [5] has determined that motors are the highest energy consumers in manufacturing facilities in the U.S.A. To properly account for motor energy use, information on

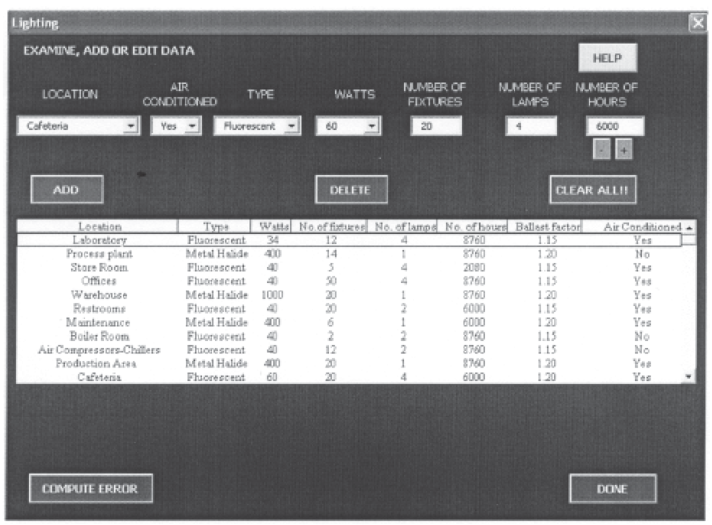

Figure 5. The Lighting Interface Screen.

their use factor (or hours of use) and load factor is required. The same information is needed for machines, production lines, processes and/or operations. Our experience tells us that a typical average motor load factor is in the range of 40-50 percent, although higher load factors can occur. It is also important to note that not all motors run at the same time with the same load factor in a given facility.

The diversity factor is a variable that is appropriate to use when a group of motors is not running at the same time. Data on motor size and efficiency can usually be found on the nameplate. In Figure 6 we show the motor's data entry window from the IEB main screen (Figure 2). The room (location) of the motor, motor efficiency, number of units, rating, hours of usage (annual), and the load factor are all the motor information used by the IEB.

Air Compressors

Part of the information necessary for air compressor data entry can be found in the nameplate. This is horsepower or kW, full load amps, and efficiency. In addition, the load factor, diversity factor, and hours of operation are needed. Figure 7 shows the screen with the required information for air compressors, also obtained from the IEB main screen (Figure 2).

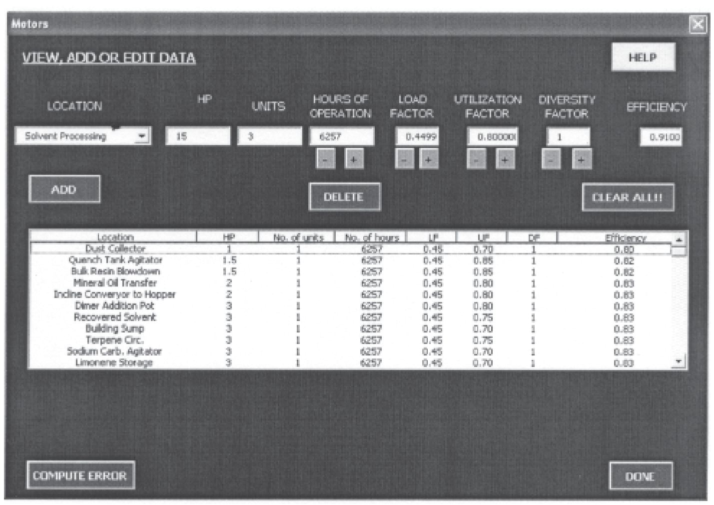

Figure 6. The Motors Interface Screen

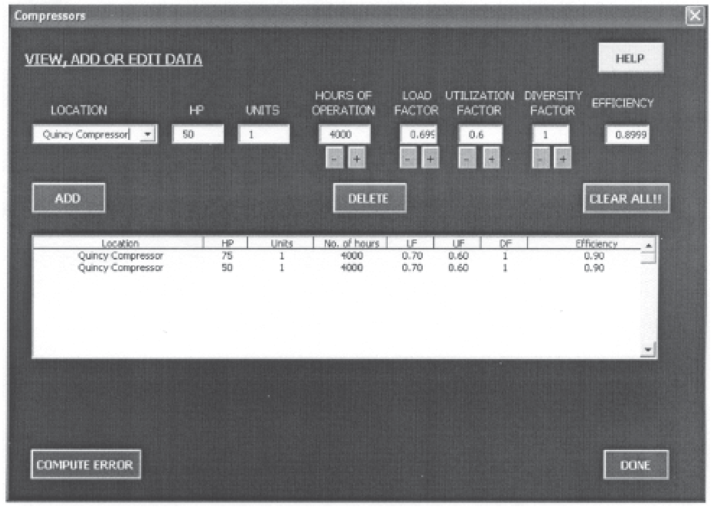

Figure 7. The Air Compressors Interface Screen.

Air Conditioning

The HVAC information required by the IEB is shown in Figure 8. This is tons, full load equivalent operating hours (see Table 1a), diversity factor, and EER (energy efficiency ratio) or SEER (seasonal energy efficiency ratio; Table 1b), or COP (coefficient of performance).

On some units, information on tons of capacity is given in the model number. For example: BTC036C100A2. The 36 correspond to 36,000 Btu/hr. There are 12,000 Btu/hr per ton, thus the AC unit is 3 tons. Other models do not list it this way, and you will need to ask a maintenance person, or get it from the ARI website [7].

Chillers

The refrigeration compressors and chillers information window for the IEB is shown in Figure 9. Compressors are often rated in HP, while most chillers are rated in tons. For compressors, the size in HP, the motor efficiency, and the full load amps are needed for data input. For chillers, the size (in tons) and the EER or COP, are needed for data input. Chillers under 100 tons of capacity are often rated in terms of their EERs, and larger chillers are almost always rated with a COP. The EER, COP, HP and efficiency are used to calculate the electric power load in kW. The type of compressor or chiller is also of interest—reciprocating,

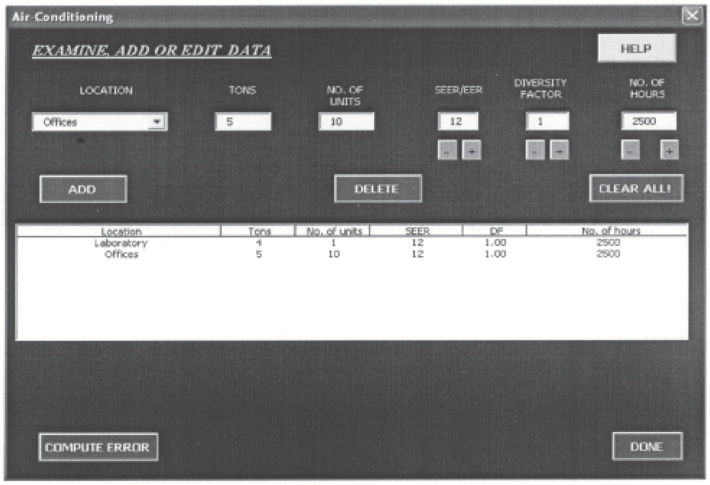

Figure 8. The Air Conditioners Interface Screen.

Tables 1a and 1b: Full Load Equivalent Operating Hours of Cooling Season (FLEOH, in hrs/yr) for Florida (1a), and SEER Values For AC Units According to Its Tonnage and Equipment Age (1b) (Note that: *SEER* or *EER* = Total Seasonal Cooling Output/Total Electrical Input).

Location	Cooling Season (Hr/yr) FLEOH	Tons	Age	SEER/EER
Pensacola	1,997	< 5	New	12
Jacksonville	2,163	> 5	New	10—11
Tampa	2,392	> 5	Old	7—9
Orlando	2,402	< 5	Old	8—10
Miami	2,605	> 10	Old	6—8

(1a) ***(1b)***

screw, or centrifugal. Also, the number of full load equivalent operating hours (FLEOH) must be provided. This is often a fairly difficult number to get and must be estimated from detailed knowledge of the cooling load provided by the compressor or chiller. The FLEOH is used directly for the chiller; for the compressor, it is used to estimate the load factor and use factor. This information is needed to calculate the annual kWh used by the chiller or compressor. Finally, if there are multiple compres-

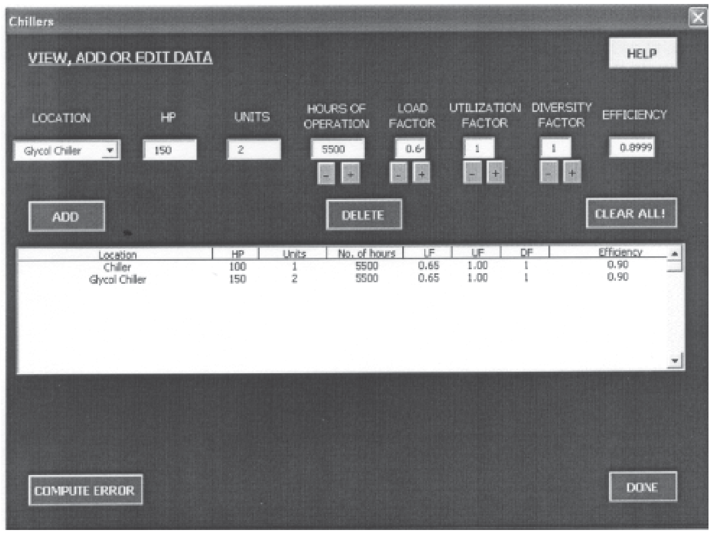

Figure 9. The Refrigeration Compressors Interface Screen: Chillers.

sors or chillers, there may be a diversity factor of less than one if all the units are not in use at the time of the facility's electric peak demand.

Others

There may also be other pieces of electrically powered equipment which must be included in the overall facility energy balance. Common examples of such equipment might be electric drying, curing, or baking ovens; electric hot water heaters or boilers; electric resistance heaters for plastic injection or extrusion machines; electric welders; and battery chargers for small vehicles and fork lift trucks. For each piece of equipment, the maximum load in kW, the average load (LF), and the hours of use (UF) must be supplied. If there are multiple pieces of equipment in one category, a diversity factor less than one might be needed. The data input screen for this category of other equipment is not shown here.

THE ENERGY BALANCE

Purpose

Balancing energy consumption is the heart and main purpose of all the data entry (and the most complex section of the software). Here the energy usage calculated from the equipment list is compared with the actual energy usage as shown by the energy bills (entered in the energy interface described above and shown in Figure 4). Upon completion of all the equipment and energy data entry, the balancing interface shown in Figure 2 and Appendix A-2 provides a relatively easy solution for this problem. The relations governing the electrical loads and consumption of the facility equipment calculated in the energy balance can be found in any energy management book (see for example reference [1]).

Using historical data from the UF-IAC energy audit database, typical load factors, usage factors, and diversity factors are used as parameters to control energy usage (for example, the load factors in the mobile home industry—0.4) [3]. The interface tries to match the energy usage by using default values according to the manufacturing sector the facility belongs to. If the error (deviation) is not acceptable (default is the maximum: 1 percent), the user is presented with several choices to modify the parameters. The software permits the user to change these factors manually and see the resulting changes. By increasing or decreasing the energy usage, iterations are made by the software to balance energy use. This relatively simple way to calculate the energy usage of equipment is faster, more efficient, and provides a non-redundant way to balance energy usage in a facility.

Reconciliation and Verification of Data

Reconciliation between the estimated energy used in the facility and its energy bills is the last step of the energy balance. When a first energy balance attempt fails, it is very tempting to immediately try to adjust the load factor of the equipment. However, chances are that important equipment loads have been overlooked. Consequently, we believe that a few additional steps need to be taken before the load, usage, and diversity factors are adjusted:

- Check that all equipment and processes in existence in the facility have been listed in the energy balance, especially large pieces of equipment.
- A second look at the energy bills is also a good strategy. Check that the total energy usage and the peak kW are correct.
- A common source of error is the number of operating hours assigned to the equipment. This is an important step in the analysis,

because not all of the equipment works the same number of hours each year.

- The diversity factor should be used in the adjustment if there is equipment that does not operate at the same time as the facility peaks in kW use.

The purpose of an equipment list and an energy balance is two-fold. First, the energy balance allows the facility production managers and engineers to have a better feeling on how much energy a piece of equipment is consuming, and how much it costs to run it. Second, the equipment list is very useful for knowing the equipment in existence, as well as the possible replacements in emergency cases.

The IEB software interfaces well with the U.S. Department of Energy's Motor Master software [6]. With the Industrial Assessment Center's shift to an Industries of the Future (IOFs) focus, less time will be spent on generating standard equipment replacement recommendations, so the team can concentrate on larger process recommendations.

Case Study

We now consider an example facility based on an actual assessment performed by the University of Florida Industrial Assessment Center. Data shown in Figures 4—11 correspond to this case study. Widget Manufacturers Inc. (WMI) has an annual production of a hundred thousand widgets. In order for the plant's energy managers to determine the energy usage as consumed by individual equipment, a number of steps are performed sequentially.

Step 1

The actual energy costs of the company, taken from the last twelve months energy bills are listed, and monthly demand and monthly energy usage are calculated as shown in Figures 4a and 4b. This task is simplified by the IEB, as the energy auditors at WMI simply enter the values from the electricity bills into IEB's user friendly interface. The IEB calculates all costs and presents a summary to the user. These figures will be used to compute the individual equipment energy usage and costs, as described in the next step.

Step 2

The next step is to determine the energy used by each piece of equipment, which would allow WMI to calculate energy cost, associated with individual equipment. The IEB software classifies equipment into predetermined categories such as lighting, motors, compressors, etc., and presents the energy manager with interfaces specific to the type of equipment. These data are automatically entered into a centralized database, which serves as an equipment list. The base energy costs are derived by IEB from the previous step, and need not be entered again (see Figures 5—12).

Step 3

The final step involves balancing the energy use calculated in step two with the total energy use found by step one. The IEB provides an interface to perform this task. The user can iteratively test the hours of operation, load factor, diversity factor, use factor values, and SEER on the balance options (+ and -) using the buttons provided in the corresponding windows (see Figures 5—9). This is accomplished by highlighting the equipment whose parameters will be adjusted. Finally, and to check the influence of the corrections on the final energy balance, the user can click on the "computer error" button provided at the bottom left of each of the windows. The process should be repeated until a balance within an acceptable error is achieved.

The final equipment list serves as a useful tool for WMI in determining realistic energy usage and therefore optimum times for equipment running, replacement, maintenance, etc. With this information, we were able to recommend energy savings in lighting, air conditioning, compressed air, and motors. The cost savings, simple payback, energy, and demand savings in these areas are summarized in Table 2. Notice that the savings are approximately 11 percent of the WMI electric energy expense of $209,291/yr.

GRAPHICS

One of the more advantageous features of the IEB is its graphics capabilities. Once the energy balance is obtained, the user can, by clicking on the "Graphics" button of IEB's main menu, select from a list of five graphs. These five graphs are: monthly peak electric demand (kW), monthly electric energy cost ($), monthly electric energy consumption (kWh), monthly electric demand Cost ($), and total electric energy cost ($). In addition, two pie charts are displayed in a percentage scale: energy (kWh) consumption by type of equipment, and the utility cost. We consider these graphics to be of significant importance, and consequently we have designed the IEB software to provide them by default. However, the one chosen by the user will be displayed in the screen, and the others are available by clicking in the bottom of the Excel file. The monthly electric energy consumption plot (Figure 10) and the kWh consumption pie chart (Figure 11) for the present case study are displayed below as examples.

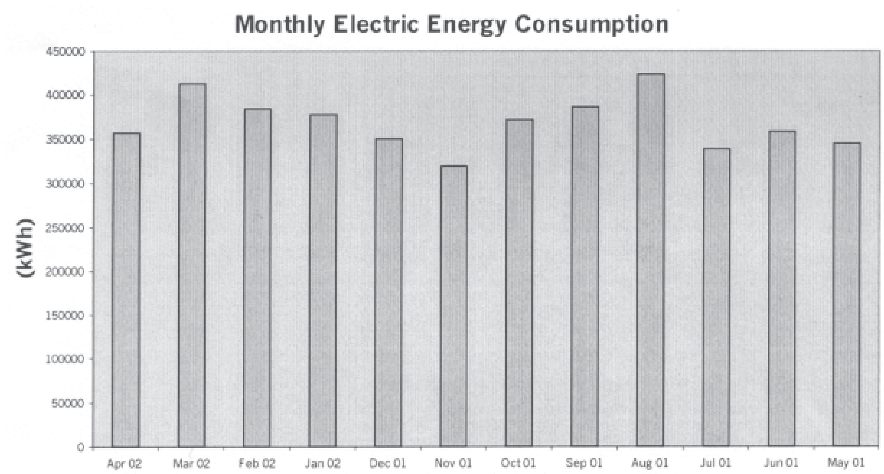

Figure 10. The WMI Monthly Electric Energy Consumption (kWh) plot.

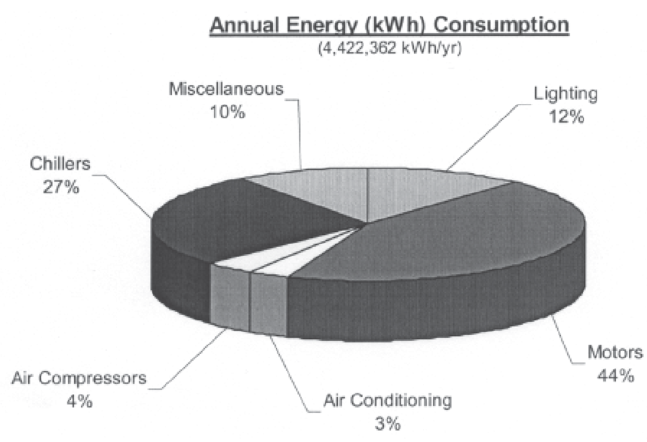

Figure 11. The WMI Annual Electric Energy Consumption (kWh) plot. The "others" equipment is not included here as there was none considered in this case study.

Table 2: Some Energy Saving Recommendations for WMI in the areas of Lighting, Air Conditioning, Compressed Air, and Motors. Cost Savings (CS), Simple Payback Periods (SPP), Energy Savings (ES), and Demand Reduction (DR) are shown. Savings for Motors were obtained using Motor Master+4.0 [6].

RECOMMENDATION	*CS ($/yr)*	*SPP (yrs)*	*ES (kWh/yr)*	*DR (kW)*
1. Turn Off Motors When Not in Use	7,234	Immediate	270,041	—
2. Turn Off Lights When Not in Use	6,081	0.5	225,214	—
3. Install High Efficiency Lighting	3,904	2.0	116,314	15.05
4. Retrofit V-Belts with Cogged V-Belts	2,715	Immediate	57,760	—
5. Install a Hi/Lo System for MH Lights	2,711	0.1	57,688	
6. Turn Off Air Compressors When Not in Use	1,175	0.1	43,517	—
7. Reduce Pressure of Compressed Air	1,023	Immediate	21,758	—
8. Repair Compressed Air Leaks	598	0.7	23,499	—
Totals	$25,441/yr	815,791	15.05	

RECOMMENDATIONS

Besides all the features we have shown for the IEB, we have also incorporated a "Recommendations" button. This option allows the user to make quick calculations to estimate the savings that a given energy savings project might provide based on the information provided. By clicking on this button, a window is displayed so the user can choose among four different types of equipment: air conditioning, air compressors, lighting, and motors. They contain in total 12 recommendations that are found in the majority of the facilities that have these types of equipment. Some of them contain more than one, as is the case of the lights, because the user can explore savings possibilities for different types of lamp wattage retrofits. In the case of air compressors, and depending on the application, energy savings for different pressure reductions can be explored. In this section, we briefly consider two specific projects: install lower wattage lighting and reduce pressure of compressed air system as examples.

Install Lower Wattage Lighting

We briefly consider here the case of the installation of lower wattage lamps. This requires the auditor to be aware of potential retrofits for the lamps used in the facility. This information can be obtained from catalogs such as Grainger, or others of specialized lamp manufacturers. As an example, we have chosen to retrofit the metal halide warehouse's existing 20 fixtures (one lamp per fixture) of 1,000 Watts lamps, with 760 Watts/lamp. To explore the potential savings of this project, we start by clicking on the "Recommendations" button, selecting lighting, and then choosing the option for installing lower wattage lighting. A window containing the lighting list, coming from the energy balance (equipment list) pops up.

We start by clicking on the lights we want to retrofit. The location is the warehouse, and the type of lighting is metal halide, with a wattage of 1000 Watts. The IEB requires some minimum information to be entered: number of fixtures to be replaced, we chose them all, 20; updated wattage for the selected lights, we will replace them with 760 Watts lamps. When the location is air conditioned, it is assumed that the fraction of the year in the cooling season is 70 percent, and that the fraction of daily lighting load to be met by mechanical cooling is 90 percent. This warehouse is air conditioned according to the data provided to the IEB. We then click the "Update Sheet" button, and the savings are displayed: total demand reduction of 5.76 kW, total energy savings are 59,497 kWh/yr, and the total cost savings are $1,606/yr. The results are shown in Figure 12. In this case no change of ballasts is required. Also, the foot candles provided by the new lamps and their lifetimes are practically the same as the 1000 Watts lamps.

It must be pointed out that additional retrofits can be explored. For

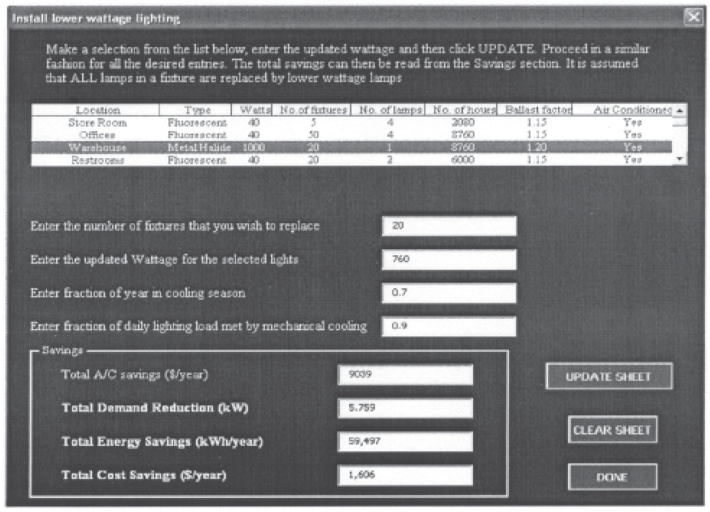

Figure 12. Working window for retrofitting WMI lights through the "Install Lower Wattage Lighting" recommendation.

example, replacing all forty 400 Watts lamps for 300 Watts lamps will provide demand, energy, and cost savings of 4.8 kW, 44,601 kWh, and $1,194/yr, respectively. Similarly, replacing all two hundred and eighty eight 40 Watts/fluorescent lamps (F40T12) with 32 Watts (F32T8) counterparts will provide demand, energy, and cost savings of 4.49 kW, 12,234 kWh, and $1,104/yr, respectively.

In summary, this option could reduce the demand by approximately 15.05 kW and provide energy and costs savings of 116,332 kWh/yr and $3,904/yr, respectively. Additional considerations are the need for electronic ballasts required for the fluorescent lamps retrofit.

Reduce Pressure of Compressed Air

For simplicity, we will consider that the user decides to inspect the use of compressed air in his facility, which is currently delivered at 125 psig. He finally realizes that the maximum required operating pressure is 80 psig. How much savings are involved? As before, we explore the result of this energy savings project by clicking the "Recommendations" button, selecting air compressors, and then choosing the option to reduce pressure of compressed air system. A window, shown in Figure 13,

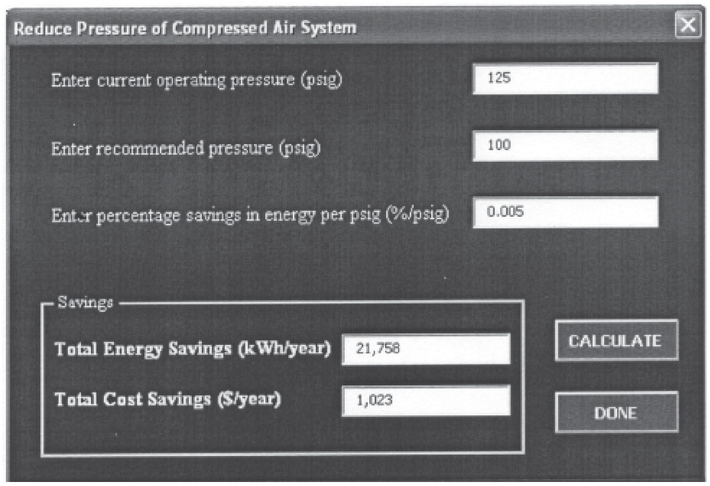

Figure 13. Energy and Cost savings suggested by IEB for the Reduce Pressure of the Compressed Air System recommendation for WMI

is displayed where some input is required: current operating pressure (125 psig), recommended pressure (100 psig), and percentage savings in energy per psig (default is 0.5 percent). After the values are entered and the "Calculate" button is clicked, savings are displayed: energy: 21,758 kWh/yr, and the associated cost savings: $1,023/yr.

For this particular case, the implementation cost of the project is minimal, as it just requires that the outlet pressure be adjusted to 100 psig. Note that we have allowed a 25 percent pressure safety factor to account for potential line losses and air leaks. Overall, this is a simple and beneficial project that requires only a few seconds of the user's time to estimate its benefits.

Summary of Recommendations

In Table 2 we summarize some recommendations and the energy, demand, and cost savings they can provide for this particular case study. We have listed our recommendations from highest to lowest cost savings. Similarly, other projects can be explored, and we encourage the user to do so. In the appendix (see section A-3), we give some additional information for each of these recommendations. We invite the reader/user to follow these examples.

CONCLUSIONS

We have presented an interactive energy balance software (IEB) that automatically generates an energy balance and equipment list, and therefore eliminates the actual need to manually balance an energy account. It also allows the user to alter chosen data. Further, its versatility ensures that any change in the user-entered data is replicated in all its places of use, so that repeated changes are not required. Estimation of savings can be obtained in the areas of lighting, motors, air compressors, and air conditioning for the user.

Future work on the IEB software includes analysis of energy costs for at least five years, to compare energy usage trends for longer periods. We plan to extend the software capabilities to other energy sources (i.e., natural gas, propane, fuel oils, etc.). This extension will be provided in the future. In addition, direct links to other software packages will be explored (e.g. DOE's Motor Master software MM+4.0 [6]).

Acknowledgments

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8. a) B.L. Capehart, W.C. Turner, and W.J. Kennedy, *Guide to Energy Management, Third Edition*, The Fairmont Press Inc., Lilburn, Georgia, U.S.A., 2000; b) W.C. Turner, *Energy Management Handbook, Third Edition*, The Fairmont Press, Inc., Lilburn, Georgia, U.S.A., 1997; c) Dr. Barney Capehart's website: *www.ise.ufl.edu/capehart/*

APPENDICES

A-1. THE BILLING PERIOD AND ENERGY COSTS WMI

Table A-1. The Billing period

Month	*Demand (kW)*	*Demand Cost ($)*	*Electricity consumption (kWh)*	*Electricity cost ($)*	*Taxes ($)*	*Total cost including taxes ($)*
May 01	706	7,140	344,804	9,393	2,057	11,379
Jun 01	754	7,704	358,178	9,670	2,109	17,414
Jul 01	711	7,240	338,321	9,150	2,047	16,499
Aug 01	768	7,847	423,506	11,522	2,237	19,310
Sep 01	729	7,704	386,382	10,062	2,135	17,802
Oct 01	742	7,581	371,836	10,047	2,126	17,663
Nov 01	706	7,213	319,208	8,580	2,009	15,932
Dec 01	701	7,072	350,007	9,356	2,050	16,541
Jan 02	814	8,317	377,074	10,503	2,246	19,436
Feb 02	792	8,092	383,782	9,010	2,191	18,619
Mar 02	818	8,357	412,553	11,254	2,314	20,439
Apr 02	729	7,448	356,711	9,933	2,166	18,258
Total	8,970	91,712	4,422,362	118,480	25,687	209,292
Average	748	7,643	368,530	9,873	2,141	17,441

Energy Costs
Average Cost of Demand **$10.22/kW-month**
Average Cost of Energy Without Demand **$0.027/kWh**
Average Cost of Energy Including Demand **$0.047/kWh**

A-3. SUMMARY OF RECOMMENDATIONS:

All the recommendations are made considering that they will not affect the facility operations. The calculated savings are shown in Table 2. Most of the calculations were performed using the IEB. While most of the recommendations are self-explanatory, some additional details are provided below.

Recommendation 1: ***Turn Off Motors When Not in Use***

This is a self-explanatory recommendation.

Recommendation 2: ***Turn Off Lights When Not in Use***

This recommendation addresses the issue that lights are left on when no operations are happening in the facility. Hence, starting a turn-lights-off program, or perhaps the installation of timers, should be considered. Here it has been estimated that the 400 Watts, 1,000 Watts, and the 40 Watts fluorescent bulbs can operate for a reduced 6,000 hrs, 4,000 hrs, and 3,000 hrs respectively, without affecting the facility operations.

Recommendation 3: ***Install High Efficiency Lighting***

Here it is suggested that light bulbs be replaced with more efficient ones through a complete relamping. Fluorescent 40 Watts T12 bulbs (F40T12) should be replaced by F32T8. Similarly, metal halide 1000 W and the 400 W should be replaced with 760 W and 300 W bulbs, respectively. A minimal reduction on the amount of light (foot candles) should be expected.

Recommendation 4: ***Retrofit V-Belts with Cogged V-Belts***

Cogged V-belts last twice as long as standard V-Belts, reducing maintenance and downtime with the additional advantage of reducing slippage. No implementation cost is associated with this recommendation, as the belts must be replaced anyway, and the savings will be realized as soon as the recommendation is implemented.

Recommendation 5: ***Install a Hi/Lo System***

Turning on and off metal halide lamps is both impractical and expensive. In some areas where light is needed intermittently, this system allows metal halide lamps to maintain a minimum level of light and energy consumption—low mode, keeping the filament hot. The bulbs will very quickly come up to full brightness when required—high mode. The system reverts to low mode through the use of an occupancy sensor when only a small amount of light is needed.

Recommendation 6: ***Turn Off Air Compressors When Not in Use***

This is a self-explanatory recommendation. The savings come from the observation of the fraction of time that the compressed air system is running at times when it is not required. In this case study, we recommend that both air compressors run for 3,000 hours/yr.

Recommendation 7: ***Reduce Pressure of Compressed Air***

See "Reduce Pressure of Compressed Air."

Recommendation 8: ***Repair Compressed Air Leaks***

The parameters considered are the fraction by which air leak flow can be reduced (0.9) and the fraction of air compressors' energy loss due to leaks (0.15), for a total of five air leaks.

A-2. THE EQUIPMENT LIST AND ELECTRIC ENERGY BALANCE CHART WMI

LIGHTING

Location	Type	Watts	No.of fixtures	No. of lamps	No. of hours	Ballast factor	Air Conditioned	kW	kWh	Total Cost
Laboratory	Fluorescent	34	12	4	8760	1.15	Yes	1.9	16441	674
Process plant	Metal Halide	400	14	1	8760	1.20	No	6.7	58867	2414
Store Room	Fluorescent	40	5	4	2080	1.15	Yes	0.9	1914	165
Offices	Fluorescent	40	50	4	8760	1.15	Yes	9.2	80592	3305
Warehouse	Metal Halide	1000	20	1	8760	1.20	Yes	24.0	210240	8621
Restrooms	Fluorescent	40	20	2	6000	1.15	Yes	1.8	11040	524
Maintenance	Metal Halide	400	6	1	6000	1.20	Yes	2.9	17280	820
Boiler Room	Fluorescent	40	2	2	8760	1.15	No	0.2	1612	66
Air Compressors-Chillers	Fluorescent	40	12	2	8760	1.15	No	1.1	9671	397
Production Area	Metal Halide	400	20	1	8760	1.20	Yes	9.6	84096	3448
Cafeteria	Fluorescent	60	20	4	6000	1.20	Yes	5.8	34560	1640
								64.1	**526312**	**22073**

MOTORS

Location	HP	No. of units	No. of hours	LF	UF	DF	Efficiency	kW	kWh	Total Cost
Dust Collector	1	1	6257	0.45	0.70	1	0.80	0.4	1840	101
Quench Tank Agitator	1.5	1	6257	0.45	0.85	1	0.82	0.6	3250	163
Bulk Resin Blowdown	1.5	1	6257	0.45	0.85	1	0.82	0.6	3250	163
Mineral Oil Transfer	2	1	6257	0.45	0.80	1	0.83	0.8	4064	209
Incline Converyor to Hopper	2	1	6257	0.45	0.80	1	0.83	0.8	4064	209
Dimer Addition Pot	3	1	6257	0.45	0.80	1	0.83	1.2	6059	312
Recovered Solvent	3	1	6257	0.45	0.75	1	0.83	1.2	5680	302
Building Sump	3	1	6257	0.45	0.70	1	0.83	1.2	5302	292
Terpene Circ.	3	1	6257	0.45	0.75	1	0.83	1.2	5680	302
Sodium Carb. Agitator	3	1	6257	0.45	0.70	1	0.83	1.2	5302	292
Limonene Storage	3	1	6257	0.45	0.70	1	0.83	1.2	5302	292
Flaker Belt Drive	5	1	6257	0.45	0.90	1	0.88	1.9	10790	526

Dimer Receiver	5	1	6257	0.45	0.75	1	0.88	1.9	8992	478
Tank Farm Sump	7.5	1	6257	0.45	0.75	1	0.90	2.8	13187	701
Dowtherm Heater	7.5	1	6257	0.45	0.80	1	0.90	2.8	14066	725
Stripper Hot Oil Circ	15	1	6257	0.45	0.80	1	0.91	5.5	27729	1428
Solvent Storage	20	1	6257	0.45	0.70	1	0.92	7.3	32033	1762
Sieve Blower	20	1	6257	0.45	0.75	1	0.92	7.3	34321	1824
Dechlor. Agitator	20	1	6257	0.45	0.75	1	0.92	7.3	34321	1824
Flaker Spreader Pan	1	1	6257	0.45	0.80	1	0.80	0.4	2103	108
Bagger	1	2	6257	0.45	0.75	0.7	0.80	0.6	3943	179
Stretch wrapper	1	1	6257	0.45	0.85	1	0.80	0.4	2235	112
Bagger	1.5	1	6257	0.45	0.75	0.7	0.82	0.4	2868	130
Production Bldg. 2nd floor	3	1	6257	0.45	1.00	1	0.86	1.2	7310	341
Palletizer	3	1	6257	0.45	0.70	1	0.86	1.2	5117	282
Production Bldg Mezanine	3	1	6257	0.45	1.00	1	0.86	1.2	7310	341
Boiler Roof	5	1	6257	0.45	1.00	1	0.88	1.9	11989	559
Chiller Room Fan	5	1	6257	0.45	1.00	1	0.88	1.9	11989	559
Bagger	7.5	1	6257	0.45	0.75	0.7	0.88	2.0	13488	611
Waste Water Lift Station	7.5	1	6257	0.45	0.70	1	0.88	2.9	12588	693
Hot Oil Cooling Pump	10	1	6257	0.45	0.75	1	0.90	3.7	17407	925
Chilled Water Tank	10	1	6257	0.45	0.70	1	0.90	3.7	16247	894
Condensate Tank	15	1	6257	0.45	0.70	1	0.91	5.5	24263	1335
Cooling Tower	15	2	6257	0.45	0.90	0.5	0.91	5.5	62390	2364
Dust Collector	20	1	6257	0.45	0.70	1	0.92	7.3	32033	1762
Cooling Tower	30	2	6257	0.45	0.90	0.5	0.93	10.8	122094	4627
Cooling Tower	100	2	6257	0.45	0.90	0.5	0.94	35.9	403937	15307
Cooling Tower (West)	100	2	6257	0.45	0.90	0.5	0.94	35.9	403937	15307
Solvent Processing	5	14	6257	0.45	0.75	1	0.88	26.7	125312	6660
Drying / Separation	7.5	15	6257	0.45	0.70	1	0.90	42.0	183792	10111
Resin Processing	10	9	6257	0.45	0.80	1	0.90	33.6	168038	8656
Solvent Processing	15	3	6257	0.45	0.80	1	0.91	16.6	83096	4280
								288.8	**1948721**	**88043**

AIR CONDITIONING

Location	Tons	No. of units	SEER	DF	No. of hours			kW	kWh	Total Cost
Laboratory	4	1	12	1.00	2500			4.0	10000	761
Offices	5	10	12	1.00	2500			50.0	125000	9509
Average COP			**3.5**							
								54.0	**135000**	**10270**

AIR COMPRESSORS

Location	HP	Units	No. of hours	LF	UF	DF	Efficiency	kW	kWh	Total Cost
Quincy Compressor	75	1	4000	0.70	0.60	1	0.90	43.5	104440	8159
Quincy Compressor	50	1	4000	0.70	0.60	1	0.90	29.0	69627	5439
								72.5	**174067**	**13598**

CHILLERS

Location	HP	Units	No. of hours	LF	UF	DF	Efficiency	kW	kWh	Total Cost
Chiller	100	1	5500	0.65	1.00	1	0.90	53.9	296328	14611
Glycol Chiller	150	2	5500	0.65	1.00	1	0.90	161.6	888983	43833
								215.5	**1185311**	**58444**

OTHER

Location	kW	No. of hours					kW	kWh	Total Cost
							0.0	**0**	**0**

	kW	kWh	Total Cost
CALCULATED FIGURES	630.8	3969411	192428
MISCELLANEOUS (10% of actual kW, kWh and cost (from bills))	76.0	442236	20929
TOTAL	706.7	4411647	213357
MIN ACTUAL kW	701.0		
MAX ACTUAL kW	818.0		
ACTUAL CONSUMPTION	759.5	4422362	209291
ERROR IN kWh		-0.24	1.94