ENERGY AUDIT FOR BUILDINGS

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1. INTRODUCTION

The energy audit in a building is a feasibility study. For it not only serves to identify energy use among the various services and to identify opportunities for energy conservation [1], but it is also a crucial first step in establishing an energy management programme. The audit will produce the data on which such a programme is based. The study should reveal to the owner, manager, or management team of the building the options available for reducing energy waste, the costs involved, and the benefits achievable from implementing those energy-conserving opportunities (ECOs).

The energy management programme is a systematic on-going strategy for controlling a building's energy consumption pattern. It is to reduce waste of energy and money to the minimum permitted by the climate the building is located, its functions, occupancy schedules, and other factors. It establishes and maintains an efficient balance between a building's annual functional energy requirements and its annual actual energy consumption.

2. STAGES IN ENERGY PROGRAMME

The energy audit may range from a simple walk-through survey at one extreme to one that may span several phases. These phases include a simple walk-through survey, followed by monitoring of energy use in the building services, and then model analysis using computer simulation of building operation. The complexity of the audit is therefore directly related to the stages or degree of sophistication of the energy management programme and the cost of the audit exercise.

The first stage is to reduce energy use in areas where energy is wasted and reductions will not cause disruptions to the various functions. The level of service must not be compromised by the reduction in energy consumed. It begins with a detailed, step-by-step analysis of the building's energy use factors and costs, such as insulation values, occupancy schedules, chiller efficiencies, lighting levels, and records of utility and fuel expenditures. It includes the identification of specific ECOs, along with the cost-effective benefits of each one. The completed study would provide the building owner with a thorough and detailed basis for deciding which ECOs to implement, the magnitude of savings to be expected, and the energy conservation goals to be established and achieved in the energy management programme. However, the ECOs may yield modest gains.

The second stage is to improve efficiency of energy conversion equipment and to reduce energy use by proper operations and maintenance. For this reason, it is necessary to reduce the number of operating machines and operating hours according to the demands of the load, and fully optimize equipment operations. Hence the ECOs would include the following:

- Building equipment operation,
- Building envelope,
- Air-conditioning and mechanical ventilation equipment and systems,
- Lighting systems,
- Power systems, and
- Miscellaneous services.

The first two stages can be can be implemented without remodelling buildings and existing facilities.

The third stage would require changes to the underlying functions of buildings by remodelling, rebuilding, or introducing further control upgrades to the building. This requires some investment.

The last stage is to carry out large-scale energy reducing measures when existing facilities have past their useful life, or require extensive repairs or replacement because of obsolescence. In this case higher energy savings may be achieved. For these last two stages, the audit may be more extensive in order to identify more ECOs for evaluation, but at an increased need for heavier capital expenditure to realize these opportunities.

3. SURVEYING THE BUILDING

A walk-through survey of a building may reveal several ECOs to the experienced eye of the auditor. The survey could be divided into three parts.

3.1 Preliminary survey

Prior to the walk-through survey, the auditor may need to know the building and the way it is used. The information can be obtained from:

- architectural blueprints,
- air-conditioning blueprints,
- electrical lighting and power blueprints,
- utility bills and operation logs for the year preceding the audit,
- air-conditioning manuals and system data, and
- building and plant operation schedules.

3.2 Walk-through

Thus having familiarized with the building, the walk-through process could be relatively straightforward if the blueprints and other preliminary information available describes the building and its operation accurately. The process could begin with a walk around the building to study the building envelope. Building features such as building wall colour, external sun-shading devices, window screens and tint, and so on are noted as possible ECOs.

If a model analysis is included in the study, the building must be divided into zones of analysis. The survey inside the building would include confirmation that the air-conditioning system is as indicated on plans. Additions and alterations would be noted. The type and condition of the windows, effectiveness of window seals, typical lighting and power requirements, occupancy and space usage are noted. These information could be compared against the recommendations in the relevant Codes of Practices such as CP 13:1999 [2] and CP 24:1999 [3].

System and plant data could be obtained by a visit to the mechanical rooms and plant room. Nameplate data could be compared against those in the building's documents, and spot readings of the current indicating panels for pumps and chillers recorded for estimating the load on the system.

3.3 Operator's input

The auditor may discuss with the building maintenance staff further on the operating schedules and seek clarification on any unusual pattern in the trend of the utility bills. Unusual patterns such as sudden increase or decrease in utility bills could be caused by changes in occupancy in the building, or change in use by existing tenants. It is not uncommon for tenants to expand their computing operations that may increase the energy use significantly.

3.4 Report

At this stage, ECOs could be found in measures such as:

- Reduce system operating hours,
- Adjust space temperature and humidity,
- Reduce building envelope gain,
- Adjust space ventilation rates and building exfiltration,
- Review system air and water distribution,

- Adjust chiller water temperatures, and
- Review chiller operations.

The benefit from adopting each ECO should be compared against cost of implementation. Caution should be exercised in the cost-benefit analysis given the wider range of certainty of the projections made. However, a survey at this level may be sufficient for small buildings.

4. MEASUREMENTS

The capability of the energy auditor and the scope of an audit could be extended by the use of in-place instrumentation and temporary monitoring equipment. In-place instrumentation refers to existing utility metering, air-conditioning control instrumentation and energy management systems (EMS). Such facilities have been required by legislation since 1989 and its use is recommended in the current version of CP13:1999 [2]. The use of in-place utility metering and temporary monitoring equipment in energy auditing can yield valuable information about the building systems such as:

- Energy signature and end-use consumption analysis,
- Discovery and identification of ECOs,
- Quantification of energy use and misuse,
- Establishing bounds for potential energy reduction, and
- Data acquisition for further calculation and analysis.

4.1 Existing information

Existing instrumentation such as utility meter readings, and energy billings could be used to establish energy consumption patterns for the building. The regularity of consumption pattern is an indicator that no significant change in consumption occurred prior to the audit. This can also be used to check the validity of projections based on extrapolated short-term monitored data. Utility data could be used to establish useful indices such as kWh/m^2/year to compare relative energy performance of buildings.

Air-conditioning control instrumentation such as chilled water temperature probes, water flow meters could be used to estimate cooling load demand and plant operation. For example, chilled water temperature outside the designed range may indicate that cooling coils may be operating under off-design conditions.

4.2 Short term monitoring

The building may not be equipped for monitoring energy consumption and it may be necessary to install temporary measurement devices such as instantaneous recorders (strip chart, data loggers, etc) and totalizing recorders (kWH meters) to obtain data over the period of a week for the study.

Monitored data is also useful for completing the energy model of a building for use in some building energy simulation software. For example the total building energy consumption would include energy used in the vertical transportation system and potable water pumps which are not modelled in the software.

An estimate for annual consumption is extrapolated from the typical week consumption profile. Regularity of the weekly consumption profile means that the annual consumption could be estimated with confidence and the value used to cross check with the annual energy bills.

5. MODEL ANALYSIS

Building energy consumption in simplest terms is just the product of rate of consumption of a system and the period of operation. In lighting systems, its energy consumption could be determined manually with precision as it does not interact with other consumption variables. Energy consumption of cooling systems, however, is many times more complicated as it is affected by the internal heat gain within a building as well as weather variables which varies in a complex manner over time.

Building model analysis using computers offers several improvements over manual calculations. These include:

- Precise schedule of building parameters,
- Precise determination of weather impact,
- Specification of part load performance of plant and equipment, and
- Consideration of parameter interactions such as lighting load on air-conditioning consumption.

5.1 Software

Some software such as DOE-2 [4] permit hour-by-hour calculations of building consumption for the entire 8760 hours of the year, but require thorough knowledge of the software to carry out accurate and meaningful analysis. Simplified software based on consumption analysis on characteristic days in a year such as BUNYIP [5] may also be considered. However, the improvements in computational power of the desktop PC has introduced several powerful features and user-friendly graphical interface possible in more recent versions of such software making it more accessible to the practising engineer.

5.2 Analysis

The general procedure for an analysis would be to establish a model giving an annual consumption within 10% of the measured data. This establishes the base model. The impact of ECOs on energy consumption would be compared against the base model. ECOs could be considered singly or in combinations to determine interactions between them. The results of the energy savings in each analysis should not be taken as absolute but rather taken to be relative to the base run so as to give an indication of the order of magnitude of savings. Thus those ECOs which shows significant gains would be implemented.

6. CASE STUDY OF MULTI-TENANTED OFFICE BUILDING

This is an audit on an office building of 22,300 m^2 gross area of which 16,700 m^2 is conditioned. The building air-conditioning system was served by a central chilled water plant which has a total capacity of 800 RT from two chillers (COP 5.87).

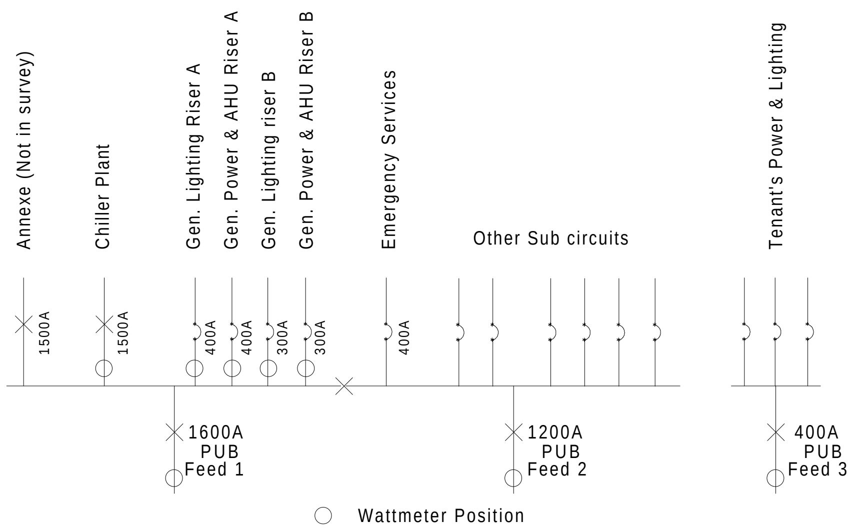

Figure 6.1 Example of wattmeter location for short term monitoring.

The main single line electrical schematic diagram shown in Figure 6.1 indicates the location of clip-on instrumentation used for whole building and end use power monitoring. Clip-on power and current transducers with dc output are used to measure the energy use in the main and selected sub-circuits. A stand-alone type data logger captured the output signal from the transducers and stores the data in the integral storage which is downloaded periodically for analysis on a micro-computer. A modem link could also be used for remote data retrieval.

A typical 24-hour consumption profile of an office building is shown in Figure 6.2. Power consumption attributed to chiller plant, lighting, general lighting and AHU fans, and other services are also shown. The energy signature help identify the operating hours of the building and also some energy conserving measures being practiced. The dip in AHU fan consumption between 1200 - 1300 h on weekdays is attributed to switching off AHUs during lunch breaks. Savings could be identified easily for graphical presentation to management. A high base load during off hours could mean that some services may be operated outside normal hours. This could be checked against the operation schedule to identify wasteful operational practices. In this instance, the base load is about 80 kW and is attributed to extensive outdoor lighting.

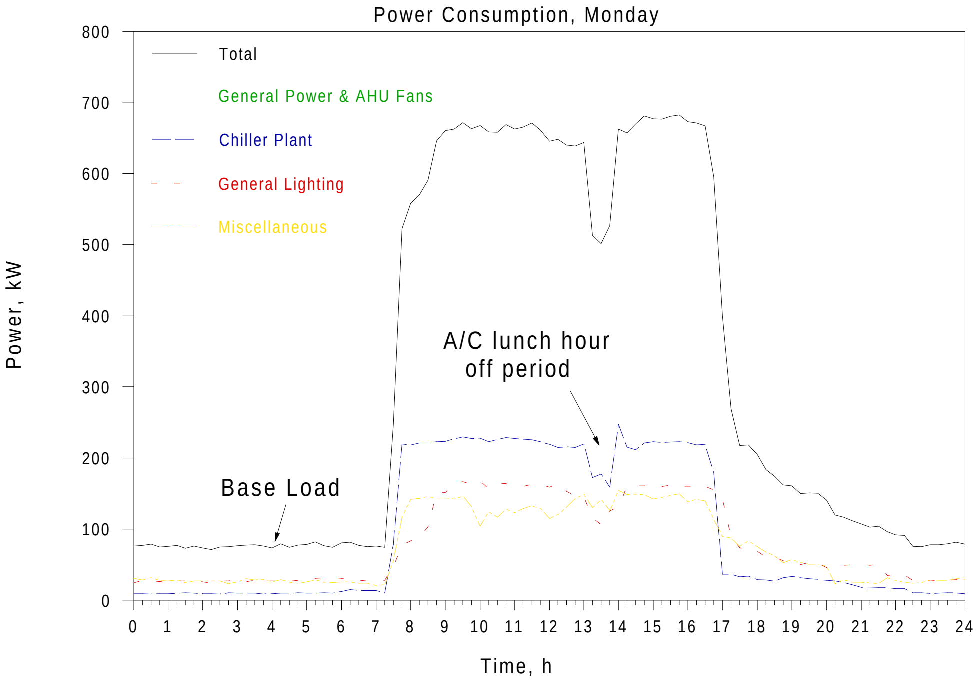

Figure 6.2 Typical weekday consumption profile of an office building

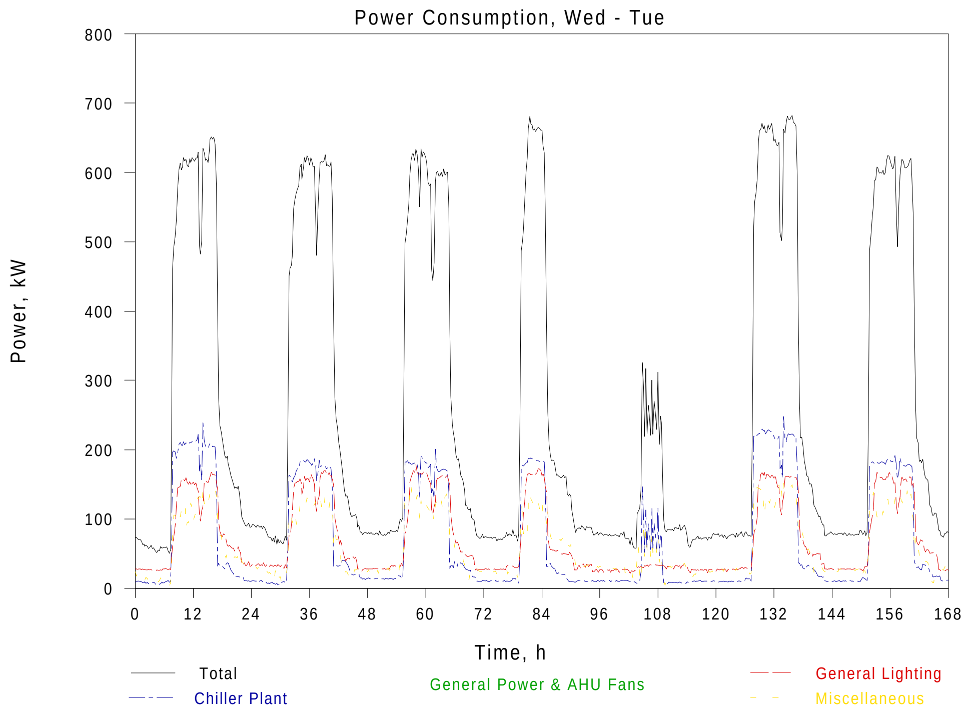

Figure 6.3 Example of weekly consumption profile of an office building.

Figure 6.3 shows a typical week consumption profile. The plot of the energy end-use by systems is shown in Figure 6.4. An upper boundary could be defined for consumption by general lighting. This would prevent overestimate of savings in selecting ECOs as each ECO is concerned with a particular parameter in building operation whereas in fact the ECO may have secondary effects on other parameters in the building operating dynamics.

The annual electricity consumption of 2037 MWh was obtained from 12 consecutive monthly records kept by the operator's manual logging of the electricity meter and confirmed by checks with the utility bills. The annual energy intensity was 122 kWh/m^2/year as opposed to the value of 142 kWh/m^2/year or the base simulation model. As the building has implemented an energy management programme, the additional ECOs that the audit could suggest was to delay the air-conditioning plant start-up by 15minutes every day to save about 45.6 MWh per annum, and to do an extensive upgrade of the fluorescent luminaires. The luminaire upgrade could save an additional 31 MWh of energy by a 5% reduction of the connected lighting energy intensity to 12 W/m^2.

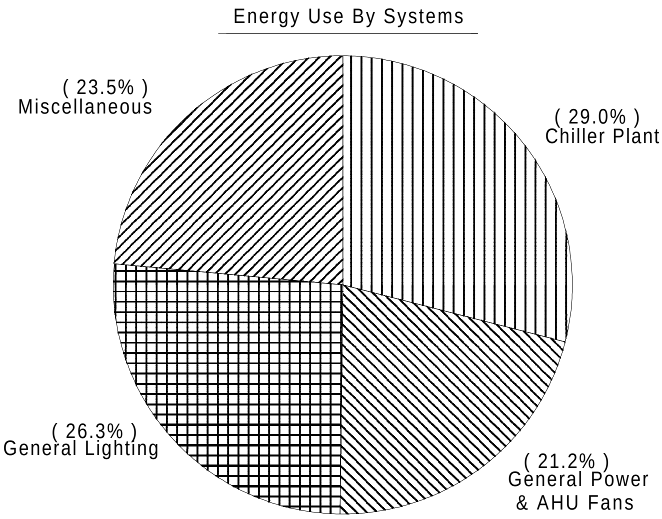

Figure 6.4 Example of energy consumption by services in an office building

7. SUMMARY

The objective of energy audit is to identify the end use of energy in a building and its ECOs; and as a feasibility study leading to implementation of an energy management programme. The audit procedure can be expanded as needed in the various phases of the energy programme, with the application of each succeeding phase yielding more information on energy use, and more opportunities for raising energy efficiency.

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