

31

Energy audits

A necessary tool in any energy management program is the energy audit. An audit as defined in Webster's is "a formal or official examination and verification of accounts." In the case of an energy audit, what is being accounted for is the energy consumed. Such energy audits can be considered in many ways analogous to financial audits, both in their degree of thoroughness and in their purpose. Regarding thoroughness, just as with a financial audit, specificity is absolutely required. The extent of verification, however, is dependent on the accuracy desired; elements not well substantiated or verified must be so qualified.

Two types of energy audits

There are two major types of energy audits. One is the initial or exploratory audit; the other is the ongoing management audit. The exploratory audit is generally performed as a preliminary step prior to instituting an energy retrofit or an energy management program. It is the exploratory audit that reveals all additional efforts that can or should be made to reduce energy consumption. In this regard, a poorly performed audit is like an inferior foundation under a building. If the exploratory audit is not done well, the entire implementation or management program will almost certainly fail!

The ongoing management audit is analogous to a periodic financial audit of the records of a business. Without the periodic financial audit, the business manager cannot be certain of his financial position, successes, or failures. Similarly, without a periodic energy audit, one cannot ascertain the success of the energy management program. A major difference between the two audits is that the exploratory audit is necessarily conducted

with the information available from past records whereas the ongoing management audits rely on metering and other recording devices incorporated into the systems to provide input to the energy management program.

Develop annual energy profile

The first step in the exploratory audit is to develop an annual building energy profile. Most buildings employ two types of energy, purchased and provided at the building boundary: electrical and thermal. The electric energy is generally used for lighting and power drives and the thermal for heating and, possibly, thermally motivated cooling (in some cases, of course, electric energy is utilized to provide the thermal needs). The electricity, in the vast majority of circumstances, is metered; and thus, the information contained in the metering records provides reliable historical data for the electrical energy profile. Further, this information is generally provided to the building owner monthly on his electric bill by the utility company. The information typically provided, in addition to the cost, includes:

- *Service period.* This defines the dates of service covered by the bill, or the dates on which the meter was read for the current and previous billings. The service period is most important in constructing an energy profile.
- *Energy consumption.* The energy consumed, in kilowatt-hours (KWH), is always shown; and on most forms the actual meter readings at the beginning and end of the period are shown.
- *Power or demand.* If the rate under which the energy is being sold contains a demand charge, the highest 15 minute integrated demand for the period is shown. Although the demand itself is not used to develop an energy

profile, it can be used for the demand analysis of an audit.

Although only the energy consumption and the dates of service are required to develop the energy profile, an energy management program cannot be instigated until the analyst has a thorough understanding of the utility's rate structure. Thus, at this stage of the study, he should obtain and thoroughly study the rate structure (see Chapter 32).

To develop the profile, the analyst obtains billing information for the immediately preceding calendar year, January through December. For each month (or closest period thereto), the energy consumed is divided by the number of days of the billing period, providing the average KWH per day of the period. *This normalization is essential in developing a profile.* The periods between meter readings will often vary by as much as 40 percent, thus having more effect on the energy consumption during that period than other variables such as weather, building occupancy, etc. The normalized energy consumption data are then plotted on the ordinate against the months on the abscissa.

If thermal energy is purchased in a metered form, as is the case with natural gas or steam, the profile development is similar to that for electricity. The amount of energy, either in the quantity billed or that quantity reduced to thermal units (Btu) is normalized by dividing by the days of the billing period and plotted against the months.

The annual energy profiles so developed reveal a significant amount of data about a building's energy systems and their management.

Figure 31-1 is a typical electrical energy profile for a building in the Midwest. It is immediately evident that this profile is for a building with electrically driven air conditioning and not with electric heat. The lower plateau from January through March and November through December is called the "base" use. This base use is generally not weather related but rather more directly related to use patterns, systems, and occupancy schedules.

Figure 31-2 is a typical thermal energy

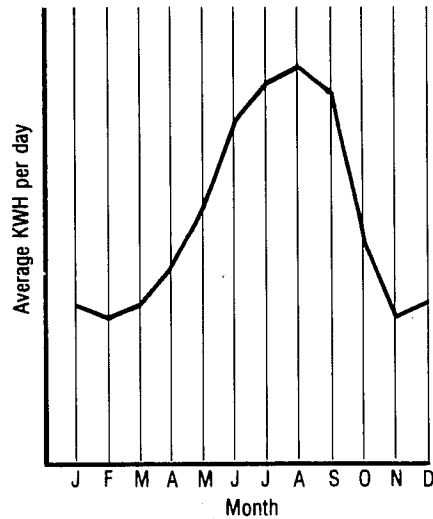


Fig. 31-1. Electrical energy profile.

profile for a building in the Midwest. This is a common profile for a gas heated building with some minimal gas use for service hot water and perhaps cooking. The curve shape relates very closely to heating degree-days.

From these two simple shapes, many other combinations appear, such as electric heating, reheat control, dual-stream control, absorption cooling, etc. With very little experience, the analyst finds that these profiles reveal untold information about the building's energy systems. The development of these pro-

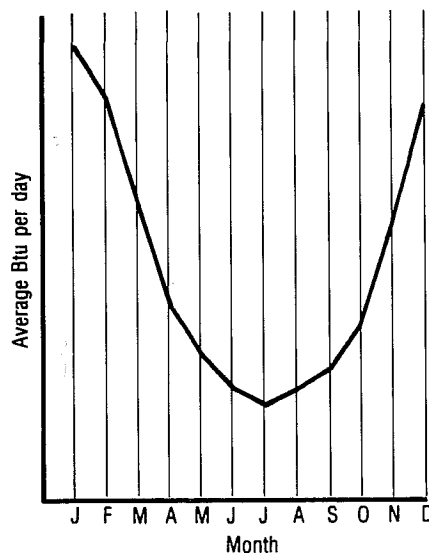


Fig. 31-2. Thermal energy profile.

files is quite simple and takes very little time. Yet the profiles represent one of the most important tools, both for performing the audit and effecting the ongoing management program.

Components of energy use

The next step in conducting an audit is to identify the component uses that created the historical profile. Again, since an audit by definition implies specificity, the degree of approximation and guesswork must be held to a practical minimum. If there is *any* difference between so-called mini-audits and maxi-audits, it should not lie in the general scope but simply in the degree of thoroughness and exactness in carrying out *this* step.

The general categories of use that are included in audits for commercial or institutional buildings, such as office buildings or schools, will be discussed here for illustrative purposes. Other types of buildings, such as health care facilities, manufacturing plants, etc., would usually have additional categories.

Conceptually, the categories are end-use categories. Generally, these are defined by the point where the energy in the form purchased is converted to accomplish an intended function, such as electric energy being converted to “fan” energy or “light” energy, or fuel energy being converted to a form usable for space heat. If the categories are subdivided into more components, the audit is not necessarily more accurate (since all elements must be included regardless), but it may be more useful. Thus, a major decision in the organization of the audit is the categorization of components. For example, the fuel energy that is converted in the boiler to hot water for building heat could be categorized as “heat” energy. A more useful option might be to subdivide this further into categories of space heat and ventilation. Another and still more useful step might subdivide the energy (in, say, a reheat or dual-stream system) into transmission net heat, ventilation heat, and control heat. The concept is that the more finely the pie is sliced, the more information will be available to make constructive use of the audit.

Categories grouped for audit

For illustrative purposes, a grouping of categories and a brief discussion of the methods of developing the audit quantities follows. Assume that for the example building, electricity is purchased to serve the lighting and power drive (mechanical) requirements, refrigeration is vapor compression, and utility natural gas is purchased to satisfy all end-use thermal needs.

- *Lighting*—All of the light fixtures in the building must be inventoried in a systematic and logical manner and categorized by switching circuits. Then, through thorough consultation with the building management group, the operators, and the occupants, a use schedule for each day of the week, with appropriate seasonal variations, is developed. The use schedule in some format relates the hours that the lights are on in a given period. If multiple switching circuits are combined, the schedule can use the technique of decimal portions of the whole. In any event, for each group of lighting, the energy consumed is simply the product of light (plus ballast) wattage and the hours of use, expressed in kilowatt-hours. As for all use categories, this is done on a monthly basis, then summed up for the year. The purpose of the monthly calculation is to permit comparison of the final totals with the historical profiles as discussed above.

- *Fans*—These could be subdivided into more than one subcategory, such as supply fans, return fans, exhaust fans, etc. The inventory technique and energy use development are somewhat similar to those for lighting. The first step is to inventory each fan, identifying its use and motor size. For better accuracy, the motor current and voltage can be measured with relatively simple and inexpensive instruments so that the actual operating power (kilowatts) can be determined from a motor characteristic curve. As with the lighting, the operating hours for each fan are then determined and the multiplication performed to obtain the fan energy consumed for the period.

- *Heating and cooling auxiliaries*—Again, at the analyst’s option there are several possible categorizations. One such grouping (depending on the relevance to the specific sys-

tem) might be chilled water pumps, condenser water pumps, cooling towers, heating water pumps, and boiler fans (forced or induced draft). Although the previous categories of lighting and fans account for the majority of energy consumption in most modern commercial and institutional buildings, the auxiliary category introduces the need for more complex calculations. These will be considered individually.

Pumps are of two types

Chilled water pumps and heating water pumps generally fall into one of two types. If they circulate a system with either wild flow loads or three-way valve loads, they will generally run continuously whenever the system is in operation. In this case, the pumps are inventoried in the same manner as the fans to determine their kilowatt power requirements, which are then multiplied by monthly hours of system operation to determine monthly energy consumption.

If the pumps circulate a system with throttling valve load control, the flow rate can be assumed to vary linearly with load; then by simply linearizing the part load performance of the pump-motor assembly, one can obtain the energy consumption from the product of the full load power requirement, the hours of operation, and the load factor for those hours.

In the calculations prior to this one, the energy determinations could be made by simply multiplying load sizes by their hours of operation. Their accuracy could not be improved by any other method, no matter how much more sophisticated than a pen, pad, and knowledge of basic arithmetic. The necessary introduction of the load factor multiplier at this point, however, could conceivably be accomplished with a great deal more precision by using appropriate computer techniques. It is important to realize that the use of the computer will simply improve the accuracy of the results. But in many cases, *skilled analysts* can achieve a perfectly acceptable degree of accuracy with manual calculations.

Condenser water pumps are generally if not always arranged for constant flow when operating. Thus, the monthly energy consumption

is simply the measured kilowatt power requirement for the pump or pumps times the hours of operation. Since the pumps are interlocked with the refrigeration unit or units, their operating hours are the same as the refrigeration apparatus. Understanding the piping, interlock system, and operating procedures is important since it has been found that the majority of systems with multiple refrigeration machines utilize a common condenser water circuit. Thus, even though there may be, say, three chillers and three pumps, if it is a common circuit all the pumps may run even when only one chiller is required. It may be, however, that the operators manually valve out the condensers of the "off" chillers and thereby stage the condenser water pumps. Thus the necessity of understanding all three elements—piping configuration, interlock system, and method of operation!

Several methods can be used

The hours of operation can be determined by any of several methods. The least sophisticated and least accurate is a statistical estimate adjusted by the historical energy record for the unit; the most accurate is a thorough mathematical load analysis for the refrigeration system, one that reveals the need for specific amounts of cooling for a given number of hours each month or year. The latter is an extremely time consuming and complex calculation, usually not attempted without the use of a computer.

The energy consumption of the cooling tower fan(s), also a product of the actual kilowatt consumption times the hours of operation, is determined in the same way that the pump energy was calculated. The thorough or more analytical calculation approach, however, is a bit more complex because of the cycling of the fan, not only on low building loads but also when the wet bulb temperature is lower. Again, it is imperative that the auditor or analyst understand the manner in which the cooling tower fans are controlled and/or operated.

Other auxiliaries are related to the heating system and include burners, induced or forced draft fans, condensate pumps, and boiler

room ventilating fans. Although these are usually a relatively small component of use, they should not be neglected. It is often the smaller motor loads that are found to run for many hours that are significant contributors to the energy consumption and offer the greatest opportunity for conservation. An understanding of the control methods for these auxiliaries will provide the key to calculating the hours of operation. The monthly and annual consumptions are then calculated in much the same manner as the cooling auxiliaries.

- *Refrigeration compressor energy*—In many buildings, the air conditioning refrigeration compressor(s) is the largest individual motor or power component. If the building is relatively simple in its configuration or the environmental system operates in a “heat-cool-off” mode, the refrigeration compressor energy can be determined within a reasonable degree of accuracy by a simple cooling degree-day calculation. In more complex systems, somewhat more complex calculations may be mandated. In such cases, the most rudimentary approach is to break the time-integrated cooling loads down into the components of: transmission and solar; internal; ventilation; and reheat or other false load.

In this manner, by dividing the operating hours into selected divisions of occupancy modes and weather-related “bins,” one can make a reasonably accurate approximation. If a higher degree of accuracy is desired, a digital computer program that includes these parameters in all relevant details can be employed.

- *“Other” electrical energy*—This category, in a given building, could include components such as elevators, conveyors, door openers, office machines, computers, and any other loads connected to the electrical system. For each, the energy consumption is estimated by the simple (but sometimes tedious) process of multiplying the hours of use by the power requirement (kW or watts) and the use load factor (equal to or less than unity).

Thermal energy components

Thermal energy in a building like the example described has fewer categories to be con-

sidered than electrical energy. It could, however, be a much more significant cost item than electrical energy. The major components are space heat, domestic hot water, and “other.”

- *Space heat*—The method of determining the thermal or fuel energy required for space heat is similar to that used for calculating refrigeration drive energy. If the building has a simple heat-cool-off system, with small internal loads, a simple degree-day calculation utilizing a fuel conversion efficiency based on a series of relatively simple combustion efficiency tests will provide a reasonably accurate answer. If, however, there are appreciable internal loads, and/or the environmental system consists of simultaneous heating and cooling for control, more rigorous calculations are mandated.

These calculations, like those for cooling, are best segmented into components of transmission, ventilation, and control heat and then performed considering operating hours, occupancy schedules, and weather bins. Also, like the refrigeration energy determination, manual calculations including the necessary algorithms can provide acceptably accurate results, but there is reason to rely on computer calculations if that methodology is available.

- *Domestic hot water*—Domestic hot water consumption in buildings such as the example building is usually quite small. The monthly and annual use can be determined statistically by using consumption rates from the National Plumbing Code or ASHRAE data and adding the piping system losses (which often exceed the consumption energy). Improved accuracy can be achieved if the hot water is metered, but this is seldom available for an exploratory audit.

- *“Other” heat*—Consumption of fuel or thermal energy for cooking, deicing, snow melting, or any other use should be investigated and added into this category. The important thing is that no use or consumption category be left unidentified. For example, in a large steam system it is quite common to vent the return system. This “venting” consumption must be recognized; it could represent a significant use.

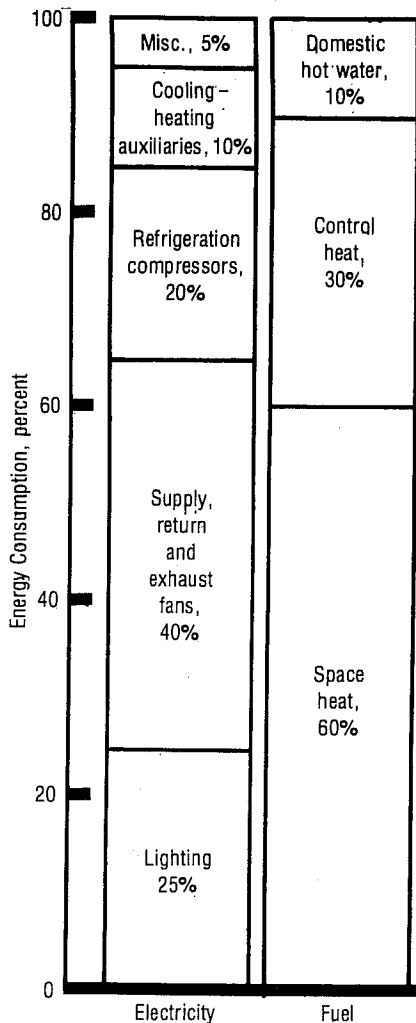


Fig. 31-3. Annual energy consumption in electric and thermal forms for example building.

The accompanying bar charts in Fig. 31-3 show the results of the use category phase of a typical audit of a building of the type considered.

Various uses of audits

The mathematically developed monthly consumption values are plotted on an energy profile diagram. The preferred method is to superimpose the calculated profile plot on the historical. This provides an easy method of determining the accuracy of the calculated values. In most cases, the initial attempt at this comparison will reveal a significant deviation between the two graphs. Generally (particu-

larly with electricity), it can be assumed that the metered values are correct (if proper care was exercised in developing the historical profile) and that any deviation is a result of inaccuracies in the calculated values. The nature of the deviations, however, will almost assuredly point to the source of the error. For example, if the metered profile for electrical energy indicates a considerably higher annual consumption but the monthly deviation is constant (same shape curve but higher), the analyst should look for an underestimate in some nonweather-related component such as lighting. It may be that in establishing the operating hours-percent usage matrix, the use by night custodial personnel was overlooked.

If considerably more fuel and electrical energy were used in the spring and fall and the system has electric refrigeration and fuel-fired reheat, the deviation would point to an error in estimating or calculating the reheat (or control energy) input from both sources.

Thus, after analyzing the extent and the nature of the deviations, the analyst recalculates the use components in subsequent "tries" until an acceptable match is obtained. Generally, a deviation on the order of 5 percent is the target although it is not uncommon to accomplish a match within 2 to 3 percent deviation. Once the match is deemed acceptable the mathematical model for the energy consumption can be considered valid.

Bar charts such as those illustrated in Fig. 31-3 are then developed for the final model. This could be considered the final step in the exploratory audit.

There are numerous uses for an audit, but the commonest are to serve as the basis for energy management feasibility considerations, as a format in setting future energy budgets, and as base consumption data against which future use patterns can be compared.

Referring to the bar charts in Fig. 31-3, the following use percentages are illustrated:

- *Electricity*—Lighting, 25 percent; supply, return, and exhaust fans, 40 percent; refrigeration compressors, 20 percent; cooling and heating auxiliaries, 10 percent; and miscellaneous, 5 percent.
- *Fuel*—Space heating and ventilation, 60

percent; control heat, 30 percent; and domestic hot water, 10 percent.

Study determines feasibility

A comparative study of the use percentages leads quickly into the feasibility considerations. For example, the fans are seen to represent the largest single component of electrical consumption. It could readily be determined how many hours per year the fans could be cycled off if an unoccupied control mode were added. The calculation would be redone with the new operating hours, and the results of that singular effort specifically identified. Similar reasoning is applied to each use component, the analysis done, and the results obtained. The new energy use quantities thus calculated for each feasibility option are extended to a monetary savings by application of the appropriate rates; and by comparison to the estimated implementation cost *for that respective option*, the feasibility is determined.

The value of this approach as the introductory effort in an energy management program cannot be overemphasized. It is the only approach that will provide a quantitative, confirmable, relatively accurate method for determining the value of investing capital for the purpose of reducing energy costs.

Consider other "action" steps

The subsequent "action" steps of the energy management program include retrofit, operation, and monitoring. Following the retrofit work and/or appropriate changes in operating techniques (for both the building use scheduling and the energy systems), the success of the efforts is determined through various techniques of monitoring. One such technique, requiring little effort and suggested as a minimum, is to plot the base consumption profile (historical) and superimpose it on the new anticipated profile obtained from the mathematical model containing the final retrofit and operation modifications. Then, each month the energy invoices are analyzed, normalized to the days in the billing period, and compared to the "budget" on the graph. If the

budget is not being met (i.e., actual use exceeds the budget) the cause should be determined and appropriate changes or corrections made.

Management audit is next step

The next step of sophistication is to extend the monitoring into the format of the ongoing or management audit. This consists of a periodic (usually monthly) component use development analysis of the energy consumption. With proper planning, this can be accomplished quite simply. Several types of submetering are available that can be used to provide the data for a reasonably accurate monthly audit. Examples of such devices are volumetric displacement water meters in domestic hot water makeup lines and in steam condensate systems, lapsed time clocks on constant power electrical loads such as many fan and pump motors, and electric (kilowatt-hour) meters on variable electrical loads. Then, when the actual usage deviates from the budgeted quantities, these continuing or management audits will tend to pinpoint the sources of such deviations.

The energy audit and budget, as well as the entire concept of energy use management, represent a new and unproven field of endeavor. Although the need has been almost universally recognized, the implementation techniques have been misdirected, misused, and oversimplified to the point of counter-effectiveness in energy conservation. The techniques discussed herein are direct and have been effectively employed commercially for a number of years.

Earlier it was emphasized that these audits can be done with reasonable accuracy using manual calculation methods. Computerized techniques for the exploratory audit analyses, operations, and management auditing are strongly recommended when they are available, however. Considered in this way, both the value and the proper use of the computer as it applies to energy conservation efforts can be kept in perspective.