# Manual Method for Energy Auditing

Alan F. Stewart, P.E.
Stewart Engineering Services Corporation

## DOCUMENTING THE SUCCESS OF ENERGY MANAGEMENT COST REDUCTION INITIATIVES

The scope of this paper is to offer methods to document energy saving projects. The examples used are based on actual industrial facilities. I will define concepts to be used in the analysis of the industrial work place energy consumption. With the concepts defined we can begin to apply the documentation strategy for some specific examples. Why should we be interested in auditing the results of energy projects?

Nearly every industrial facility has embarked on the road to energy efficiency. As one of my plant engineer associates relates "If all our energy saving programs were working as stated the power company would be paying us." The underlying principles in this statement are true. Does it mean we as technicians, engineers and managers of energy projects have failed? No, we have however failed to finish the job and document the results. My experience has shown there is good support and enthusiasm for those energy projects we begin. It is also my experience that a well documented successful project provides many levels of satisfaction. Large energy management projects involve a major financial commitment. Documenting the results provides all those who supported the project from finance, management and the technical staff the positive reinforcement to support your future projects. We should begin by defining what an energy audit is and what is the expected result of an audit?

### The Energy Audit

The energy audit is a document which tabulates the results of energy related savings associated with a specified course of action. The most important aspect of the energy audit is to measure the actual consumption and account for deviations in the expected energy consumption. Audits should be produced on a timely basis which may be daily, weekly, monthly or quarterly as necessary to achieve your goals. Energy audits will vary in complexity depending on the utility rate cost structure, utility billing cycles, weather, production volumes, and frequency of equipment changes.

Energy audits can be used for a wide variety of projects. In the most simple case we eliminate some energy consuming activity. For example, we eliminate the operation of some equipment on weekend hours. In the more complicated case we modify the method of consuming energy. For example we replace an air-conditioning system with a more efficient unit. In our home environment we could expect to see reduced utility bills to document the latter example. However, in the industrial environment many changes in energy consumption are occurring simultaneously. We must identify change in our energy consumption pattern quickly because of the potential for waste and the inability for the workers to describe the events leading up to the change after several weeks have passed. Some change may be due to new equipment operation but we should be able to record the reasons for change.

**Historical Utility Information**

Two years worth of billing data are required, three years are better. You should also have two years production data again three are better. I look for change in consumption or production data over the years and seek out those within the plant who can explain why the changes occurred. Based on the energy data and production data I begin to model the performance of the facility. The first pass at my model will be by hand calculation. A recent audit showed the most recent year to have reduced energy demand and energy. After conducting several interviews I learned one of the larger machines was out of service for the previous summer period. Additionally, the plant had moved to just in time production and had drawn down all of the products stockpiled the previous year. A rail strike also had caused abnormal production as raw materials were not available. All of these conditions yielded an energy usage and cost below the trend of previous years. This reconciling historical data to facility use and production levels is a critical component of the audit. Fine tuning will occur throughout the audit but your ability to compensate for change in the facility use or production levels will be only as accurate as your original calculations for the first few audits. Major changes in your baseline data well into the audit process can lead management to lose confidence in your audit.

A first pass at developing the major energy cost centers can be accomplished as shown in the table. A cost center can be energy use for a specific piece of equipment or a larger department level. Cost centers should be established to make resource management more effective. This particular table is based on the total annual consumption with demand values at a maximum. This process can be repeated for summer and winter months.

# Utility Analysis

The plant is approximately 260K square feet.

Assume 50% office/production and 50% warehouse.

Office/production at 2 Watt per SF.

Warehouse at 1 Watt per SF.

| | | KW | Annual hrs | MKWH |
|---|---|---|---|---|
| Lighting | | | | |
| Office/production | 260KSF*.50*2W/SF = | 260 | 8760 | 2.28 |
| Warehouse | 260KSF*.50* 1W/SF= | 130 | 8760 | 1.14 |
| | | | | |
| Air compressors | | | | |
| 3 at 200HP | 3*200HP*.8KW/HP= | 450 | 4300 | 1.94 |
| | | | | |
| Battery chargers | | | | |
| 16 at 10KW | 16*.4*10= | 64 | 1900 | 0.12 |
| | 40% usage factor | | | |
| HVAC | | | | |
| 350 Tons at 1.1KW/Ton= | | 440 | 5000 | 2.20 |
| Roof Top HVAC units | | 100 | 4500 | 0.45 |
| Process cooling requirements | | | | |
| at 150 Tons *1.1KW/Ton | | 165 | 6500 | 1.07 |
| | | | | |
| Process loads | | 900 | 6500 | 5.85 |
| Process chilled water 150 Tons | | 165 | 6500 | 1.07 |

| | | | |
|---|---|---|---|
| Miscellaneous power | 100 | 1000 | 0.10 |
| | ==== | ====== | ====== |
| TOTAL | 2674 | | 16.12 |

Calendar year 1990 showed 2765KW and 15.9MKWH energy use

**Utility Rate Structure**

Many different rate structures are in place across our country. The most common similarities are the treatment of energy consumption (KWH) and energy demand (KW) as two separate entities for billing purposes. Most rate structures (or tariffs) provide the maximum benefit to those facilities were the load can be maintained at a constant level all year long. For most of us this type of load profile is unattainable. We must recognize how to use the rate structure to our advantage. Energy demand costs can comprise over 50 percent of your bill. Further with 12 month ratchet clauses a high consumption level in one metering period (usually 15 to 30 minutes) can cause a new peak demand which must be paid for over the next 12 months. A thorough audit will begin with a complete understanding of your rate structure as KWH saved must be computed at the marginal purchase rate. That is the rate the utility will charge for one additional KWH. Which is a very different number from the average cost of a KWH (Total utility bill divided by the Total utility cost). Energy demand must also be computed at the marginal rate. The required rate information will be explained on the tariff filed with your Public Service Commission.

**Utility Billing Cycles**

Most utilities still read the meter by hand. The exact time and date cause the monthly bill from year to year to have different periods. For example the January 1991 bill may have 33 days and the January 1992 may have 29 days. If the bill is not factored for the proper number of days the data from January 1992 could look overly optimistic. It is important to make sure that the proper number of week days and weekend days are accounted for as these days have very different energy usage in most facilities.

**Weather Adjustment**

Manual methods for developing energy audits have long relied on the concept of degree-days. This method of accounting for the impact of weather is rooted in the residential energy auditing process. The premise of this system is that there is a temperature at which the building envelop and contents are in thermal equilibrium with the outside conditions. It was reasoned that a typical home is in equilibrium at approximately 65 degrees Fahrenheit. Measurements support the reliability of the 65 degree Fahrenheit outside air temperature figure as the balance point where internal home heat loads cancel external heat loss in modern home structures. After determining the balance point at 65 degrees Fahrenheit some method of quantifying the effects of higher and lower outside air temperatures was required. The mean temperature for each day was chosen as the representative temperature for each particular day. The effect of higher (or lower) temperatures could now be quantified as the difference between 65 degrees Fahrenheit and the mean temperature for the day. Mean temperatures above the 65 degrees Fahrenheit would be referred to as cooling degree days and mean temperatures below 65 degrees Fahrenheit would be heating degree days. For example, if the mean temperature was 55 degrees Fahrenheit then that day would be counted as having 10 heating degree days. As the resistance to heat flow is linear with the thermal gradient between two surfaces, so it was decided to aggregate the sum of the hours above (or below) the 65 degree Fahrenheit.

Having established the beginnings of the degree day method for quantifying weather impact on facilities we now need to examine the suitability for industrial facilities. We desire to establish the balance point for thermal equilibrium. In industrial plants it is common to require cooling as low as 55 degrees Fahrenheit outside temperatures. Generally, air side economizers allow outside air to be used for cooling with outside air temperatures below 55 degrees Fahrenheit. Some unique applications will require cooling to 45 degrees Fahrenheit outside air temperature. (Large internal heat loads without the benefit of air side economizers can require the use of mechanical refrigeration.) Standard degree-day data will be presented for use based on the 65 degree Fahrenheit balance point. For use with your facility the data will require adjustment for your balance point temperature.

To establish a new balance point we must remember that the degree-day is based on the mean temperature. For example let's assume the balance point is 55 degrees Fahrenheit and the data we are adjusting shows a particular month has 600 heating degree-days. For a thirty day month we calculate the following:

Deg-days=(deg-day data) - ((65-55)*30 days)
Deg-days=600 -(10*30)
Deg-days=300 degree-days

We are able to take advantage of the fact that the degree-day data is based on the mean temperature so to reduce the balance point by 10 degrees we subtract 10 degree-days for each day of the month.

Heating systems tend to respond in a linear fashion to the colder temperatures. So the adjustments we made above should help the correlation between heating fuels consumption and weather data. Cooling systems tend to respond in nonlinear fashion to weather data. Two main reasons exist for the nonlinear response:

1. When large cooling plants are started the loads are low and cooling plant efficiency is low. The result is much higher energy consumption than would be expected for the connected loads. The cost to produce a unit of cooling can approach twice the cost per unit when the cooling system is well loaded. (The cooling system consists of the chiller, pumps, fans, and air handlers,)

2. Most chillers in use require the entering water temperature to the condenser to be 85 degrees F. With lower outside air (below say 85 degrees F, main concern here is wet bulb temperature) the wet bulb temperature can be expected to be in the low to mid 70 degrees (for Atlanta, GA). The result of 95+ degree Fahrenheit out side air temperatures and mean coincident wet bulb (75+ degrees Fahrenheit) can drive the condenser water above the 85 degree Fahrenheit design levels resulting in increased energy consumption per cooling unit produced. Residential air conditioning on the other hand responds more uniformly to the increase in outside air temperatures as the unit adjusts run time to meet the cooling loads.

My goal with the above discussion for degree-day calculations is as follows:
1. Demonstrate the validity of the heating energy usage correlation with degree-day data and the appropriate balance point for heating.
2. Demonstrate the nonlinear response for most industrial facilities of cooling energy load and cooling degree-days.
3. Based on the discussion for chiller energy use it should be evident that an unusually hot day can set a new demand peak for your facility without appreciably affecting the overall weather data for the month.
4. A computer model of your facility with hourly chiller load data will provide the most useful data to manage energy consumption and energy demand for the annual cycle. The portion of energy consumption subject to weather impact will be easily established. The error in extrapolating from the weather data of the thirty year average will be much smaller than the error from degree-day data.

**Production Volumes**

This is one of the most difficult areas for the auditor. The goal in this area is to establish a correlation between the number of products produced and the energy consumed. A very true statement is "You cannot manage that which you cannot measure". Now is the time you desire those separately metered histories, but in most plants the data does not exist. Almost immediately you realize that production will have fixed cost and variable cost. Many machines used in industry consume energy whether producing product or sitting idle but ready to produce. The operation of this machine is a fixed cost, independent of throughput. An example of such a situation would be a large heated tank for cleaning machine parts. Often the energy use between production and idle is insignificant. In large plants there may be several machines producing the very same end product however each machine may have a different energy consumption. This can be the case for injection molding machines where the mold used is based on the current requirement for containers. A machine with variable cost for energy is, for example, a metal stamping press. We should remember that almost all machines have some fixed cost. If your facility is served by a utility with an energy demand ratchet operation of your equipment for one measuring period of 15 or 30 minutes will incur demand charges for the next 12 months, whether you use the machine again or not.

One area to examine is the amount of processed material. If historical data can show a correlation to processed material you may use the volumes for energy correlation. In my studies I have found areas where for example certain types of resins may be worked two or three times if the product is not acceptable on the first pass. The amount of energy can vary widely per unit of processed material. There will be some waste associated with most processing, the waste may or may not be quantified.

Additional utilities in use are compressed air, vacuum air, water, chilled water, steam, and hot water. Many more utilities are in use in plants. Some of these utilities are shared between production and personnel comfort heating and cooling systems. Part of your task will be to prorate the utility usage. It may be determined that a particular utility should be metered, however in most applications you will have to estimate utility consumption based on knowledge of the load served. It helps me to estimate the individual loads and then develop the expected total consumption. Total consumption can be reconciled with the total available quantity for each utility. For example chiller logs will be helpful to determine maximum consumption for chilled water, however process and non-process usage will have to be determined.

**Measuring Results**

A metering plan should be developed as the result of your work. The analysis performed above will show where each utility is most exposed to waste. Additionally, you may wish to meter to establish cost centers. Cost centers help us develop budgets that can be achieved. Many utilities can be wasted without visible warning signs, metering will quickly pinpoint such losses. Leaking steam traps can significantly increase energy consumption, without meters and a baseline for appropriate consumption in may be several months before major leaks are detected.

The results of your energy program should be proudly displayed for all. I can think of no better way to get support for your program than to put up some nice color charts that demonstrate your success. Charts should show comparisons to historical billing data for the following areas: energy cost, total Btu values, KWH, KW, and other sources of energy. All to often we believe the results of various energy saving projects are inherently obvious. With all the change going on in most plants savings get lost or offset by new consumption. This level of accounting can best be handled by a computerized energy management system. One of the most important events to occur is a physical inventory of all plant energy consumers.

**Physical Audit**

We have already talked about the need for good utility consumption history. Now we need to know how the plant equipment has changed over the last few years. We could go to each department and take inventory, however, that process could take months. A better approach would be to visit your purchasing department and ask for a list of all equipment purchased for the last two years. By tracking down each piece of equipment you will develop the energy consumption profile from your interviews with the end user of the new equipment. Also the end user can tell you if some equipment was replaced or removed. Some plants regulated by federal agencies may go through extensive testing of machines and produce no product. If in doubt ask the equipment user. The result of your work will be a table in the energy audit which adds new loads and subtracts removed loads. New loads will be added to your baseline data so you can project where the current energy consumption would have been without the energy initiatives.

**Summary**

This paper discusses the building blocks for a successful energy audit in the post-energy project phase. This comprehensive approach is warranted to fully disclose results of energy initiatives. Many of the tasks discussed can and should be automated. Analysis of deviation for energy consumption is most effective if completed a short period after the event. Weeks after a major change in energy consumption patterns no one may remember what caused the event.