An Interactive Energy Balance: A Case Study

Cristian Cardenas-Lailhacar, University of Florida
Shiva Krishnamurthy, University of Florida
Diane Schaub, University of Florida
Dale Kirmse, University of Florida

ABSTRACT

Due to its relative importance and usefulness, an energy assessment for production plants should include an account of all the energy used by the facility, quantifying the energy usage for each piece of equipment. In this work we show new interactive software that will allow the user to perform energy management studies that track energy consumption for a generated equipment list in an easy and efficient manner. This software stores information on all major equipment along with its energy usage rate, load, diversity and usage factors. This data is then "balanced" against the facility's overall energy consumption to look for trends and make useful comparisons. Additionally the software provides for calculation of net demand, energy use, and allocated costs on a monthly and annual basis. This information is invaluable when making decisions to purchase new equipment, or upgrade energy-inefficient equipment.

Introduction

One of the very first steps in an energy assessment should be to analyze the energy bills of the facility on a monthly basis, for at least a one-year period. From these values, computer plots can uncover patterns and trends on energy usage and consumption, and will allow the identification of particular seasonal behaviors in energy usage. The examination of the energy bills can perhaps suggest the need for power factor correction or the possibility of peak shavings, (for example, turn on equipment at off peak times). From the data analysis, an average cost of energy without demand (CEWD, in $/kWh), and an average demand cost (CD, in $/kW-month) are computed. Demand costs are the utility's charges for peak power usage as calculated over a short period of time. These average energy and power costs are useful for economic justification for upgrading equipment, and for other assessment recommendations as well. An additional parameter can also be obtained when the demand reduction cannot be quantified; this is the average cost of energy including demand (CEID, in $/kWh, where CEID > CEWD). The cost parameter is useful when recommendations are to be made to upgrade or replace air compressors or air conditioning equipment.

To prepare an equipment list, and to then perform an energy balance [1], traditionally requires the entry of data into a spreadsheet. Preparing reliable equipment lists, and then using the spreadsheet information, is a tedious time-consuming process and has high probabilities of human error. Furthermore, changes made to the spreadsheet data require multiple corrections in other spreadsheet locations, and require a cumbersome re-balance; ultimately this equates to unnecessary re-entry of data with many redundancies.

In order to simplify this process, we have developed a GUI (Graphic User Interface)-based application using Microsoft Visual Basic / Microsoft Access, to present the user with a user-friendly interface. The main goals of this package include the elimination of redundant data entry, and integration of all energy data into a single application database in order to create, and estimate energy cost savings calculations for improvement projects. The software presented in this work is based on experience of audits performed by the University of Florida Industrial Assessment Center (UF-IAC), to more than 270 manufacturing facilities in Florida. The UF-IAC currently provides an energy balance to clients using a series of M/S Excel spreadsheets [2]. We have improved our own productivity by updating the manual spreadsheets into the database format. With the energy balance information, the process of developing recommendations for improvements in operations, production and equipment has been greatly expedited. Typically the recommendations made will provide savings of around 40% of the clients' electric energy consumption.

In the next section we present the rationale of our work, which includes definitions and equipment analyses. In section 3 we discuss the importance of balancing this energy analysis and show how this is done. A case study is presented in section 4. We finally present our conclusions in section 5.

Rationale

Each facility has its own unique characteristics, even two companies that manufacture the same products. The energy manager should have an inventory of all the types of equipment in use in a facility, along with its pertinent energy-related data. A convenient way is to organize the data into general 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). It is highly recommended that the inventory of the equipment be made in reference to its in plant location, assisted by the use of a plant layout. Also, any additional information that is believed to be relevant should be recorded (i.e., rusty equipment, age, severe ambient conditions of work, etc.). In this paper, we will consider electrical equipment only. However the software can be easily extended to other energy sources (i.e., natural gas, propane, fuel oils, etc.).

In agreement with Pawlik, et. al. [2], we suggest that data should be collected on all major energy consuming equipment, and then calculate an additional 10% of this total to be allocated as miscellaneous, which typically includes small pieces of equipment, such as very small motors, desk lamps, office equipment (e.g., computers and peripherals). Because information on the equipment energy consumption is necessary, we define a few concepts that will become useful later on when we discuss different types of equipment. The *Load Factor* (LF) for a given piece of equipment is the ratio of the load electrical current actually drawn by the equipment to its full load current (i.e., the maximum current the equipment has been designed to draw). The load factor can be obtained by direct comparison of the current being consumed by the motor and its rated current (values range between 0.4 and 0.5). Also, the *Use Factor* (UF) is the ratio between the time that a particular piece of equipment is in use and the total time that it is available for use (this factor is variable and depends on the intensity of use of the piece of equipment). Finally, the *Diversity Factor* (DF) is defined as the probability that a particular piece of equipment will come on line at the time of the facility's peak load (this factor considers equipment that will be turned on as needed, but that in general is kept as a backup for actual running systems).

These factors are necessary for each piece of equipment in the facility, and can be obtained using information from the equipment's name plate (LF), annual time which the equipment is on (UF), and how many of those same pieces of equipment (equally rated motors for example) are on at the same time (DF).

It is important to keep documented equipment information such as those identified here, because it allows the knowledge of the energy use and the costs associated with the operations of all pieces of equipment considered. This is a powerful tool as it helps the user to make decisions on how to better operate the equipment. Good equipment maintenance logs can sometimes provide information on equipment life and usage. We will come back to these issues later on.

The IEB Software

The interactive energy balance (IEB) software runs in any Microsoft Windows based system requiring minimal memory and storage space. Figure 1 shows the startup screen. First, energy bill data is entered from which energy costs are computed, and then information on the particular pieces of equipment is input. Finally the total energy consumption of the equipment listed is compared, and balanced, against the last twelve months energy bills. The simplified Data Flow diagram for the energy database is illustrated in Figure 2. Four types of equipment, that are most likely to be found in any building, manufacturing or commercial facility, are included (more will be included in the future. Help is a click away, which provides simple explanations for the way in which calculations are performed.

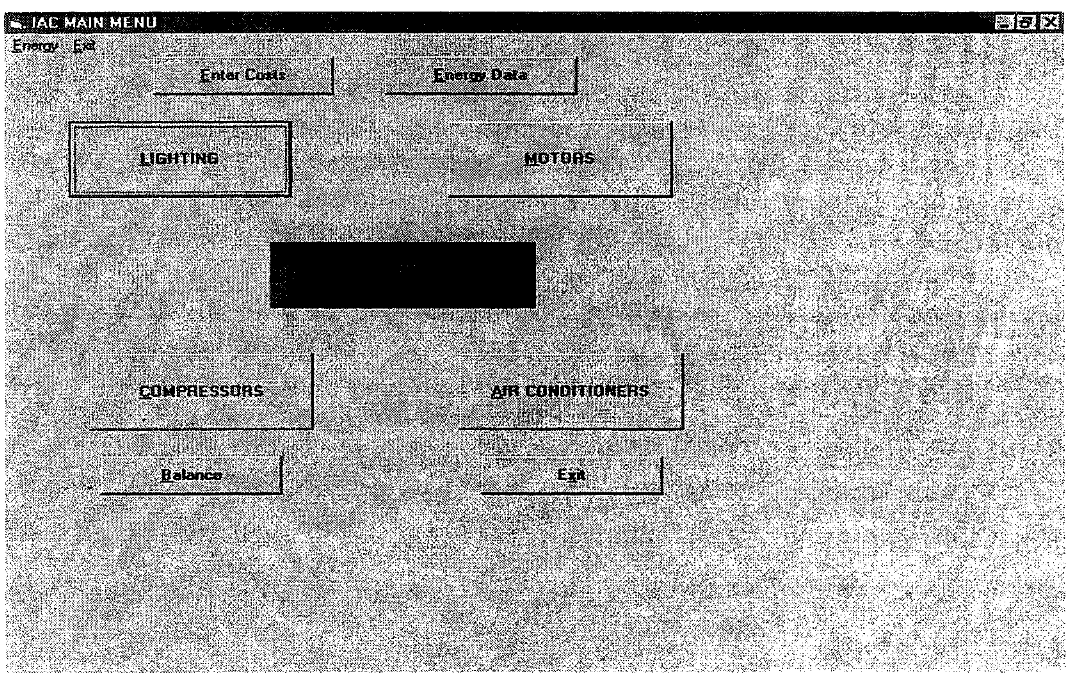


Figure 1. The Interactive Energy Balance (IEB) Main Screen

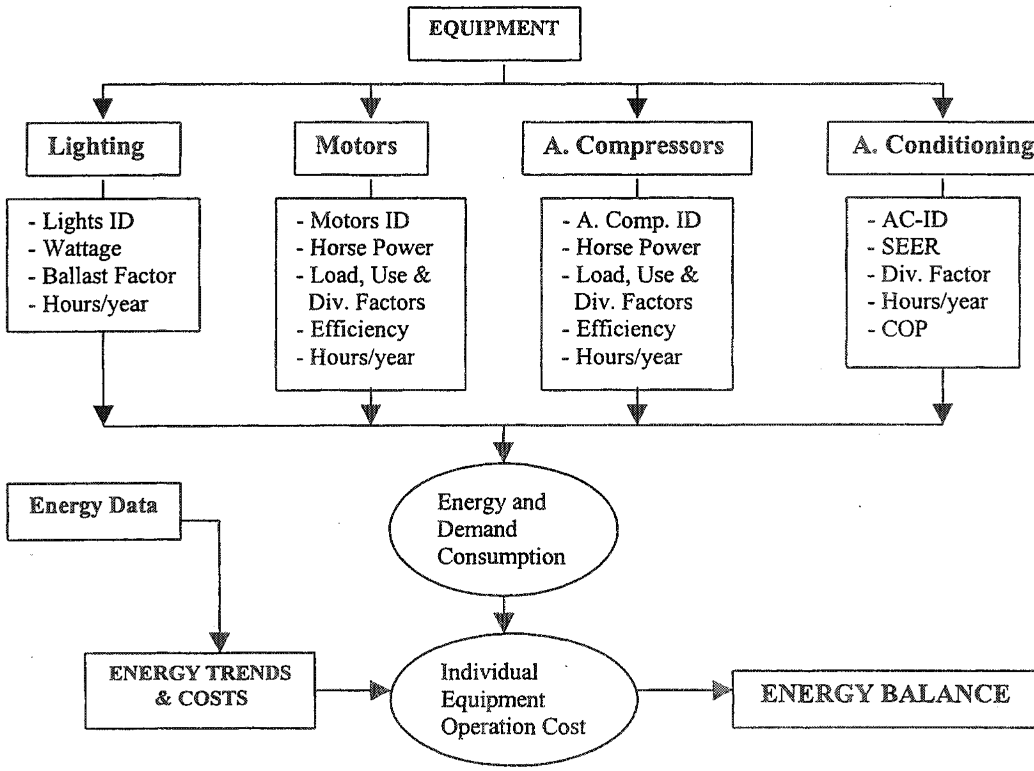


Figure 2. The Interactive Energy Balance (IEB) Simplified Data Flow Diagram

The interactive energy balance allows the user to track the energy consumption by the facility for a period of twelve months. An interface is provided for the entry of monthly energy consumption and energy costs as shown in Figure 3. The average energy cost with demand is calculated and used in other parts of the software. For example, the energy costs associated with lighting, motors etc. is calculated by other parts of the software and need not be recalculated even if the energy data is modified. We consider this data to be very valuable as it will allow the reconciliation between energy bills sent by the utility company, with the actual energy being used by the individual pieces of equipment, including their annual operational costs, as discussed in the Energy Balance section. Additional periods will be included in the future (say 5 years of energy consumption history), together with other sources of energy commonly used (natural gas, liquid propane, fuel oils, diesel, etc.

The operating equipment data entry interfaces (Figures 4, 5, 6 and 7) provide the user with easy-to-use drop-down boxes, with pre-programmed commonly found values. For example, the various possible locations, types and ratings of the equipment commonly found are chosen by the user for each drop-down box and need not be entered manually. The user completes the entry of a particular type of equipment (lights, motors, etc.) and then adds it to an equipment list.

After all the equipment data is entered, the list is automatically stored in an MS ACCESS database. This relational database identifies each piece of equipment by unique Equipment ID, and various lookups are possible. This database is connected with all the interfaces and can be modified by any of them.

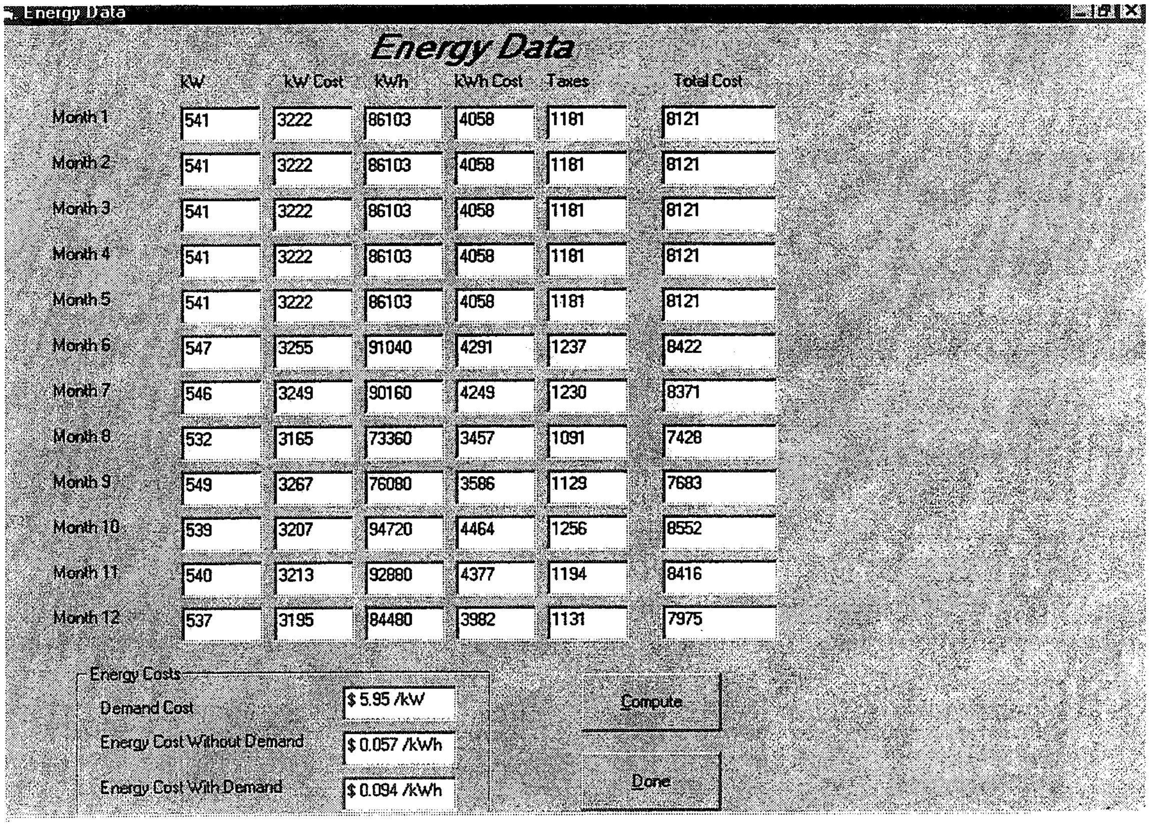


Figure 3. Energy Data screen where Historical Electrical Data Should Be Entered (data energy costs parameters are determined from these input data)

Energy Bills Analysis

The main window of the IEB environment, shown in Figure 1, consists of a choice of energy costs, data, and equipment. Typically, a user will enter the data from energy bills for the last twelve months, as shown in Figure 3 to determine energy costs. By clicking in *Compute*, IEB will calculate the Demand Cost, Energy Cost Without Demand, and the Energy Cost With Demand. These energy parameters are of primary importance, as they will be used mainly to perform the energy balance, and subsequently to compute energy and demand costs of equipment. 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 data is entered, the user must enter data pertinent to equipment. In Figure 1 buttons for *Lighting, Motors, Air Compressors, and Air* are displayed (Figures 4 - 7). These options are discussed in the following sections.

Lighting

The Lighting data entry window is shown in Figure 4. Here the user should start entering lighting data. For this purpose, IEB contains fields that are essential for the listing and computation of energy usage and costs. The room location and type of light under consideration have been furnished with typical sites and types of bulbs. Next, the number of Fixtures, Lamps per Fixture, Hours of Usage and Wattage (Current) is required. After clicking on the Add button, the data will be automatically displayed in the table at the bottom of the Lighting window, as shown in Figure 4.

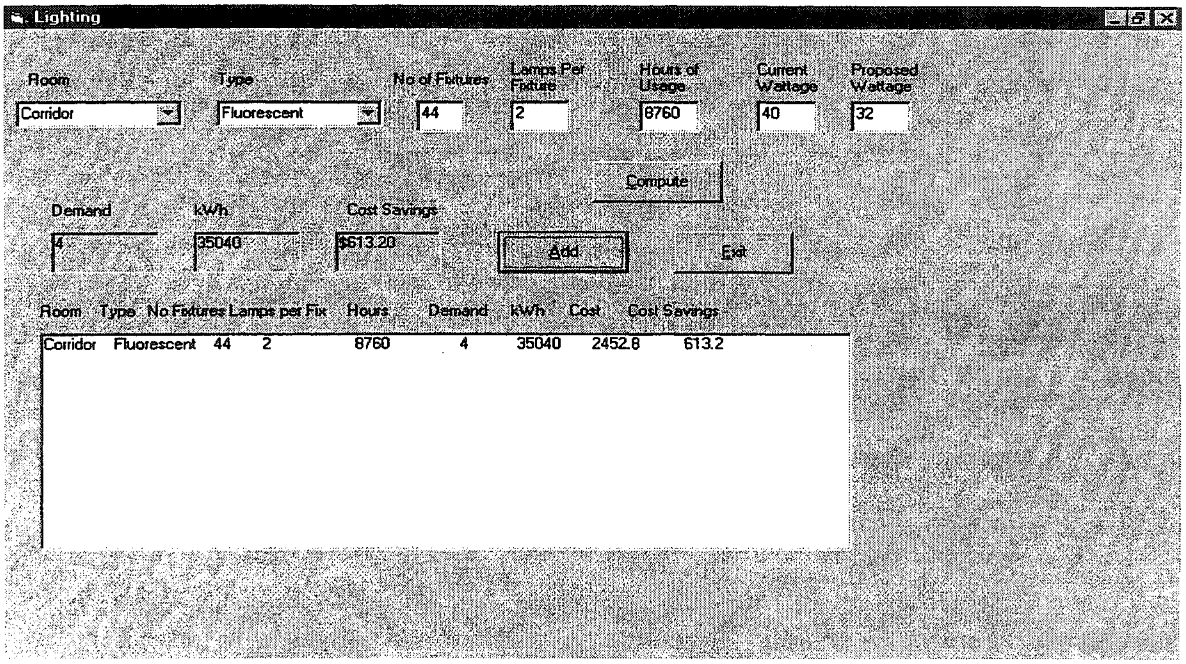


Figure 4. The Lighting Interface Screen

Lighting is an important energy consumption area that is usually assumed to be an overhead expenditure. However, collecting additional data on lighting intensity levels provides information about under- and over-illuminated areas of the facility. This data will help you to decide if a complete or partial re-lamp is appropriate, as well as any other suggestions like the installation of skylights, or to physically lower some fixtures are appropriate. 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 their use factor (or hours of use) is required. The same information is needed for machines, production lines, processes and/or operations. Experience tells us that a typical motor load factor is in the range of 40% to 50%. Higher factors do 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 are not turned on at the same time. Usually most of the relevant information needed about motors could be found on their nameplate. In Figure 5 we show the MOTORS data entry window from the IEB main screen (Figure 1). Notice that a direct link to DOE's Motor Master software MM3+ [6] is included. The room (location) of the motor, the motor efficiency, number of units, rating, hours of usage (annual), and the load factor are the IEB required motor information.

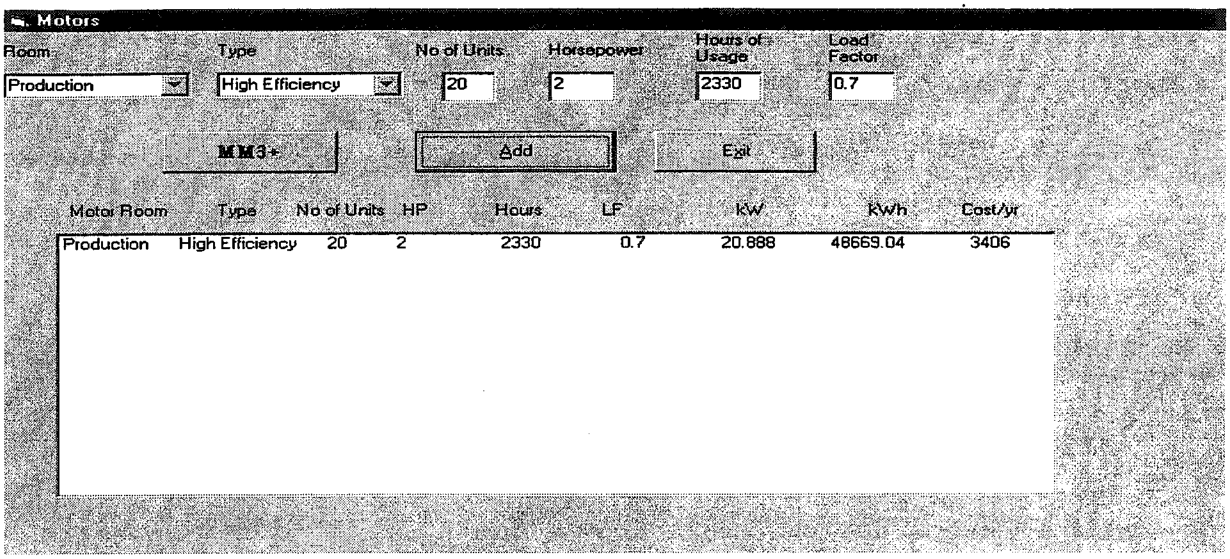


Figure 5. The Motors Interface Screen

Air Compressors

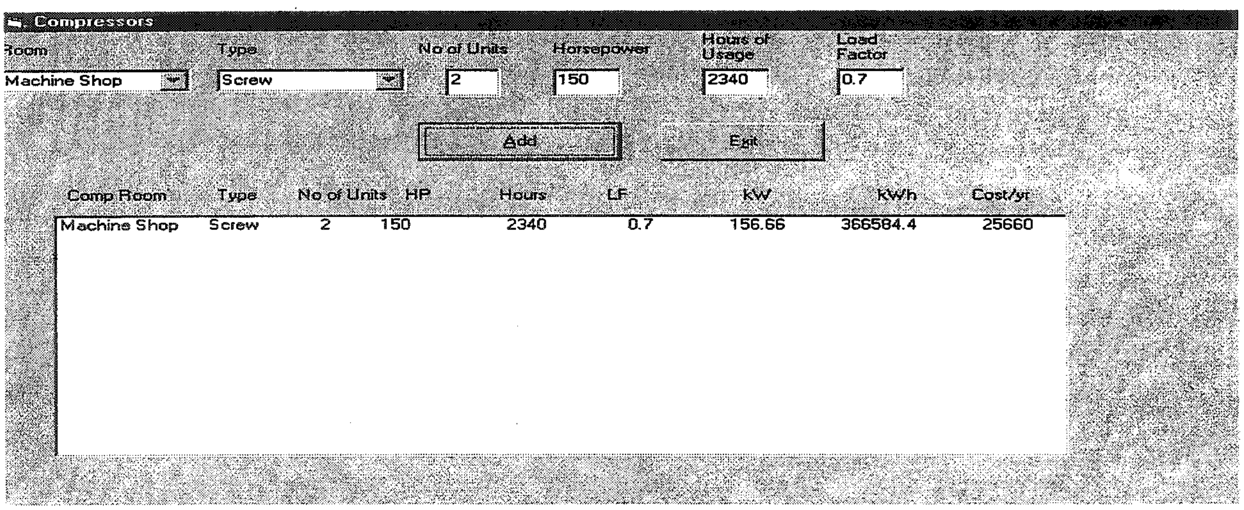


Figure 6. The Air Compressors Interface Screen

The information necessary for the air compressors can be found in the nameplate. This is, horsepower (kW or tonnage) and Amps. In addition, the load factor and hours of operation are needed. Figure 6 shows the screen with the required information for air compressors, also obtained from the IEB main screen (Figure 1).

Air Conditioning

The AC information required by IEB is shown in Figure 7, this is, tons, cooling hours (see Table 1a), diversity factor, and seasonal energy efficiency rating (SEER) (see Table 1b).

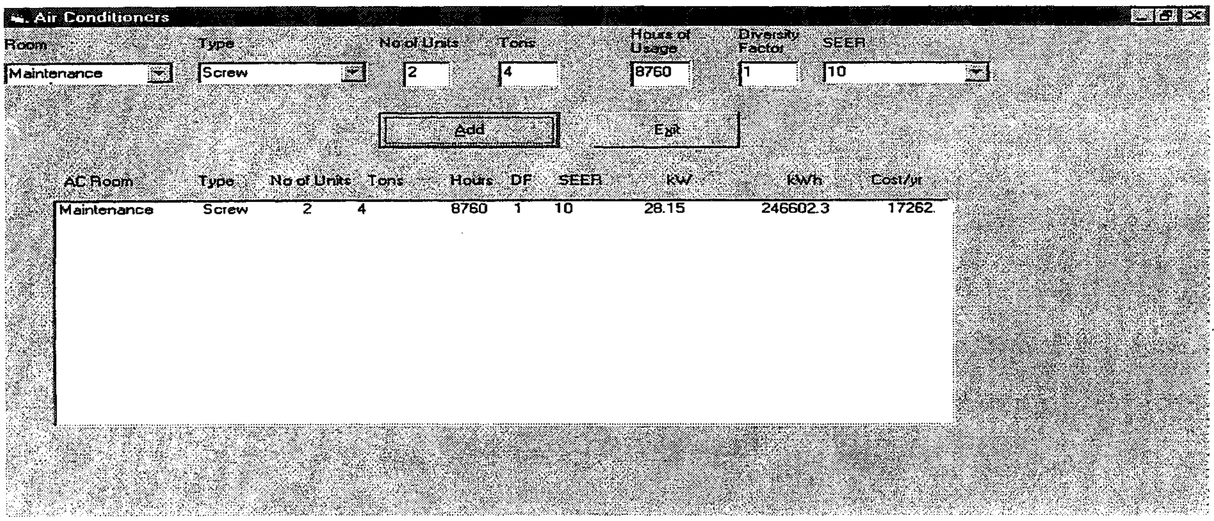


Figure 7. The Air Conditioners Interface Screen

Table 1: Annual Hours Of Cooling Season (in hrs/yr) for Florida (1a) and SEER Values for AC Units According to its Tonnage and Equipment Age (1b) (Note that *SEER/EER* = total seasonal cooling output / total electrical input)

Location	Cooling Season (Hr/yr)
Pensacola	1,997
Jacksonville	2,163
Tampa	2,392
Orlando	2,402
Miami	2,605

(1a)

Tons	Age	SEER
< 5	New	12
> 5	New	10 – 11
> 5	Old	7 – 9
< 5	Old	8 – 10
> 10	Old	6 – 8

(1b)

On some units this number is given in the model number. For example: BTC036C100A2. The 36 correspond to 36,000 BTU/hr. There are 12,000 BTU per ton, thus the AC unit is 3 tons. Other models don't list it this way, and you'll need to ask a maintenance person [7].

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 adjustment is attempted:

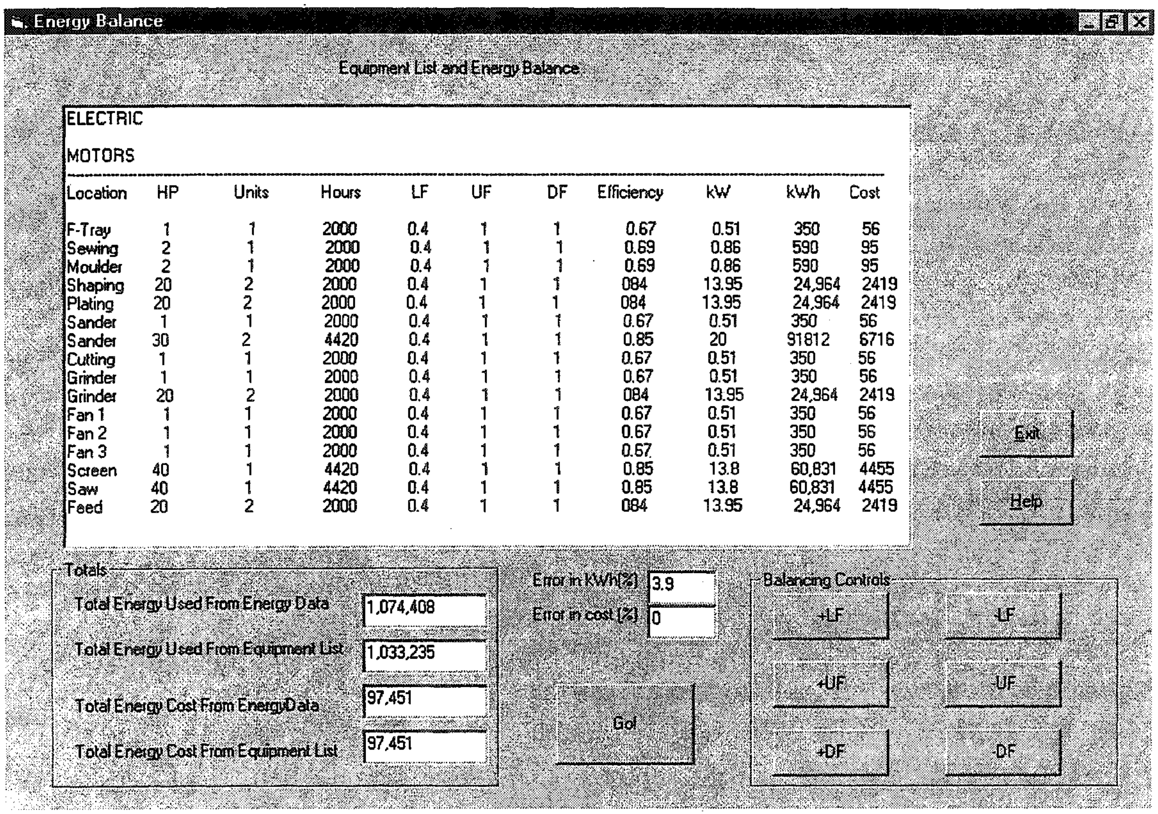
- Check that all the equipment of all processes in existence in the facility has been listed in the energy balance, especially large pieces of equipment.
- Make sure that all the equipment of all the processes involved has been included.
- A second look at the energy bills is also a good strategy. Check that the total energy usage and the peak kW are correct.
- A common source of error is the number of yearly hours assigned to the equipment. This is a relevant step in the analysis, because not all of the equipment necessarily works the same number of hours each day of the year, not even year after year.
- The diversity factor should be used in the adjustment if there is equipment that does not come on at the same time, as the facility peaks in kW use.

The Energy Balance

The balancing of the energy consumption is the heart and main purpose of all the data entry (and most complex section of the software). Here the energy usage calculated by the equipment list is balanced with the actual energy usage as calculated by the energy bills (entered in the energy interface described above and shown in Figure 3). Upon completion of all the equipment and energy data entry, the balancing interface shown in Figure 8, provides a relatively easy solution for this problem. The relations governing the energy balance can be found in any energy management book (see for example references 1, in particular reference 1-c).

Using load factors, usage factors, and diversity factors, 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 1%), the user is presented with several choices to modify the parameters. The software permits the user to change these factors manually and to see the resulting changes. By either increasing or decreasing the energy usage, iterations are made by the software to balance the energy use. This relatively simple way to calculate energy usage of equipment is faster, more efficient and provides a non-redundant way to balance energy usage in a facility.

The purpose of an equipment list and an energy balance is twofold. 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. Secondly, the equipment list is very useful to know the equipment in existence, as well as the possible replacements in emergency cases.



Location	HP	Units	Hours	LF	UF	DF	Efficiency	kW	kWh	Cost
F-Tray	1	1	2000	0.4	1	1	0.67	0.51	350	56
Sewing	2	1	2000	0.4	1	1	0.69	0.86	590	95
Moulder	2	1	2000	0.4	1	1	0.69	0.86	590	95
Shaping	20	2	2000	0.4	1	1	084	13.95	24,964	2419
Plating	20	2	2000	0.4	1	1	084	13.95	24,964	2419
Sander	1	1	2000	0.4	1	1	0.67	0.51	350	56
Sander	30	2	4420	0.4	1	1	0.85	20	91812	6716
Cutting	1	1	2000	0.4	1	1	0.67	0.51	350	56
Grinder	1	1	2000	0.4	1	1	0.67	0.51	350	56
Grinder	20	2	2000	0.4	1	1	084	13.95	24,964	2419
Fan 1	1	1	2000	0.4	1	1	0.67	0.51	350	56
Fan 2	1	1	2000	0.4	1	1	0.67	0.51	350	56
Fan 3	1	1	2000	0.4	1	1	0.67	0.51	350	56
Screen	40	1	4420	0.4	1	1	0.85	13.8	60,831	4455
Saw	40	1	4420	0.4	1	1	0.85	13.8	60,831	4455
Feed	20	2	2000	0.4	1	1	084	13.95	24,964	2419

Figure 8. The Equipment List and Energy Balance Chart. Also Shown Is The Balancing Options Screen, Which Includes The GO ! Button to Balance The Equipment Energy Consumption Against Electrical Energy Bills

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

A 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 3 – 8 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 borne by the company, taken from the last twelve months WMI energy bills are listed, and monthly demand and monthly energy usage are calculated as shown in Figure 3. This task is simplified by the IEB, as the energy managers 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 costs, as described in the next step, greatly simplifying the calculations for the energy manager.

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. This data is 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 4 - 7).

Step 3: The final step involves estimating the individual equipment energy use and balancing the costs as calculated in step 2 with the total energy costs calculated by step 1. The IEB provides an interface to perform this task. The user can iteratively test the Load factor, Diversity factor and Use factor values on the balance options, and balance (see Figure 8).

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 correspond to approximately 20% of the client electric energy expense ($97,451/yr).

Table 2. Some Energy Saving Recommendations made to 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+3.0 [6].

Recommendation	**CS ($/yr)**	**SPP (yrs)**	**ES (kWh/yr)**	**DR (kW)**
Install Efficient Lower Wattage Light	1,183	1.1	16,354	3.5
Clean Skylights & Turn Off Lights	350	0.0	4,830	2.0
Install Occupancy Sensors	213	1.5	3,737	0.0
Reduce Pressure of Comp. Air System	544	0.0	5,789	0.0
Use Vac.. Cleaner Instead of Comp. Air	367	3.3	7,806	5.1
Install Premium-Efficiency Motors	1,627	4.4	19,146	5.2
Balance Offices HVAC System Temp.	6,874	0.2	120,600	0.0
Apply Energy Mgmt. to HVAC System	8,482	3.4	148,800	0.0
Sub-Total	***19,640***	***2.0***	***327,062***	***15.8***

Conclusions

We have presented a software (IEB) that automatically generates an energy balance, an 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 software includes the evaluation of energy recommendations in all four areas considered, and the analysis of energy costs for a period of at least 5 years so to compare energy usage trends for longer periods. The same analysis for other sources of energy (natural gas, fuel oils, etc.) is an area that we will explore.

Acknowledgements

The authors would like to acknowledge support from the US Department of Energy's Office of Industrial Technologies through their Industrial Assessment Center grant to the University of Florida.

References

1. 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 web- site: www.ise.ufl.edu/capehart/

2. K-D. E. Pawlik, L.C. Capehart, and B.L. Capehart, *Analyzing Energy Use: A Balance Act*, Proceedings of the World Energy Engineering Congress 2000, Atlanta GA, October 25-27, U.S.A., 2000.

3. E. Rios, *Master Degree Project*. August 2000. Department of Industrial and Systems Engineering, University of Florida. Gainesville, FL 32611.

4. Illuminating Society of North America, Lighting Handbook, Reference & Application, Eighth Edition, IESNA, New York, U.S.A., 1993.

5. 1999 State Fact Book, Office of Industrial Technologies, Office of Efficiency and Renewable Energy. U.S. Department of Energy. ; b) Also see: EPRI Journal, 1992.

6. Motor Master+3.0. U.S. Department of Energy, Office of Industrial Technologies. Free software that can be downloaded from: www.oit.doe.gov/bestpractices/motors/

7. This web-site gives the tonnage of the unit, provided that the serial and model numbers are known (i.e., obtained from the name-plate): www.ARI.org