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THE ROLE OF THE ENERGY AUDIT IN REDUCING BUILDING ENERGY CONSUMPTION

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Abstract

The application of the energy audit process to the reduction of energy consumption in buildings is described. A methodology for selecting from an inventory of buildings those buildings which are candidates for a detailed energy audit is presented, and the analysis of energy consumption and cost savings resulting from implementation of energy conservation opportunities (ECO's) is detailed. A practical payback period formula is presented which includes escalating energy costs. The audit and analysis procedures are illustrated by two case studies.

1. INTRODUCTION

The energy audit is a component of the broader concept of energy management which is recognized as involving the following five major elements.

(1) The commitment of management
(2) The availability of a reliable energy information data base
(3) The energy audit
(4) Identification and analysis of energy conservation opportunities (ECO's) from the audit
(5) Implementation, monitoring, evaluation

The present paper discusses the application of the energy audit process to reducing energy consumption in buildings.

2. THE BILLING AUDIT

The first phase of the audit process involves analysis of historical energy consumption and energy costs for a recent period of at least one year and preferably two or three years. The source of these data is from utility bills. It may appear at first glance to be a trivial activity, but experience has shown that many consumers do not understand all of the information contained on utility bills.

It is important to express energy consumption and cost data on a calendar month basis. Billing periods frequently do not correspond to calendar month periods. A linear interpolation procedure can be used to obtain calendar month consumption as follows. Suppose calendar month n involves portions of two billing periods designated as period 1 and period 2, respectively. The energy consumption for month n is

$$E_n = n_1\left(\frac{E_1}{N_1}\right) + n_2\left(\frac{E_2}{N_2}\right) \qquad (1)$$

where E_n = energy consumption for month n
E_1, E_2 = energy consumption for billing periods 1 and 2 respectively
N_1, N_2 = number of days in billing periods 1 and 2 respectively

n_1 = number of days of month n falling in billing period 1

n_2 = number of days of month n falling in billing period 2

After expressing consumption on a calendar month basis according Eqn. (1), the data should be plotted in bar graph or histogram form. The advantage of plotting rather than tabulating the data is that trends, anomolies, and seasonal variations are readily apparent by inspection.

An important parameter to be obtained from energy consumption data is the building energy utilization index (BEUI). A frequently used BEUI is the ratio of total annual energy consumption to total square feet of the building expressed as BTU/ft^2/year. This definition of BEUI is useful in comparing the energy utilization of buildings. In comparing buildings that have similar use patterns such as schools, the BEUI gives an indication of those buildings that should be considered for a detailed field audit.

A sometimes overlooked piece of information on utility bills is the demand charge. Although reduction in demand may not reduce energy consumption, it will always lead to a reduction in cost. If a significant portion of the total utility bill is due to demand charge, the user should analyze the use schedule of energy consuming devices in the facility. The method used by the utility for assessing demand charges should be thoroughly understood to take advantage of demand charge reduction by staggering the loading of energy consuming devices.

In addition to the information contained on utility bills, the user should also be thoroughly familiar with the rate structure including such features as the base charge, relation between level of consumption and unit charge, the demand charge formula, and the fuel adjustment formula where applicable.

3. SELECTION OF BUILDINGS FOR FIELD AUDIT

Conducting a comprehensive field audit of a building is a time consuming activity, and for organizations that have a large inventory of buildings such as governmental agencies, school systems, military bases, industrial complexes, etc., a rational procedure is needed to prioritize buildings to be considered for a field audit. The use of a computer may be justified to analyze the historical energy use of a large inventory of buildings and rank order the BEUI of the several buildings. Priorities may then be established for various ranges of BEUI.

When initiating a building energy conservation program, it is important to conduct the first audits on those buildings with the greatest potential for energy conservation. Early successes in a new energy conservation program are important to maintain the momentum of the program. Thus, it is desirable to establish a data base giving rank order of the BEUI of each building in the building inventory, and the selection of those buildings with the largest value of BEUI for a field audit is essential for moving into this phase of the energy management program.

4. THE FIELD AUDIT

The specific goals of the field audit are:

(1) To allocate building energy use by function and/or physical location within the building,
(2) To observe the operation of energy consuming devices within the building,
(3) To gather information on the general physical characteristics of the building as well as its energy distribution systems,
(4) To identify and analyze potential energy conservation opportunities (ECO's).

The major categories of building energy use by function are:

(1) Lighting,
(2) Air handling,
(3) Space heating,
(4) Space cooling,
(5) Hot water,
(6) Equipment not related to space conditioning,
(7) Food preparation and storage,
(8) Special facilities such as a laundry or computing facility.

An effort should be made to allocate the total energy consumption in the building by functional end use as accurately as possible and to present the results in a pie chart graphical form. The purpose of such an allocation of energy end use is to determine the rank order of end uses by function so that the energy conservation effort can be focused on those areas of potentially greatest energy savings.

The ideal situation for allocating energy consumption by end use would be to have an energy meter on each energy consuming device in the building. This situation is termed submetering and the normal situation encountered in buildings is that very little submetering exists. Before the audit is conducted, an accurate determination of existing submetering should be made, and full advantage should be taken of any available data or data that can be obtained during the field audit from submetering.

In the absence of submetering, an estimate of energy consumption by each energy consuming device in the building can be made if the following data are available:

(1) The maximum power rating of the device,
(2) The average fraction of full load at which the device operates,
(3) The duty cycle expressed as operating hours per day or week.

The higher the reliability of the data obtained the higher will be the reliability of the functional allocation of energy use. While the maximum power rating of a device can generally be obtained from an attached name plate, the average fraction of full load use is difficult to obtain accurately and requires substantial experience and good judgment on the part of the energy auditor. In some instances for large energy consuming devices, it may be desirable to measure directly the energy consumption rate.

The allocation of energy consumption to lighting should be made first because the inventory of installed lighting capacity can be readily obtained by counting fixtures. The wattage of each fixture is also generally available by inspection. The duty cycle for lighting is relatively easily established based on normal operating schedules of the facility. However, one must be alert to the possible use of lighting outside normal working hours for such activities as custodial services or multi-shift/overtime working schedules in portions of the building.

After allocating lighting energy consumption, the energy required by the air handling units should be determined from the performance curves of the fans/blowers and the duty cycles of the equipment. It may be necessary to measure air flows from the air handlers with a vane anemometer or pitot tube. An accurate determination of air flows is important because of the often encountered situation of excess make up air in a building. Excess ventilation air results in additional energy consumption by the blower as well as energy required to heat, cool, and control humidity.

The energy consumption of equipment not related to space conditioning should be determined next. This includes equipment used in food preparation and storage, energy used in computing facilities, energy used in generating domestic hot water, and energy used in special facilities such as a laundry that are found in some commercial facilities. The energy consumption of these devices can be estimated from the power rating, the loading factor where applicable, and the duty cycles. Obtaining an accurate estimate of duty cycles is difficult if one depends solely on the perception of building operating personnel. Many energy consuming devices such as a gas or electric water heater operate at full load when on. In such cases it may be possible to obtain a reasonable estimate of the duty cycle by measuring the fraction of time the device is operating either by visual observation (e.g., for a gas water heater) or by an electrical measurement such as a clamp-on ammeter (e.g., for an electric water heater).

The final categories of functional energy use are space conditioning, i.e., heating and cooling. These are the most difficult estimates to make because of the diversity and complexity of HVAC systems. By estimating the relatively easier categories enumerated above, the estimate of space conditioning energy use may be obtained as the difference between total energy use from billing data and the sum of all functional end uses excluding space conditioning.

5. IDENTIFICATION AND ANALYSIS OF ECO'S

The "bottom line" of the field audit is the identification and analysis of potential energy conservation opportunities (ECO's). It is convenient to place ECO's into two broad categories,

(1) Procedural ECO's that can be implemented by procedural (i.e., operating) changes with little or no capital investment,
(2) Capital ECO's that can be implemented only by making a capital investment.

Potential ECO's in both categories should be analyzed in quantifiable terms to the fullest extent possible. This is particularly important for capital ECO's since it is unreasonable to expect a commitment of capital to be made to energy conservation unless a quantified analysis of the anticipated financial benefit can be made.

It is suggested that a consistent, simple format be followed in the analysis of each ECO consisting of the following elements.

(1) Description of current practice observed from the field audit
(2) Recommended action to be taken
(3) Analysis of anticipated annual energy consumption and cost savings by implementing recommended action.
(4) Financial analysis of level of capital investment which can be made for a specified payback period at a specified interest rate and a specified future escalation of energy costs.

These procedures will be illustrated by two case studies described in Section 7 of the paper.

6. FINANCIAL ANALYSIS OF ECO'S

The basis of a financial analysis of an ECO is the determination of the annual energy savings which may be considered as equivalent to an annual cash flow. The future value of such cash flows compounded over n years is*

$$F = (E)(S_0)(1 + r)^n \sum_{i=1}^{n} \left[\frac{1 + e}{1 + e}\right]^i \qquad (2)$$

where F = future value
E = annual energy consumption savings
S_0 = unit cost of energy at beginning of year 1
r = annual interest rate
e = annual energy cost escalation rate
n = number of years

The level of capital investment which would compound into the future value given by Eqn. (2) after n years is

$$F = P(1 + r)^n \qquad (3)$$

where F = future value
P = present value (or level of capital investment)

Equations (2) and (3) may be combined and reduced to the following closed form expression after some algebraic manipulations involving the binomial theorem.

$$n = -\frac{\ln\left[1 - \frac{(P)(R)}{(E)(S_0)}\right]}{\ln[1 + R]} \qquad e \neq r \qquad (4a)$$

$$n = \frac{P}{(E)(S_0)} \qquad e = r \qquad (4b)$$

where $R = \frac{r - e}{1 + e}$ is an effective interest rate including both the annual interest rate and the fuel cost escalation rate.

7. ECO CASE STUDIES

The following two ECO's are based on field audits conducted by the authors and are presented in the format described in Section 5.

7.1 ECO CASE STUDY NO. 1

7.1.1 Lighting Requirements in a Hotel Complex

Current practice. Replacement of lamps in the facility is carried out without regard to the task illumination requirements of the particular location. As a result many areas

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*"The Influence of Energy Cost Escalation on Payback Analysis of Energy Cost Savings Opportunities," F. W. Symonds and W. T. Snyder. To be published in Energy Engineering.

of the complex are over illuminated. Furthermore, much of the commercial area is fully illuminated 24 hours per day. Adequate display of merchandise can be achieved with less than continuous, maximum level of illumination.

Recommended action. Burned out lights should be replaced with the appropriate wattage to avoid upward escalation of lamp sizes resulting in excessive illumination. Lighting in the commercial area should be reduced to the level necessary for adequate display of the merchandise during non working hours.

Anticipated energy savings. The field audit analysis of electricity use by function indicated that the monthly consumption for lighting is approximately 150,000 KWH per month. From extensive measurements of illumination levels made during the field audit, it is estimated that a 10% reduction in electricity consumption by lighting is possible. In addition to the monthly energy reduction of 15,000 KWH attributable directly to reduction of lighting levels, additional savings will result due to reduction of space conditioning energy requirements. During the cooling season, the reduction in lighting energy will reduce the load on the central chilled water system. During the heating season, the contribution to space heating from reduced lighting will have to be compensated for by the central heating system, a gas fired boiler. Thus, a net reduction in energy costs will occur due to the significantly lower cost of gas than electricity.

(1) Reduced lighting

$$15{,}000\ \frac{\text{KWH}}{\text{mo}} \times 12\ \frac{\text{mo}}{\text{yr}} = 180{,}000\ \frac{\text{KWH}}{\text{yr}}$$

(2) Reduced load on water chiller
Assume an EER (Btu/hr per watt) of 7 and a cooling season of 5 months.

$$15{,}000\ \frac{\text{KWH}}{\text{mo}} \times 3412\ \frac{\text{Btu}}{\text{kwh}} \times \frac{1\ \text{W}}{7\ \text{BTU/hr}} \times \frac{1\ \text{KW}}{1000\ \text{W}} \times \frac{5\ \text{mo}}{\text{yr}} = 36{,}560\ \frac{\text{KWH}}{\text{yr}}$$

(3) Substitution of gas for electricity**
Assume a boiler efficiency of 75% and a heating season of 5 months. The increased energy requirement (negative savings) is

$$15{,}000\ \frac{\text{KWH}}{\text{mo}} \times \left(\frac{1}{0.75} - 1\right) \times 5\ \text{mo} = -\ 25{,}000\ \frac{\text{KWH}}{\text{yr}}$$

Net annual energy savings $191{,}560\ \frac{\text{KWH}}{\text{yr}}$

Anticipated cost savings.

(1) Reduced lighting

$$180{,}000\ \frac{\text{KWH}}{\text{yr}} \times \$0.023/\text{KWH} = \$4{,}140/\text{yr}$$

(2) Reduced load on water chiller

$$36{,}560\ \frac{\text{KWH}}{\text{yr}} \times \$0.023/\text{KWH} = \$\ 841/\text{yr}$$

(3) Substitution of gas for electricity
cost of electricity = \$0.023/KWH
cost of gas = \$2.10/10^6 BTU = \$0.007/KWH

$$15{,}000\ \frac{\text{KWH}}{\text{mo}} \times 5\ \text{mo} \times \left[\$0.023 - \frac{\$0.007}{0.75}\right] = \$1{,}025/\text{yr}$$

Net annual cost savings \$6,006/yr

This is a procedural ECO with no capital investment required. Some labor will be required initially to bring the facility into compliance with the regulations. After the initial effort, however, proper supervision of lamp replacement is all that is required to save \$6,006 annually.

7.2 ECO CASE STUDY NO. 2

7.2.1 Reduction of Outside Ventilation

Current practice. The facility has seven primary air handling units with a combined capacity of 59,680 ft^3/min. The air handlers are supposed to operate with 35% outside air

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**This calculation considers only energy purchased by the user. Assuming electricity is generated by a fossil powered plant with a 40% efficiency gives a gross energy savings of

$$15{,}000\ \frac{\text{KWH}}{\text{mo}} \times \left(\frac{1}{0.4} - \frac{1}{0.75}\right) \times 5 = 87{,}500\ \frac{\text{KWH}}{\text{yr}}$$

and 65% return air. It was observed during the audit that the return air dampers were locked shut and thus the seven air handlers are operating with 100% outside air. This results in an excessive energy requirement since the outside air must undergo a greater temperature change for both the cooling and heating seasons than the return air.

Recommended action. The return air dampers should be adjusted to allow 65% return air to pass through the air handlers.

Anticipated energy savings. The amount of return air that would pass through the air handlers if the return air dampers were adjusted properly is (0.65)(59,680) = 38,792 ft^3/min. This amount of air would have to undergo a smaller temperature change when passing through the heating or cooling coil downstream of the air handler than that required for the outside air. Assume a 5 month heating season and a 5 month cooling season. Assume the temperature change of the outside air when passing through the heating or cooling coil to be 25°F for the heating season and 15°F for the cooling season.

(1) Heating season energy savings
Assume a duty cycle of 24 hrs/day,
7 days/week

$$\begin{aligned}
&38{,}792\ \frac{\text{ft}^3}{\text{min}} \times 0.079\ \frac{\text{lb}}{\text{ft}^3} \times \\
&0.24\ \frac{\text{Btu}}{\text{lb}\ {}^\circ\text{F}} \times 25^\circ\text{F} \times \\
&728\ \frac{\text{hrs}}{\text{mo}} \times 60\ \frac{\text{min}}{\text{hr}} \times \\
&5\ \text{mo} = 4{,}016 \times 10^6\ \text{Btu}
\end{aligned}$$

(2) Cooling season energy savings
Assume a duty cycle of 16 hrs/day,
5 days/week

$$\begin{aligned}
&38{,}792\ \frac{\text{ft}^3}{\text{min}} \times 0.072\ \frac{\text{lb}}{\text{ft}^3} \times \\
&0.24\ \frac{\text{Btu}}{\text{lb}\ {}^\circ\text{F}} \times 15^\circ\text{F} \times \\
&347\ \frac{\text{hrs}}{\text{mo}} \times 60\ \frac{\text{min}}{\text{hr}} \times \\
&5\ \text{mo} = 1{,}047 \times 10^6\ \text{Btu}
\end{aligned}$$

$$\text{Total annual energy savings} = 5{,}063 \times 10^6\ \frac{\text{Btu}}{\text{yr}}$$

Anticipated cost savings. For the heating season, the energy supplied to the heating coil is utility steam at a cost of $4.53/$10^6$ Btu. For the cooling season the cooling coil is supplied with chilled water produced by an electrically driven refrigeration system with an assumed EER (Btu/WH) of 7 and a cost of electricity of $0.023/KWH. The annual cost savings is

$$\begin{aligned}
&4{,}016 \times 10^6\ \text{Btu} \times \frac{\$4.53}{10^6\ \text{Btu}} + \\
&1{,}047 \times 10^6\ \text{Btu} \times \frac{1\ \text{WH}}{7\ \text{Btu}} \times \\
&\frac{1\ \text{KWH}}{1{,}000\ \text{WH}} \times \frac{\$0.023}{\text{KWH}} = \$21{,}632\ \frac{\text{Btu}}{\text{yr}}
\end{aligned}$$

This is a procedural ECO with no capital investment required. Thus, by operating the return air dampers properly, an annual cost savings of $21,632 will result.