CENTRE FOR RENEWABLE ENERGY SOURCES

ENERGY AUDIT GUIDE

PART A: METHODOLOGY AND TECHNICS

COMMUNITY INITIATIVE

ADAPT

European Committee
Directorate General for Employment and Social Affairs
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The present edition constitutes part of a series of three Technical Guides published by the Centre for Renewable Energy Sources (CRES) regarding the Energy Audit procedure in buildings and in industry. The aim of these publications is to comprise a useful and practical tool for Engineers and other scientists that are going to be occupied in the field of Energy Auditing.

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1. INTRODUCTION TO ENERGY AUDITING

1.1. Use of energy general statistics in buildings and industrial facilities

Energy saving constitutes a primary measure for the protection of the environment and additionally, for the reduction of exchange efflux, which is used to purchase the polluting fossil fuels, mainly petrol. The need for energy saving is quite evident in the Greek domestic and tertiary buildings, where the use of electromechanical installations and domestic appliances is consuming 30% of the country's total energy consumption, increasing annually at a rate of 4%, from the mid-seventies. Additionally, the operation of the energy systems installed in buildings is responsible for 40% of the total CO_2 emissions to the atmosphere, a gas responsible for the creation of the greenhouse effect on our planet. As for the industrial sector, even though consumption is gradually reducing in recent years (mainly due to a decline in energy-intensive industrial sectors), its contribution to the country's total energy consumption is significant (~ 25%).

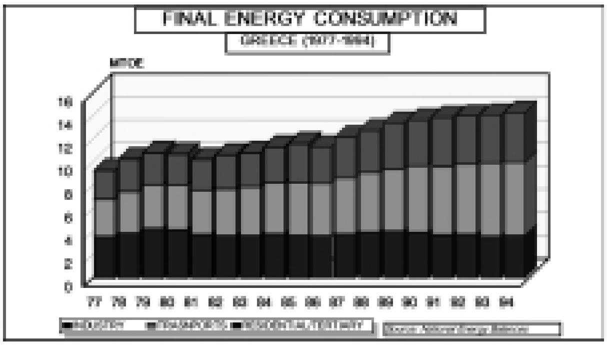

Figure 1.1. Energy consumption evolution in Greece per sector

The diachronic path of energy indexes/indicators is the result of a rapid improvement in level in our country, coupled with the usually medium quality construction/building practices on the buildings' shell and installations. These two parameters are interdependent with the lack of an integrated decretory framework of incentives and energy efficient building regulations, as well as the lack of a realistic national program on energy saving, which would be aimed at the improved construction/building quality and the sensitisation of users on energy issues.

Greece, is already committed from the early '90s, to promote such decretory, administrative and organizational measures, as well as energy efficient and environmental friendly technologies through its participation in agreements declarations and EU programmes (Buenos Aires Conference '98, EU Programmes such as SAVE, THERMIE and ALTENER, National Operational Energy Programme (O.P.E.) of the Ministry of Development in the frame of the 2nd Framework Support Programme, Action Plan of the Ministry of Environment, Landplaning and Public Service Works "ENERGY 2001", etc.) The implementation of the above agreements and programmes is expected to yield significant energy savings and entailed benefits.

1.2 Benefits of improved Energy Efficiency in buildings & industrial facilities

The implementation of Energy Efficiency (E.E.) measures in the building and industrial sectors may result to benefits at three distinct levels:

- Financial benefits which contribute to a reduction in operating costs or an increase in the profits of an organisation. These must be assessed against the cost of implementation of the E.E. measures.
- Operational benefits that assist the management of an industrial site or building improve the comfort, safety and productivity of its occupants or, otherwise, improve its general operation.
- Environmental benefits; these concern mainly the reduction of CO_2 or other «greenhouse gazes» emissions, the reduction of national energy demand and the conservation of natural resources.
- Each of the benefits is likely to be realised progressively and to have a cumulative effect. The principal benefits may become available immediately from no-cost measures, or could involve some period before a return on investment is achieved. Others may only be realised when long-term plans are implemented.

1.3 Types of energy audits (walk-through and detailed energy audits)

Depending on the level of detail on the collected information, energy audits might be distinguished into two types, the walk-through and the extended audits.

<u>Walk-through energy audits</u> assess site energy consumption and relevant costs on the basis of energy bills-invoices and a short on-site autopsy. Housekeeping or/and minimum capital investment energy saving options of direct economic return are determined and a further list of other energy saving opportunities involving often considerable capital are proposed on a cost-benefit basis.

<u>Detailed - diagnostic energy audits</u> request a more detailed recording and analysis of energy and other site data. The energy consumption is disaggregated in different end-uses (e.g. heating, cooling, different processes, lighting, etc.) and the different factors that affect that end-use are presented and analysed (e.g. production or services capacity, climatic conditions, raw material data, etc.). All the cost and benefits for the energy saving opportunities that meet the criteria and requirements of the end-energy site administration are determined. A list for potential capital-intensive energy investments requiring more detailed data acquisition and processing is also provided together with an estimation of the associated costs and benefits.

1.4. Overview of the energy audits general procedure

Energy auditing (EA) is based on the capability to perform an investigation on the energy installations as well as on the building shell. The complete procedure involves the following three stages of registration/data collection and diagnosis:

<u>1st Stage</u>: *Scheduling an Energy Audit - Collection of primary data & preliminary analysis of energy*

At this initial stage, data and information is collected related to the present/current and past energy profile, the construction and utilization of every building/unit. These data/information can be retrieved with the aid of a structured and concise questionnaire (see Annex A), which will be filled in after the first meeting between the energy auditor and the building/unit manager who has authorized the energy audit. The foundations necessary for the completion of the questionnaire are information from the Technical and Administration Managers of the building/unit as well as existing relevant data (fuel bills/invoices, technical drawings, archived studies and catalogues, recorded measurements and readings, etc.).

The preliminary analysis of all collected data should lead to the identification of the annual trend and monthly fluctuation/variation of the total energy consumption and cost of the audited building/unit, which constitutes its energy profile. Initial energy data collected, should also lead to a first approximation on energy consumption allocation in every area and sub-system of the building/unit. This is a way to express the energy balance of the building/unit. At the end of this stage, the Energy Auditor can compose/ draft an initial catalogue/list with possible energy saving actions/ activities for each building/unit, taking into account possible exemptions imposed by the owner.

***2nd Stage**: Walk-through brief Energy Audit*

During this stage, a qualitative investigation of the building shell and the electro-mechanical installations is performed, and the findings are tabulated in a specific form. This data registration coupled with instantaneous sampling measurements helps to apportion energy use and thus leads to the energy balance of the building/unit.

This procedure, coupled with the actions of the previous stage leads to a final determination of the energy savings potential, with the use of tiding-up measures and simple inexpensive measures/actions that don't need economic payback assessment through relevant energy studies. Additionally, it leads to a determination of the energy saving potential in specific areas and systems, for further examination in a following stage, by specialists/consultants or by the buildings' administration staff whenever its feasible. These potentially energy saving actions must be divided into three groups according to their energy saving potential for the particular building (high, medium, low).

***3rd Stage**: In-site thorough Energy Audit*

It involves collection (from in-site measurements) and processing of data as well as a full examination of the installed energy systems of the building/unit, which will permit to compose a thorough energy. This procedure will also permit a sound techno-economical evaluation of one or more energy-saving approaches, with medium to high investments on specific systems, after a relevant study.

The Energy audit procedure is completed with the presentation of all the energy saving proposals having the form of a summarized techno-economical report, which is composed by the Energy Auditor and presented to the Building/unit manager.

1.5 Typical tools and time frames for energy audits in various applications

Generally speaking, the typical requirements for carrying out energy audits can be summarised as:
- staff with relevant knowledge/skills
- time allocated to perform the tasks involved
- technical equipment for any measurements
- financial assistance in the above areas and for the implementation of the recommendations
- technical and operational information on buildings/plant/ services.

The time taken to perform an energy audit depends on the availability of energy data, the size of the site and the complexity of the systems. A walk-through audit might take only a few hours for a simple site for which information is readily available. On more complex sites, a week or more could be easily spent simply on analysing invoices and records.

There are no firm guidelines for deciding the time that should be spent on a site survey – it will reflect the complexity of the site, the availability of resources and the expense that can be justified. An estimate can be built-up by considering the individual elements to be examined. The largest of such sites could need the equivalent of one man-year to been comprehensively audited or, preferably, a small team to achieve a shorter audit period. One person could complete a concise audit of a small building within a day.

Time must be allowed both for those conducting an audit and those contributing in other ways. This could range from providing information to simply acting as an escort. Even with outside assistance, some in-house staff participation will always be needed. The greater the co-operation, the better the energy audits. Staff should, therefore, be encouraged to make a positive contribution.

As far as instrumentation is concerned, one should bare in mind that measurement provides the foundation for understanding the flow of energy on site. The use of metering and instrumentation will enable a quantitative analysis to be made of energy use and of the quality of service maintained. With skilled application and experience in the interpretation of results, far more knowledge is likely to be gained than from observation alone. Attention is drawn to the importance of using correctly calibrated instruments to obtain reliable information.

Temporary test equipment can readily be purchased or hired for most purposes, where a definite need for accurate measured data is identified. It should be used only to the really necessary extend to draw sound conclusions. A correctly performed test will avoid the production of excess data from too many readings or too long a recording period.

The most usually required measurements concern environmental conditions, electricity, air handling, piped services and those of the boiler plant. A concise audit may require minimal instrumentation. Comprehensive audits are normally expected to include measurement of principal energy flows and performance assessment of major plant. Reliable measurement of building areas and volumes are also needed for detailed assessment.

2. PLANNING OF AN ENERGY AUDIT

2.1. Energy audit's scope and requirements

An energy audit is the general term for a systematic procedure that aims at obtaining an adequate knowledge of the energy consumption profile of a building or an industrial plant. It also aims at identifying and scaling the cost-effective energy saving opportunities for the unit. Energy audits are crucial in the implementation of energy saving measures and in the assurance of the targets of Energy Management.

In an energy audit:
- the main goal is to achieve energy savings,
- the point of view is energy consumption and saving possibilities,
- there may be other aspects to consider (technical condition, environment) but the main interest is on energy savings,
- produces reporting on energy saving measures,

- the audit work may cover all energy using aspects of a site or certain limited parts (systems, equipment) of several sites (= "horizontal audit").

In several cases, there may be another name for the whole process (such as energy labelling, energy assessment, etc.), but the activity meets the same criteria that stand for an energy audit. Energy audit is not a continuous activity but should be repeated periodically.

2.2. Objectivity, independence and energy auditors' qualifications

Any specifications for the eligibility of energy auditors can take into account the establishment of a new institution, this of the authorised Energy Auditor, who is allowed to perform energy audits after his accredited participation in a special record of energy auditors. Energy audits can be divided, for this purpose, intï two categories, taking into account the kind of audited systems and equipment, as well as the respective energy loads:

- Electrical Energy Audits, for equipment or systems that produce, convert, transfer, distribute or consume electrical energy or for electrical loads auditing.
- Thermal Energy Audits, for equipment or systems that produce, convert, transfer, distribute or consume thermal energy or for thermal loads auditing.

Energy auditors can be accredited and recorded separately for electrical and thermal energy audits, or even for the complete energy audit of a site, which comprises both of the above categories, according to their certified qualifications. Energy audits can also be divided in different classes, according to the magnitude (N) of the total electrical or thermal power of the audited system. Energy auditors should, therefore, be classified and registered in relation to the above division, according to specific criteria and experience. The introduction of an energy auditor for both electrical and thermal energy audits should be allowed on the basis of his qualifications.

The following qualifications should be taken into account for the initial introduction of a candidate energy auditor to a specific category and class of a record of accredited energy auditors:

- The type of the first degree of its formal higher education (e.g. Diploma of Mechanical - Electrical - Energy Engineer, Degree of Energy Technologist etc.).
- Any formal postgraduate studies and/or specialisation/ training courses in the energy conservation and energy auditing-management field. Formal postgraduate studies should be at the Master of Science level and training courses should have a duration of 300 hours and above.
- The certified working experience in energy systems-services topics and especially in topics relevant to the record category of audits, where the auditor is to be introduced.

The following documents can prove the working experience of a candidate energy auditor in energy system - energy conservation topics:

- Employer certificates stating the kind and degree of involvement of the candidate in energy related issues (e.g. technical studies, commercial services, energy surveys - audits, etc.).
- Lists of energy projects carried out and/or coordinated by the candidate.
- Professional registration and higher education degree certificates.
- Training certificates.
- Copies of energy audit reports elaborated by the candidate.

2.3. Design criteria for an energy audit

In order to ensure that an effective energy audit can be developed whilst minimizing its cost, and due to the variety of audit types, the whole procedure should be designed on the basis of specific criteria. In the stage of energy audit planning, the following aspects should be specified or taken into consideration:

– Staff involvement; it is desirable the project to be directed by a person of managerial or board status to give authority to the audit and its outcomes. Whether it will be used or not outside assistance depends principally on the complexity of the site and its buildings and systems and on the availability of suitable staff.
– Site or building boundary; a single building such as an office block usually presents few problems as to the boundary of the audit. For sites with multiple buildings it is often preferable to specify each individual building to be included, particularly if the buildings vary in construction and use. Furthermore, it is important to identify any building or department, which is to be excluded from the audit for some specific reason.
– Depth of the energy audit; the depth of the audit and the detail with which it will be reported should be determined by the availability of resources and the limit placed in the anticipated energy saving opportunities.
– Audit timing; careful timing of an audit will produce the best results. Programming should seek to take advantage of seasonal factors and other planned activities.
– Access to site; restrictions might be imposed on auditing staff and working practices. Department heads and security staff should be notified of the programme and asked to co-operate in the smooth running of the audit.
– Reporting requirements; reporting procedures must be considered at an early stage. Note that the effort involved in evaluating findings and preparing a final report is normally at least as great as that spent on site work.

2.4. Preliminary energy considerations

Data on energy consumption and production output, where appropriate, are vital to all but the simplest energy audit. To this end, the collection and monitoring of consumption and output data should begin as soon as auditing is considered. The longer the period that data are available for, the better for the energy auditing procedure will be. Even where complete records are available, for instance monthly electricity bills, weekly or daily meter readings taken independently can be of great help in analysing energy use, loss or savings. In addition, when carrying out an energy balance, the more detailed consumption data will assist in quantifying specific energy flows and increasing the accuracy of the balance.

As far as the first stage of a building/unit Energy Audit is concerned, it is necessary to collect preliminary data related to its' energy-consuming behaviour. Thus it is purposeful to fill in the form (Annex A) with the following information:

- *General information about the building* (type of building, year of construction, type of use and providing services, ownership status, authorised representative, possible renovations-extensions on the shell to it's installations, building area and volume, number of users, products and relevant service support equipment, operating status, typical floor-plan layout).
- *Energy consumption data and energy invoices for the last five (5) years* (annual evolution of fuel and electricity consumption, monthly variation in consumption within the year under investigation).

- Status of Energy Management and any energy saving measures undertaken.

Additionally, the following supporting data must be collected:
- Energy bills and invoices (electricity, fuels) for the audit period, as well as for the last (or/and next) four (4) years.
- Plans and studies for the building and its electromechanical energy installations.
- Construction/structural and operational characteristics of the basic apparatus/ appliances.
- Climatic data for the period in which the auditing is conducted.
- Possible archived records with measurements from existing recorders or from theoretical estimations of the energy consumption levels at the building/unit.

The completion of the form and the collection of the supportive data are performed by the building's Manager in cooperation with the Energy Auditor. Additionally, all data and information about the building/unit can be entered in a suitable database for future retrieval, useful for the building/unit in question but also for comparison purposes with other similar buildings and installations.

2.5. Proposed tasks of an energy audit

The proposed work-tasks of an energy audit should be flexible enough, in order to allow for changes that might arise during carrying out the relevant work, based on the collected data and for the better exploitation of the available sources. Nevertheless, it has to be noticed that, according to the type of the energy audit that is going to be carried out, the relevant work-tasks that the corresponding auditor has to accomplish also change.

Thus, generally speaking, the tasks of an energy audit may include the following:
a) Objective, aims and the requirements from the audit.
b) The orientation of the units, systems and/or buildings of the complex that will be audited.
c) The description of the audit's tasks and stages.
d) Definition of the standards and methods that will be used during the audit. Both these standards and the various regulations used have to be clearly referenced.
e) The assignment of the departments or other staff of the organisation under audit that will cooperate with the auditor during the accomplishment of the energy audit.
f) The designation of other studies, databases and relevant sources that will be used for collecting reference data.
g) Analysis of the time that will be needed for carrying out the audit's tasks.
h) The specification of the energy audit team's members.
i) Possible requests for confidentiality.

3. ENERGY PARAMETERS ESTIMATION AND MEASUREMENTS

3.1. Introduction

One of the main aims of an energy audit, especially of the thorough (detailed) type one, is the configuration of energy standards regarding *reference consumption* or *reference specific consumption* or *reference efficiency* for individual installations and devices. With the use of such standards, energy consumption before and after the application of energy saving measures can be estimated.

Energy standards must be sensitive on decisive parameters, such as production quantity, quality and composition of raw materials, operating timetable and ambient temperature. Therefore, it is necessary to measure and evaluate a set of parameters that can be categorised as follows:
a) End use energy input to the unit, like electricity and fuels. In the case of solid fuels, it is necessary to include measurements for the heating value, humidity, ash, stable carbon and volatile substances. In the case of RES, measurements extend to natural quantities which specify the intensity of the RE Source (e.g. annual mean wind speed).
b) Energy flow, conversion and losses, in distinguished production and building facilities, like flows and losses of steam, hot water, electricity, thermal radiation and compressed air.
c) Energy related operating conditions, of productive installations and building spaces, like fluctuations and mean values of temperature, humidity, pressure, fluid velocity and luminance levels. It also includes the measurement of operation hours and idle/shut-off frequencies.
d) Flows of raw materials, intermediate and final products, when these are directly related to energy flows. Measurements of the products' weight, numbers of units manufactured and of the composition of the materials used, are included here.
e) Measurements regarding operation and maintenance conditions, especially in cases where preventive maintenance is directly related to energy consumption. Included here are measurements of plant availability times, as well as checking the proper operation and reliability of steam-traps, measuring instrumentation, data logging equipment, nozzles in burners and engine lubrication, is included herein, together with visual and sound checks on leaks.

The precision and the anticipatory ability of an energy standard is directly affected by two sources of error:
1. Parameter or measurement estimation error. Any uncertainty towards the quantitative or qualitative data on which the standard is developed, leads to invalid energy saving predictions.
2. Errors associated with the structure of the energy standard itself, due to inappropriate selection of a mathematical function or due to the omission of important parameters from the standard's formula. Usually, the selected function represents some physical law, but fails to take into account all relevant decisive parameters.

The duty of the energy audit is to minimise on the one-hand measurement/parameter estimation errors and, on the other hand, errors due to incorrect formulation of the energy standard. From the importance point of view, the main source of error is usually due to poor estimation/measurement of energy and mass flows, as well as due to lack of measurements or information on the state of decisive parameters.

3.2. Methodology for estimating energy parameters

The estimation of energy and/or production parameters is usually based on measuring methods. For every parameter under estimation, a suitable measuring method is selected, which could include one or more measurements of a single or more physical quantity. For example, for the estimation of a boiler's exhaust gases energy flow, the minimal requirement is the measurement of their temperature, their concentration on O_2, CO_2, CO and water vapour, as well as their mass flow.

The Auditor may use mass and energy balances in order to simplify his work, without sacrificing accuracy. For example, instead of measuring exhaust flow, the fuel consumption could be measured, thus indirectly estimating the flow, using fuel and air mass balance. In some cases, as in the estimation of heat losses on surfaces, it is not always possible to take a direct measurement. In such cases, it is usual to measure another quantity (e.g. surface temperature for the particular example), while the parameter wanted (heat loss) is calculated indirectly, using a standard.

These measurements should be repeated at least three times, in order to account for any thermodynamic unbalance or measurement error. The measurement of a parameter should be repeated for all possible typical conditions under which the installation is expected to operate. For this reason, apart from taking measurements, the Auditor should specify the decisive parameters that affect the efficiency and the specific energy consumption. The process of measuring and estimation, including the instrumentation specification and calibration, should be based on relevant national standards, as long as they exist, or on international standards (e.g. CEN, ISO). Otherwise, the Auditor should clearly state the physical law or international standard on which the estimation was based upon.

Ás long as it is necessary, the auditor could use nomograms, computational methods and PC source codes of recognized status and of widespread use (e.g. use of codes for the estimation of energy losses through walls or exhausts, based on temperature measurements). The methods and tools used, together with their source and verified accuracy, should be clearly stated by the auditor.

3.3. Portable measuring instruments

For measuring and estimating the required parameters, it is necessary to use accurate and full data for a long time period. In reality, however, full data are seldom available. Additionally, existing measuring instrumentation is not well maintained and/or calibrated, resulting in poor trustworthiness. The Auditor should assess the operational and maintenance status of the instruments and evaluate their possible measuring error.

Based on the requirements and standards of the audit, the Auditor plans the measuring activities, utilising both installed and portable instruments. The measuring activity usually takes place during the auditing phase, being of short duration. For this reason, measurements are conducted momentarily and not on a seasonal or annual basis. In reality, measurements are related to the power and not the energy itself. Power is defined as energy per unit of time and, thus, is an «instantaneous» quantity that is measured within seconds or minutes.

During the measuring activity, the Auditor should ensure that the measured system is under thermodynamic balance, indicated by the stability of the instrument readings. As a result, measurements taken with the use of portable instruments are not useful in determining directly monthly and annual energy consumption profiles, since time is not directly measured. Nevertheless, the use of portable measuring devices during the auditing process is quite useful for obtaining the efficiency of the energy consuming installations, for developing a standard for energy consumption, for checking existing/installed instrumentation and for obtaining new data.

The most usual measured quantities during an auditing session are:

- Liquid and gas fuel flows.
- Electrical measurements, such as the voltage, current intensity and power, as well as the power factor (cosö).
- Temperatures of solid and liquid surfaces.
- Pressure of fluids in tubes, furnaces or vessels (including measurements under evacuation conditions).
- Exhaust gazes emissions and contents in CO_2, CO, O_2 and smoke.
- Relative humidity.
- Luminance levels.

The auditor has to specify from the beginning a list of all required instrumentation, either available or not and/or portable or not, in order to conclude the auditing process.

3.4. Measuring and Verification (M&V) programme

When it becomes evident that the expected accuracy is not attainable during the auditing procedure, due to time, measuring, technical or other limitations, which were not foreseen in the planning procedure, then the Auditor draws up an analytical programme of Measuring and Verification (M&V). An M&V programme consists of an analytical description of required instrumentation, measurements, the typical operating conditions and the methodologies for analysing the proposed data.

The aim of the M&V programme is to accredit the estimations that are performed during the auditing procedure and to substantiate, at an accepted level, the measurements and the assumptions made during the auditing, for reference consumption and for the scale of possible energy saving measures. Additionally, it aims at creating an objective system, controlling the installation's performance or its specific energy consumption. As long as it is requested, the M&V programme can include the installation of timers for monitoring the periods during which the installation operates. In practice, the auditor should suggest an M&V programme for every energy saving measure suggested.

The duration of such an M&V programme should be long enough to ensure an accurate depiction of the average energy consumption before and after the saving measures, and it depends on the nature of the saving interventions required. The annual reflected cost of an M&V programme should not be more than 20% of the accredited economic savings due to relevant energy saving measures. It normally lies between 5 and 10%.

Moreover, the energy monitoring (E.M.) procedure requires the continuous or regular measurement of the energy behaviour of a building, a complex or a plant unit, before and, mainly, just after the application of energy saving measures on the shell or the energy producing installations. Consequently, it constitutes the means for the estimation of the energy saving measures' efficiency, comparing the energy behaviour of the building/plant before and after their application.

The following systems for energy monitoring vary in relation to the energy audit coverage breadth:

- System that covers the building as a whole (single measurement area) based on the existing multi-metering instruments, electricity and fuel bills (a single energy measuring centre).
- System that covers the building as a whole (single measurement area) based on many partial measurements (many energy measuring centres).
- System that covers separately some or every energy installation of a building (many measuring areas) based on the existing multi-metering instruments, electricity and fuel bills (a single energy measuring centre).
- System that covers separately some or every energy installation of a building (many measuring areas) based on many

partial measurements (many energy measuring centres) for every energy system-auditing area.

According to the degree of automation of the energy measurements, energy-monitoring systems are classified under the following categories:

⇒ Manual system

Counters' display is monitored by a qualified operator - Data collection from bills and invoices - Data tabulation in printed calculation form - Theoretical determination of the energy behaviour of the specific area - Manually composed report.

⇒ Semiautomatic system

A qualified operator monitors counters' display - The operator registers the data in a PC database - Automatic data processing and energy behaviour determination of the auditing area by means of an appropriate algorithm - Computer produced report.

⇒ Automatic system

Measuring instruments are connected to a PC - Automatic data input and processing by means of appropriate hardware and software - Use of hi-tech intelligent electronic systems and connection to other information systems (this is the case of a central building energy management system - BEMS).

The following Table 3.1 shows the available instrumentation, the specifications and the cost for various Energy Monitoring (E.M.) systems.

3.5. Typical measurements and instrumentation

In the following, the instruments used more often, either portable or fixed for measurements, in M&V programs are presented in brief. More interesting are the ones having the capability to give an electrical output signal, which allows to a PC to monitor measurements and collect data.

3.5.1. Measuring electrical parameters

For measuring the electrical parameters the following instrumentation are included:

Ammeter: it measures the current absorbed by appliances and motors.

Voltmeter: it measures the voltage or voltage drop in the grid or electrical circuits.

Watt-meter: it measures instant power demand of appliances/motors or the power performance of generators.

Cosö-meter: it measures the power factor or monitors the rectification devices.

Multi-meter: it measures all the above quantities.

All the above instruments are usually portable. They are connected to the wiring with the use of nippers and they could feature a data-logger. Measurements of electrical power and energy consumption should be made on all energy intensive areas and installations. Since these instruments are generally not expensive, it is advised to examine their permanent installation in some of the above cases.

During the measurement of all the above quantities, a strict distinction must be made between the total power (metered in kVA) and the active power (usually metered in kW), as well as of cosö. Care is also needed with electrical loads that are not expected to present a sinusoidal waveform, as is the case with variable speed motors and UPS. Usual measuring instrumentation is based on a sinusoidal waveform, which gives wrong readings. In such cases, the use of meters measuring real RMS (Root Mean Square) values is necessary. The function of such meters is based on digital sampling, so they could be substituted with PC-based meters.

Measurement of electrical parameters can be accomplished by the use of a complex instrument called power analyser (fig. 3.1). After the instrument's proper connection to the electrical panel of machinery or the substation under examination, measurement readings are presented on its display, which include instantaneous and programmable duration measurements for each phase and for the total voltage, current, apparent reactive and active power, cosö and energy consumption. The instantaneous measurements are repeated every 20 seconds. Furthermore, there is the possibility to store measurements in a memory pack for a long time interval.

Table 3.1. Classification of E.M. systems' components

Instrumentation	Measuring principle	Specifications	Cost
Displaying instruments	Visual display or the instantaneous value of the parameter under measurement	-Circular pane or linear. -Usually a digital display exists.	Low
Warning instruments	Audio or/and visual signals, showing that the measured value is above or below a set point	-Alert condition. -Normal operation condition. -Silent visual display condition. -Instrumentation checks condition.	Low to medium
Integrators	Visual display of the integrated value of the parameter registered by the counter	-Counter type keyboard. -Manual return. -Automatic return. -Switching action.	Low
Drawing pen instruments	Graph is produced for the time variation of the parameter under test	-Circular diagram. -Strip diagram. -Multiple pins. -Variable time base.	Low to medium
Data Loggers	Multiple registering of digital & analogue signals on paper or on electronic storage Media	-Multiple signal inputs. -Analogue and digital signals. -Data storage.	Medium to high
BEMS	Measuring principle is similar to that of the data logger	-Faster transfer & processing of larger data quantities. -Advanced programming capability. -Better presentation of results.	High

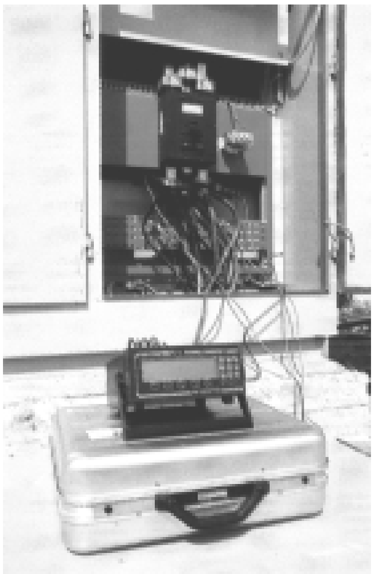

Figure 3.1. Power Analyser

The power analyser connection procedure to the electric panel is usually described in the instrument's manual. It is important for the connection of the instrument to be done properly (in this case, the display shows «OK»), in order for the measurements to be correct. If possible, a temporary power shutdown should take place and the electrician in charge, together with the auditing personnel, should accomplish all the instrument connections (voltage connectors and ammeter clamps).

Data stored in the memory pack are processed and analysed by a software package, which is described in the instrument's manual. From the processed data, graphs are automatically produced, in which the power demand and cosö variations for the auditing period are presented. Additionally, during the same period, power consumption of the device under test is registered in kWh, as well as reactive load per phase and for all the three phases.

3.5.2. Temperature measurement

PC-based temperature meters are already available in respective shops. The most usual measuring technologies include:

a) *Resistance Thermometer Detectors (RTD):* From the most technologically advanced instruments. They feature internal signals for calibration and resetting. They are very accurate and are used as permanent instruments in M&A applications.

b) *Thermocouples:* They are widely used and are not expensive. They cover a wide range of temperatures, from a few degrees up to 1000ºC and are usually portable. They need frequent calibration with specialized instruments. Their main disadvantage is that they have a weak signal, easily affected by industrial noise.

c) *Thermistors:* They are used as permanent meters and are of low cost. They are characterized by a strong, linear in variation with temperature signal and have an automatic resetting capability. Still this type and the thermocouple are not usually found in M&V set-ups.

d) *Infrared thermometers:* They measure temperatures from a distance by sensing the bodies' thermal radiation. They sense «hot-spots» and insulation problem areas. Portable and easy to use but with limited accuracy; they also require the knowledge of the emissivity coefficient.

The classical bulb - thermometers (e.g. mercury types) are accurate enough to be used in cases where isolated measurements are needed. It is worth describing in more detail the <u>infrared camera</u> and the related measuring technique, which is of particular interest to the energy auditing procedure. Thermal imaging or thermal inspection is used as a method for the determination of the thermal losses in buildings, which can be classified to the following types:

- Building's shell losses.
- Ventilation openings' losses.
- Warehouses' and fluid networks' losses (for water, air, steam, etc.).

The basic principle of the infrared thermometry is based on the fact that every body emits infrared radiation, which depends exclusively on the body's temperature and the emmissivity of its surface. The infrared camera (fig. 3.2) is equipped with a sensor which converts the infrared radiation in voltage difference and, consequently, through appropriate software, in an image having a colour spectrum corresponding to radiation levels.

Figure 3.2. Infrared camera

The emitted or reflected radiation of a body's surface is captured by the infrared camera and is converted in visible colours, presented on a display. Each colour corresponds to a certain range of temperatures, allowing direct temperature reading. Temperature reading from the camera depends on some specific camera parameters, but also on the emmitance of the body's surface and colour.

Before auditing the heating systems (i.e. boilers), these should operate at their normal temperatures, so that data coming from the measurements to be as representative as possible. The camera should operate for about 5 minutes before any measurements are taken, for its automatic self-calibration. In order to determine the heat losses from the building's shell, as well as the locations where insulation is degrading, the indoor temperature should be adequately higher than the outdoor one. Thus, a cold and cloudy day should be chosen, in order to avoid the heating effect on walls by incident radiation.

Moreover, the following are recommended for conducting in-site temperature measurements:

- <u>Calibration</u>: thermometers must always be calibrated before first used, but also in a regular time basis thereafter.
- <u>Surface temperature measurement</u>: the sensor must be protected from air conduct, using an insulating cover, and should not be in touch with radiation sources, like the sun, various radiators or windows. Furthermore, locating sensors near air inlets or outlets must be avoided. If a representative or average temperature is required, the sensor must not be located in non-representative places, like thermal bridges. As an alternative, many measurements could be made in more than one representative locations and the average of these values can

be calculated. For the surface temperature measurements, infrared sensors or cameras can also be used.

- Air temperature measurement: as in surface temperature measurements, the sensor must be protected from radiation sources, radiators, windows, etc. Measurements in a space must be made in three heights at least (stratification) and in the centre of the space, in order to avoid as much as possible the effects' of surrounding surfaces.

3.5.3. Flow measurements

To estimate heat flow through a fluid, it is necessary to measure its flux (mass or volume). Such measurements typically include air and liquid fuel, steam and hot/cold water or airflow measurements. Combined with heat measurement, they provide an estimation of heat supply. Installation of fuel flow meters is compulsory for all large boilers and furnaces. It is also recommended on steam networks and on hot water installations, used in process and boiler rooms. Combining a measurement of temperature difference with flow measurement, allows for the measurement of the thermal and energy flows.

The meter should be carefully selected, taking into account the fluid type, any diluted and corrosive substances, the speed range and the relevant costs. Flow-metering sensors can be classified as follows:

- Differential pressure meters (of perforated diaphragm, Venturi or Pitot tube type).
- Interference meters (of variable cross section, positive shift, eddy or vortex metering type).
- Non-interference meters (of ultrasonic or magnetic meter type).
- Mass meters (of Coriolis or angular momentum type).

From the above flow meters, the portable ones are usually the Pitot tube and non-interference meters. Pitot tubes are usually accompanied with an electric manometer for speed measurement. Ultrasonic meters technology has also progressed, offering accuracy close to 1-2%. They require relatively pure fluids and are easy to use. They are installed simply with the use of nippers on the measured tubing.

The most usual meters for permanent heat flow measurements are the eddy type or vortex-meters. Additionally, hot wire anemometer type instruments are used, either as portable or permanent meters. During fluid flow measurements, the instructions of the instrument's manufacturer must be closely followed. Attention should also be paid, to calibrate the meters frequently, as their calibration is most difficult.

3.5.4. Measuring air humidity

Air humidity is usually measured with dry and wet bulb thermometers. These measurements are time consuming and require care during their preparatory phase. Electronic meters have recently been developed, which have fast response but are restricted to temperature ranges up to 60ºC. More specifically, the following instruments are in use:

Psychrometer (or wet and dry bulb thermometer): it consists of two temperature sensors, one of which is covered with a cotton-cloth moisten with distilled water and records a temperature close to the thermodynamic temperature of wet bulb. Knowing dry and wet bulb temperatures and the barometric pressure, the relative humidity can be determined. Psychrometers cannot function when air temperature is below 0ºC. They need frequent cleaning and cotton-cloth replacement. If properly maintained, accuracy is about 0.5 K, if the relative humidity is above 20%.

Lithium chloride cell is an alternative for the psychrometer. It is a simple and relatively cheap instrument having a function range from -29 to +70ºC and accuracy of 2 K. Air velocity above 10 m/s can shift calibration scale, besides exposure in high humidity with a simultaneous power loss (for example a power failure) can dissolve the salts and it may be necessary to rehabilitate the instrument.

Humidity meter with ion exchange resin sensor (pope type) is another relatively cheap humidity meter. This type of sensor is often used in humidity meters for the measurement of relatively constant flow of air, because of its fast response and ability for continuous measurement. The function of pope type sensor is limited to temperatures bellow 75ºC and is very sensitive to organic solvents (e.g. oil vapour) and polystyrene glues. Some sensors are equipped with a metallic filter in order to protect them from the majority of the particles found in the air. Exposure to high humidity for some minutes can result in loss of calibration or even sensor failure.

Digital humidity meter is a portable device that senses air humidity, as well as the humidity contained in a great variety of structural materials, like bricks, wood, coatings, sand, etc. More specifically, the device provides an indication of the degree or the level of humidity in the material. In precision measurements, materials or surfaces can affect the measurement's accuracy, when air relative humidity is high or the surface under measurement is apparently wet. It consists of the main device and the sensor. Its use is simple and similar to that of electronic thermometers.

Thermo-hydrograph is used for the simultaneous measurement and recording of air temperature and relative humidity. The temperature sensor consists of a very well processed bimetallic strip, for stable operation, which expansions or contractions are transferred to the arm of a pen through a special mechanism. The humidity sensor consists of a bunch of human hair and any change imposed to its length, due to humidity change, is transferred to a graph through the corresponding pen. A transparent cover allows continuous monitoring. Measurement range is from -15 to +65ºC and for humidity from 0 to 100%.

3.5.5. Exhaust gases measurements

They are necessary in order to analyse combustion efficiency in boilers, furnaces and burners. They include CO_2, CO, SO_x, NO_x, smoke content and temperature measurements. Traditionally, these measurements are taken with low cost portable instruments. Electronic gas analysers are available today, which can measure rapidly all the above quantities and, at the same time, perform calculations for the combustion efficiency. These meters feature an automatic calibration and reset capability.

Care must be taken in comparing these electronic instruments with conventional ones. The later measure under dry gas conditions, while the electronic ones measure the gases composition continuously and under real time conditions. Moreover, before taking any in-site measurements, the boiler should operate for some time in order to reach its standard operating temperature.

The sampling probe of the gas analyser (fig. 3.3) is inserted in the chimney and its end must be placed in the middle of the core of the exhaust gases (the middle of the chimney). This can be achieved accurately because modern gas analysers have the capability of displaying the temperature of any point that the probe is located. Therefore, the appropriate sampling point is located where maximum temperature occurs, right in the middle of the gas flow.

Figure 3.3. Gas analyser

Once proper sampling is achieved, gases are analysed by the gas analyser and the percentage of the exhaust gases in CO, CO_2, O_2, SO_2, NO_x, C_xH_x is determined through built-in algorithms. Modern gas analysers are fully automatic so that when the proper sample is taken, the boiler efficiency and the percentage of the above mentioned gases are shown on the display of the gas analyser. A gas analyser can take instantaneous measurements, but it also has the ability to give the average for its total connection period with the boiler.

The same instrument can also determine the smoke index. Posing a special filter paper in the probe of the gas analyser, the measurement is directly displayed as smoke index. This is done visually, by placing the special filter paper under the comparing scale of the smoke index (Bacharach scale), in order that the smoke spot covers completely a hole of the comparing scale. The closest blackening level area to the smoke spot on the comparing scale provides the smoke index.

3.5.6. Measuring operation time

In many cases, it is necessary to monitor continuously the operation hours, as well as the time period that an appliance or installation is operating. For the second case, the use of a datalogger is needed. This measurement is necessary in order to estimate energy savings. For this reason, these meters are among the first that the Auditor suggests to be installed, as an important updating measure of the existing instrumentation.

3.5.7. Other necessary measurements

Other measurements that are usually performed during the auditing procedure are:

a) Luminance level measurements, in order to locate limit violations regarding lighting. A luminance-measuring instrument uses a light sensor having a unit for colour and incident angle correction. For best results, the sensor should be connected through a flexible cable to an analogue or digital display. This minimises the risk of shadowing the sensor when readings are taken. Measurement should take place under standard conditions (a time period should be given for the lamps to preheat). It must be confirmed that natural lighting does not affect the measurement of the electrical lighting.

b) Measurements of the Total Dissolved Solids (TDS) in the boiler's water, monitoring in this way the water treatment system and optimising blow-down water quantities.

c) Pressure measurements (being static or total) on fluids, to verify the operating condition of an apparatus (e.g. Boiler exhaust pressure measuring or temperature differences adequate to install heat exchangers for heat recovery).

d) Measurements for monitoring the steam-traps' condition, in order to trace and repair or replace defective units.

Finally, there are measurements that are necessary for the correct determination of energy losses but are not usually performed during an energy auditing procedure, such as:

a) The measurement for the <u>determination of the overall thermal loss coefficient</u>, which is performed by means of a unit consisting of the main device, space and surface temperature sensors and a heat flow sensor for the determination of the heat flow density (q). A resistance is installed on a 16-pole terminal where the terminals of the sensors are connected in order to compensate in parallel for reference temperature. The device determines the thermal loss coefficient solving the basic formula: Q=k · F · ÄT.

Instrument sensors register indoor and outdoor temperatures. If a difference occurs during measurements between these two parameters, the instrument determines the temperature difference that affects the heat flow. Besides, a plate is used to give readings for the surface heat flow density ($q = Q/F$) of the structural element. Total duration of readings for any structural element is 120 hours. During this period, mean temperature and heat flow density values are stored every two minutes, while every two hours a mean is calculated and stored separately. Every new stored value of the heat loss coefficient k is the mean of all the previous values.

b) The <u>ventilation loss measurement</u>. The ventilation air quantity of a room is difficult to be analytically calculated, because it depends on the permeability of the building shell, the arrangement of the partition walls, the indoor and outdoor temperature difference, the wind direction and velocity, the construction quality and design and other parameters.

For the measurement of buildings' ventilation, two methods are usually used:

- The <u>tracer gas method</u>, during which the indoor and outdoor conditions are not affected inside the space under measurement. This method can be used for measurements in small or medium size constructions with a clearly prescribed shell. The tracer gas must be well mixed in the room, the barometric pressure must be constant, the tracer gas inflow must not induce air density variations and the indoor air temperature, as well as the air density, must be constant.
- The <u>pressure method</u>, which is used in auditing the air-tightness of the building's shell. It is a short duration method, simple and reliable, which is accomplished by over- or under-pressurising the inside of the audited space, by mechanical means. Basic equipment required includes a fan for inducing the pressure difference between the room and the environment (blow-door), a manometer for monitoring the pressure difference and a flow meter for monitoring the airflow caused by the pressure difference from the building's shell.

Finally, in cases of energy projects like RES, there is a requirement for a special measuring set-up, so as to accurately estimate energy production and system performance. The specific instrumentation required depends on the nature of the RES and the type of technology used. What is usually measured is the intensity of the energy source as well as the relevant meteorological data, which affect the specific RE Source.

Typical measurements for RES applications are:

- Measuring total solar radiation (direct and diffused) or just direct, with the use of pyranometers (for incident solar radiation) or/and pyrheliometers (just for direct radiation). The pyranometer registers the instant and the global solar radiation. It consists of a photometric sensor connected to an integrator for data collection. The built-in memory of the integrator usually has a storage capacity of more than 100 days.
- Wind measurements, which are practically needed in every Wind farm installations, while they might be also necessary in other RES installations, e.g. Passive Solar Systems, and consist of wind speed measurements at a specific height above ground level (anemometer) and wind direction (wind-vane).
- There are other necessary measurements like dry bulb temperature, humidity levels or wet bulb temperature, as well as the barometric pressure (using appropriate manometers).

4. ENERGY ANALYSIS AND DOCUMENTATION

4.1. Energy consumption expression

The level/quantity of energy consumption in a building or industrial unit are expressed according to their physical units of measurement (e.g. kg, ton, lit, m^3, kWh, etc.). On the other hand, different forms of consumed energy can be expressed using a uniform unit of measurement, the GJ, according to the conversion table found below. These coefficients express the thermal energy content (heating value) of each fuel.

	kJoule	Btu	kcal	kWh	ÔÉÐ
kJoule	1	0,9478	0,2388	0,000278	$2{,}38 \cdot 10^{-8}$
Btu	1,0551	1	0,252	0,000293	$2{,}52 \cdot 10^{-8}$
kcal	4,187	3,9683	1	0,001163	$1 \cdot 10^{-7}$
kWh	3.600	3.411	859,84	1	0,000086
ÔÉÐ	$4{,}187 \cdot 10^{7}$	$3{,}9683 \cdot 10^{7}$	$1 \cdot 10^{7}$	11.630	1

In order to express energy consumption on a monthly basis, and when relevant data are not available, a time-apportioning method is proposed, imposed on invoiced consumed energy (electricity, petrol, gas bills). Apportioning can be done using simple methods (linear interpolation and extrapolation) or with time-functions relating consumed energy with other dimensions, like production levels, outside temperature, etc. The energy auditor has to appropriately justify the choice for the time-apportioning method preferred.

4.2. Energy time-charts

Processing all the selected data during the first stage of the energy audit of the building/unit, allows a preliminary analysis of its energy consuming behaviour. Thus, during the in-site survey of the energy systems characteristics, a picture about their historical and seasonal energy consumption behaviour can be obtained. Using the primary data selected according to the guidelines of paragraph 2.4, it is possible to produce energy consumption vs. time charts.

An energy consumption time chart of an industrial unit or a building block is a graphical representation of the power contained in a particular energy source as a function of time, for a specific time period. It is constructed using the data logged on the energy meters (electricity, petrol, gas, etc.). This type of chart provides the observer with direct information and allows for a first estimation about the way and the main areas of energy use in an hourly, daily, monthly and also in a seasonal basis.

During extensive audits, such energy time-charts must be constructed for all available energy meters and at least for the following cases:

– Electricity consumption time-chart on an hourly basis;
– Electricity consumption time-chart on a daily basis;
– Fuel consumption time-chart on a daily basis.

As long as the aim of the auditing procedure is to locate the peak energy saving potential of the building/unit, it is purposeful to construct a time chart of the typical daily (or monthly) load coefficient. This coefficient is defined as the ratio of the electrical peak load and daily (or monthly) hours product, to the respective energy consumption.

Following are typical examples where the above-mentioned tasks are applied in a building of the tertiary sector. In a first step, the following are defined:

- A time-chart of consumed energy quantity and cost (Figs. 4.1 and 4.2).
- The analytical monthly variation of last years' energy (Figs. 4.3 and 4.4).
- The electrical energy monthly demand obtained by analysing the electricity bills (Fig. 4.5).
- The specific consumption of fuels and electricity - Building energy indexes, expressed in kWh per m^2 or m^3 of useful space, kWh per unit of product/service provided (office studies, appliances sold, standard meal) or per unit of supporting device (bed, table, PC), kWh/person (resident, employee) (see Fig. 4.6).

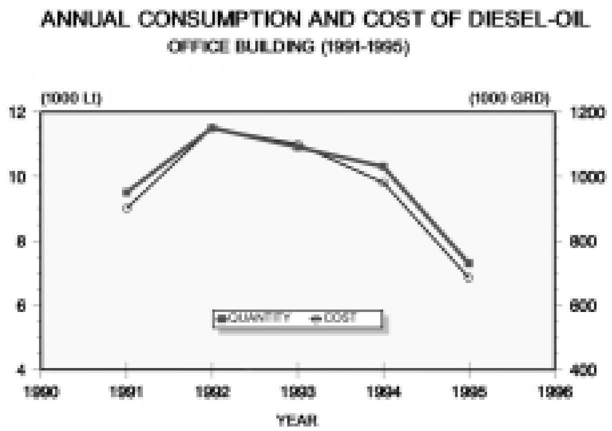

Figure 4.1. Annual fuel consumption evolution

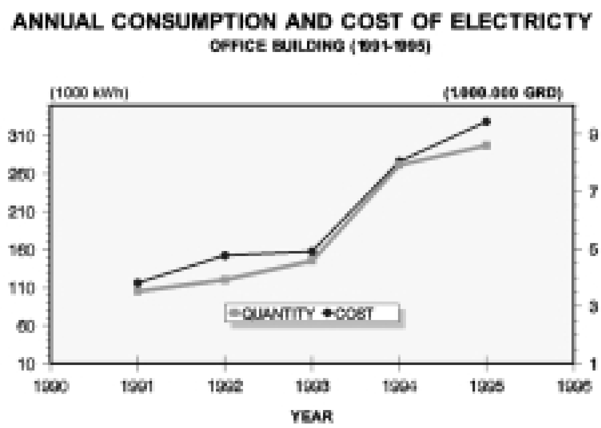

Figure 4.2. Annual electricity consumption evolution

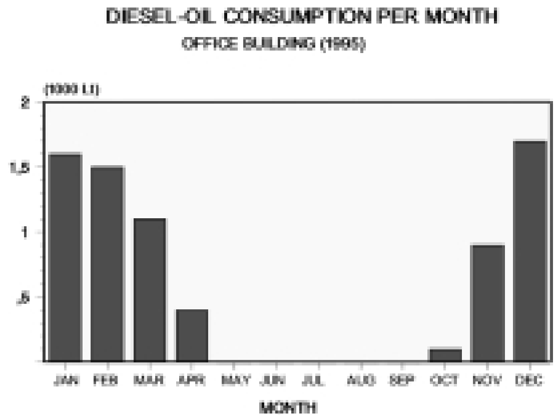

Figure 4.3. Monthly fuel consumption variation

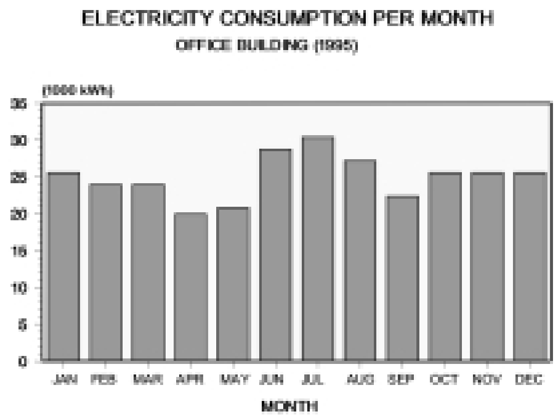

Figure 4.4. Monthly electricity consumption variation

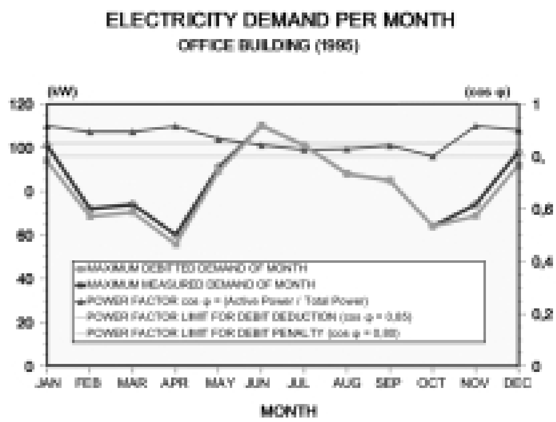

Figure 4.5. Monthly electricity demand variation

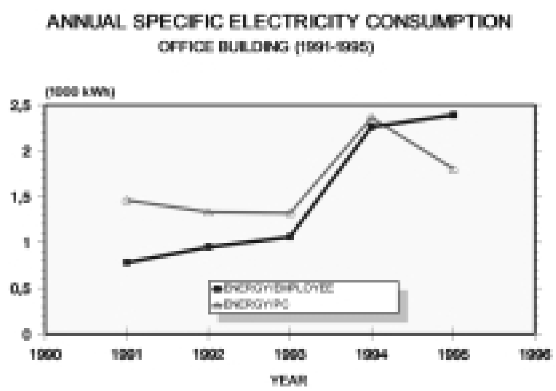

Figure 4.6. Annual electricity specific consumption evolution

Consecutively, the following actions should take place:

- Comparison of the energy indexes with these acting as targets-indexes from similar buildings of prototype construction and/or rational use of energy, as these have resulted from measurements or theoretical calculations on sample buildings of various categories.
- Correlation of monthly energy consumptions with relevant climate parameters (e.g. degree-days) or/and recorded monthly volume of products or services (figures 4.7 and 4.8). This correlation will allow an initial theoretical forecasting of the consumption, using real climate and building use data, allowing in turn a comparison of these forecasts with the measured consumption values in the future.
- Distribution of energy costs per fuel and comparison of the total energy cost with other annual costs for the building/unit (Figs. 4.9 and 4.10).

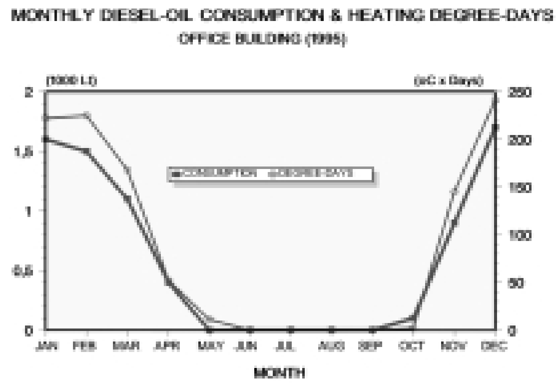

Figure 4.7. Monthly fuel consumption and heating degree-days

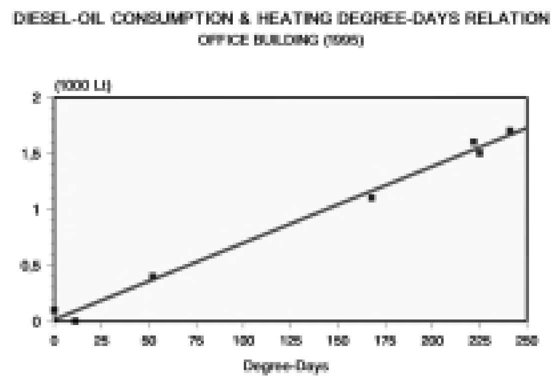

Figure 4.8. Fuel consumption and heating degree-days correlation

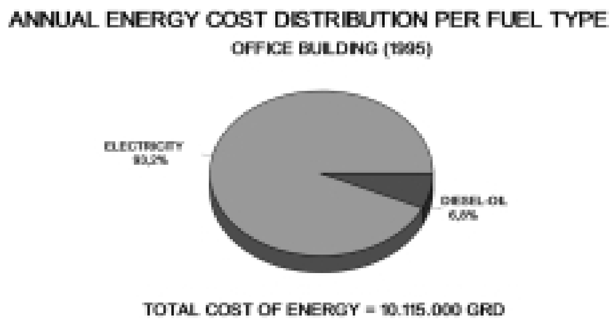

Figure 4.9. Distribution of energy costs per fuel

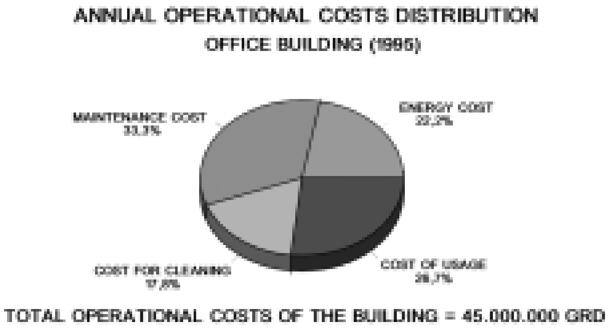

Figure 4.10. Contribution of energy costs in the total operational costs

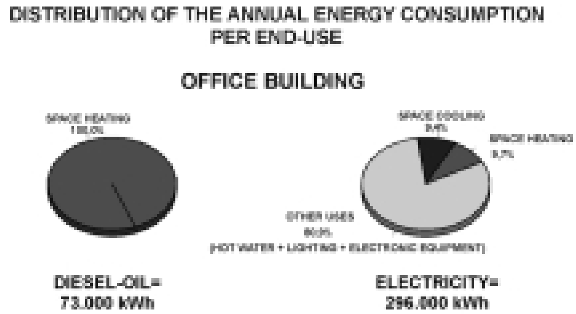

Figure 4.11. Annual fuel and electricity consumption per energy use distribution

Based on the observation of the monthly energy consumption profile of a building/unit (Figs. 4.3 and 4.4), it is possible in a first step to determine the basic consumption components of the building/unit and, therefore, the base and peak loads, namely:

- *The insusceptible by climate conditions (time-unaffected) components* (e.g. loads related to elevators, constant volume pumps, office equipment, catering and sanitary hot water)
- *The climate dependent components* (e.g. space cooling and heating loads)
- *The time dependent and sensitive to use components* (e.g. loads dependent on windows opening, cooling and heating system response to inhabitation changes, on the energy system operation programming).

Therefore, a first distribution of energy consumption per use is attainable, based on up to date data, thus determining the initial energy balance between electricity and fuels, as is shown in Figure 4.11 for the building examined herein. Possible "black areas" in the energy balances, like the use of energy for domestic hot water, lighting, and appliances, can be quantified at a next stage, thus improving the energy balances picture. This can be achieved after the energy related measurements that will follow, during the in-site auditing.

4.3. Energy balances (Sankey diagrams of energy flows)

4.3.1. The use of Sankey diagrams

Energy flow in a building/unit, from its internal distribution to its final consumption per use and per energy system, can be easily understood when each system is represented with the aid of a Sankey diagram. In these diagrams, the energy losses-outflows, the energy gains-inflows, as well as the useful energy in every energy system, are represented quantitatively and in proportion to the total energy inflow, according to existing data from energy bills and invoices, from calculations and in-site measurements of the building/unit.

Representing energy flows visually with the aid of the Sankey diagrams helps to locate the more critical energy consuming areas of the building, unit or building block, and, at the same time, to identify the sources that lead to energy losses. This ascertainment leads to a sound evaluation of each system's behaviour, as well as to a better scheduling of the proposed energy saving measures.

In the following paragraphs, the Sankey diagrams of the primary energy systems of a building are analysed. The energy quantities shown in these diagrams, representing energy inflows and outflows in the building shell (heat and electrical gains and losses from the

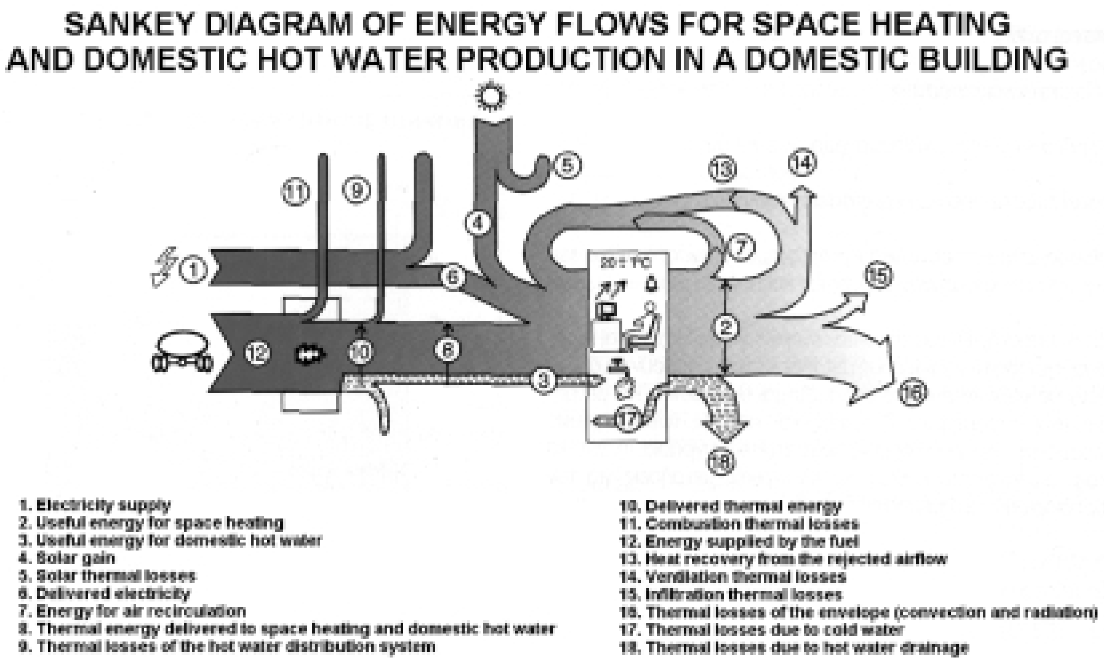

Figure 4.12. Energy flows in the case of residential space heating

production to the end-use of energy), are the result of primary data and estimations, of theoretical calculations and/or suitable measurements, as these were derived in the frame of the in-site audit.

4.3.2. Heat balance of the building shell

The Sankey diagram shown in Figure 4.12 represents the flow of the primary energy used for space and water heating in a residence. Oil is used for water and space heating, while electricity is used for the part of the space-heating load not covered by the oil-fired system. There is also a heat exchanger system that recovers heat from the building's mechanically induced warm airflow.

Moreover, in the Sankey diagrams shown in Figure 4.13 the thermal energy flows in an air-conditioned space, during cooling and heating periods, respectively, are represented.

4.3.3. Energy balance of HVAC systems

The Sankey diagram shown in Figure 4.14 represents the energy flow in a boiler-burner central system (producing hot water or steam, using solid, liquid or gas fuel). The auxiliary electrical energy that is shown in the diagram is used to start operating the burner equipment. Various heat/thermal losses (exhaust gases, surface losses, etc.) result from relevant calculations, measurements, as well as with the use of appropriate chart interpolations.

Sankey diagrams of Figs. 4.15 and 4.16 represent the energy flows in a central cooling plant and a heat pump system, respectively. In these diagrams, the inflow of primary/source energy represents the electrical and/or the fuel thermal energy that is used for the operation of the cooling system and/or the heat pump, respectively. Primary energy conversion losses are rela-

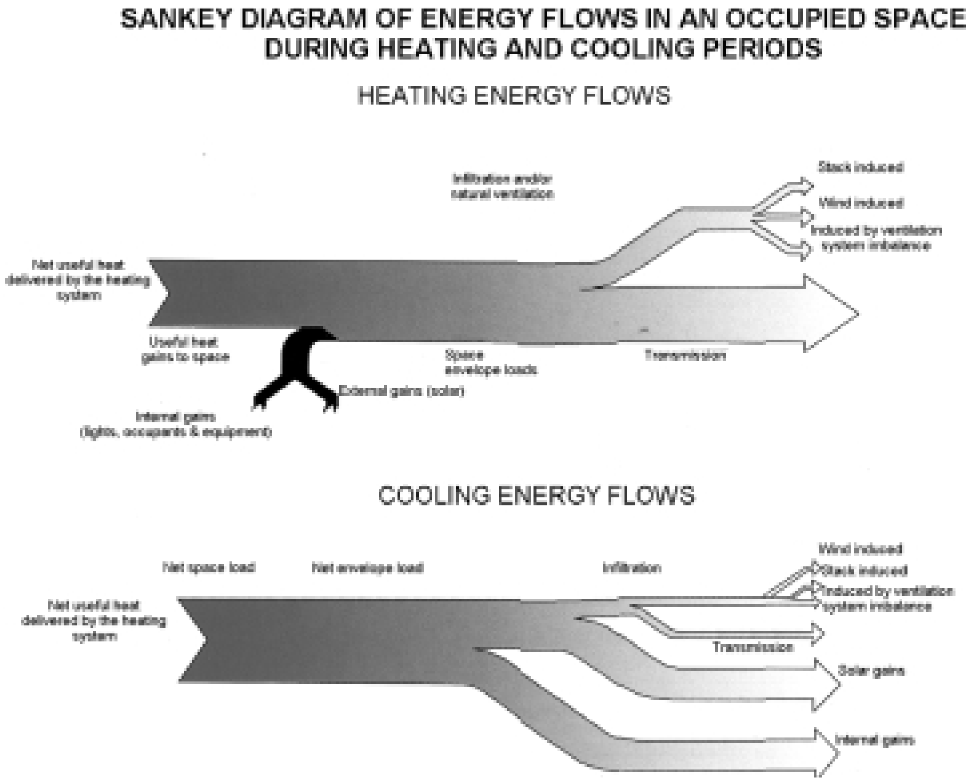

Figure 4.13. Thermal flows in a conditioned space (heating and cooling)

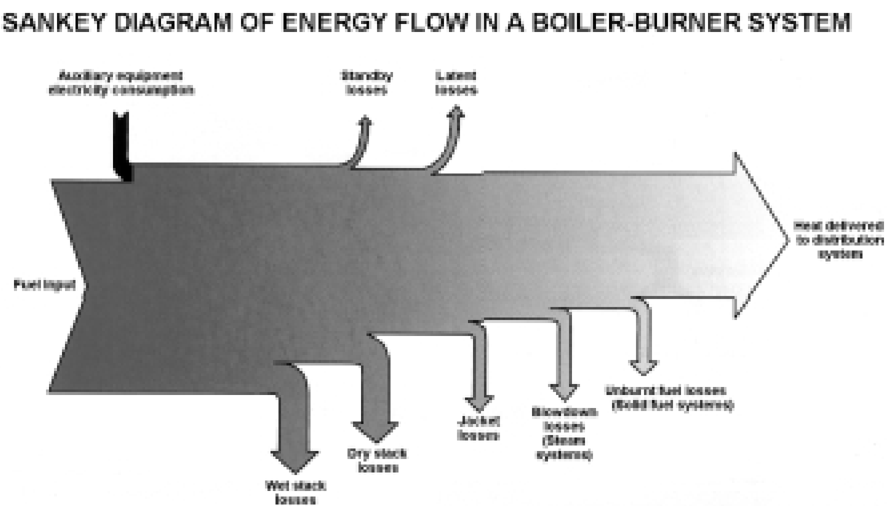

Figure 4.14. Energy flows in a boiler-burner central system

ted only to absorption cooling installations using fossil fuels. The same is true for energy recovery due to heat exchange between surfaces and exhaust gases (Figure 4.16).

The cooling losses (Heat gains) in Figure 4.15 and the thermal losses in Figure 4.16 represent, respectively, the total heat exchange between the cooling system and/or the heat pump and the environment, both in the various surfaces (evaporator, condenser) and from cooling liquid leakage. Losses in auxiliary systems refer to electrical energy consumption in fans, circulation pumps, control devices, resistance, etc. Losses in chiller control devices depend on the way the management of the chiller's output power reacts to variable cooling loads.

4.3.4. Energy balance in air-conditioning piping systems

Sankey diagram in Figure 4.17 represents energy flows in cold and warm water piping network. Energy inflows in piping net-

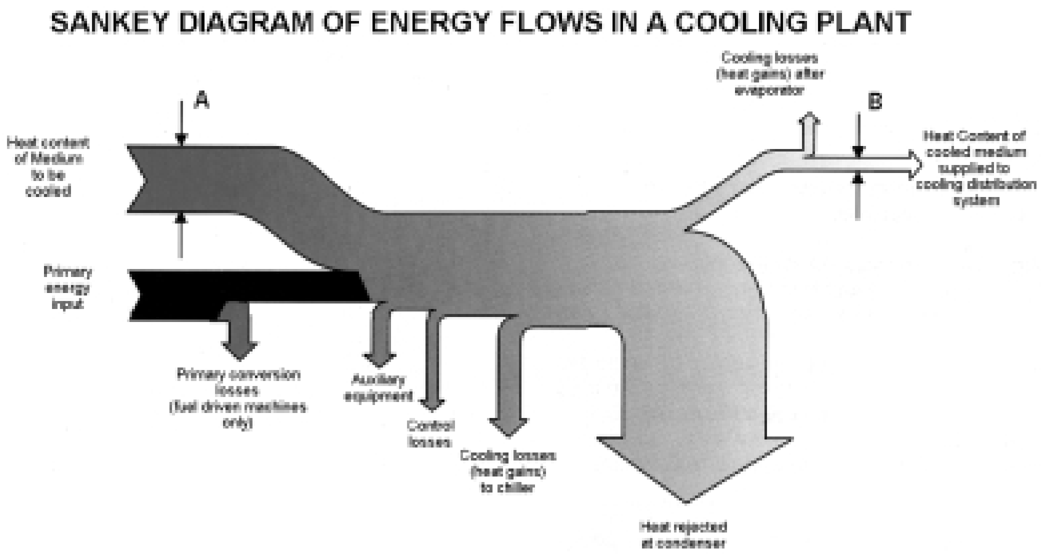

Figure 4.15. Energy flows in central cooling plant (A-B = Net cooling output delivered to the distribution system)

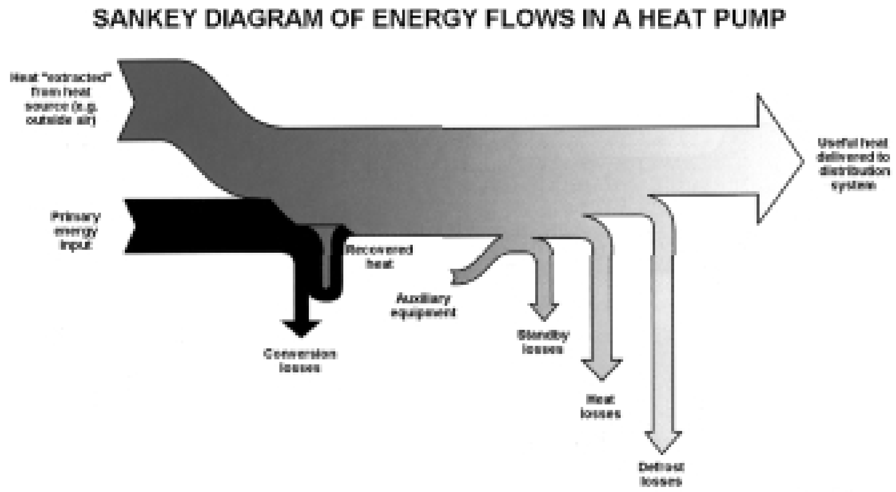

Figure 4.16. Energy flows in a central heat pump system (Heating operation)

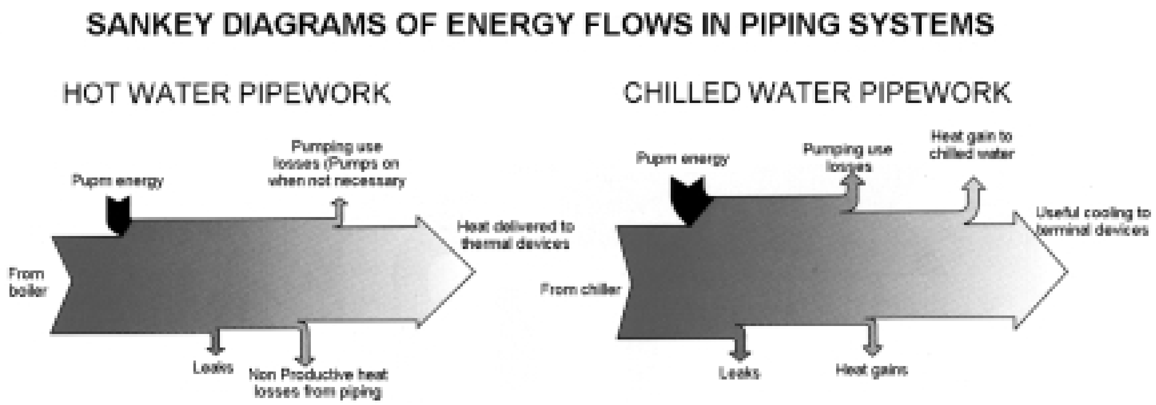

Figure 4.17. Energy flows in water distribution piping systems

works are owed to production (boilers, chillers, heat-pumps) and heat exchange (water-air) units and are supplemented by the necessary energy consumed by circulating pumps, which transfer the fluids' thermal energy. Heat losses, in this case, are due to the heat transfer medium leaks, to deficient piping system insulation and to idle operation of pumps.

4.3.5. Hot water preparation system energy balance

The Sankey diagram shown in Figure 4.18 represents the energy flows in a production, storage, distribution and end-use of hot water system. Energy inflows originate, according to the system type, from fossil fuels (through the use of a boiler), electricity (through the use of a resistance or a heat-pump) or from other sources (sun, heat recovery, etc.) and are supplemented by the electrical energy consumed in circulating pumps. Thermal losses appear in all stages of energy flow, from the production to its final distribution.

Storage losses are due to loose connections between the water -heater and the piping system, inefficient insulation, poor stratification due to high flow rates and mixing with return water, oversized resistance coil that induces strong electric currents, etc. Distribution energy losses are due to poor piping insulation and to the operation of circulation pumps. Finally, end-use losses are due to the overuse of water at excessive temperatures, for unnecessarily long periods.

4.3.6. Energy balance of an artificial lighting installation

The Sankey diagram shown in Figure 4.19 reflects the energy flows in a building lighting system. Luminance losses, due to electrical energy conversion to luminous energy, depend on the light bulb and ballast type and maintenance, the colour and texture of the internal lighted space and the light diffusion parameters. They also depend on the operation time of lighting in contrast with the real lighting needs of the areas under consideration.

4.4. Typical standards of specific energy consumption

In Industrial units, relating energy consumption with production volumes constitutes the primary method for monitoring the energy consumption levels of these units or their Specific Energy Consumption (S.E.C. is the energy consumed per unit product). The technique presented below is supported by data collected during a detailed energy audit.

The usual correlation formula is a linear one of the following form:

Å= *á* Ð + *â*

where Å is the input energy and Ð is the energy absorbed by the final product. Estimating coefficients *á* and *â* is possible using a graphical method, based on existing hourly or monthly data, and using the least square method. In this way, the following quantities are defined:

– Constant energy (*â*),
– Variable energy (*á* Ð),

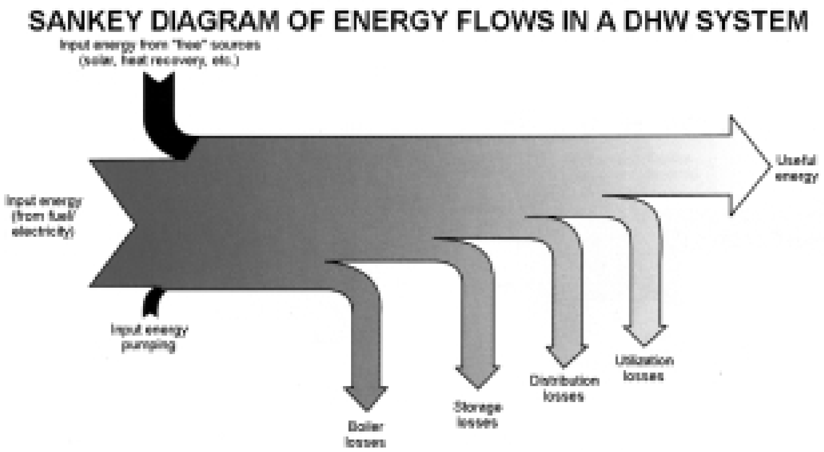

Figure 4.18. Energy flows in Domestic Hot Water (DHW) system

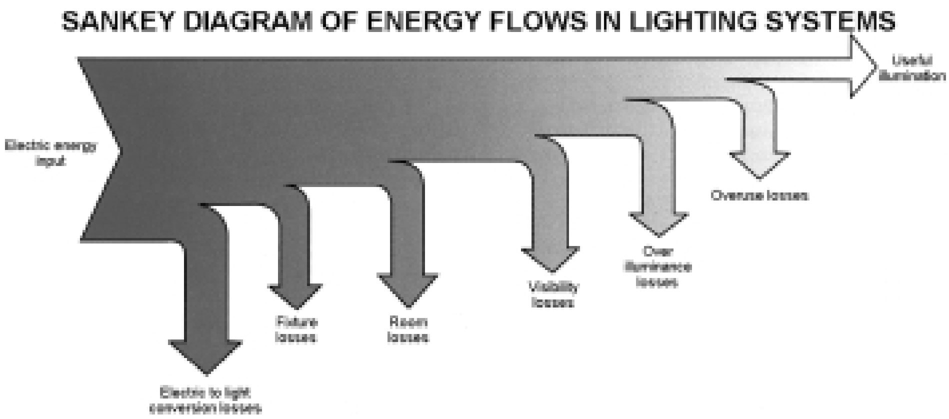

Figure 4.19. Energy flows in an artificial lighting installation

The “Constant energy” does not depend on production or service levels. It is consumed in lighting, ventilation, due to the energy transfer line loss or/and the losses related to the energetic equipment. Variable energy is directly related to production volumes or services provided. Such type of energy (variable) is the steam consumption in industrial processes or the electrical energy consumption by electric furnaces.

Using the diagram representing total energy consumption vs. production rates, both constant and variable energy consumption levels can be monitored. It is obvious that efficiency calls for very low constant energy levels. High level of constant energy consumption, as related to the level of the variable one, indicates large energy losses or enough idle time intervals of operation. On the contrary, high consumption levels of the variable energy correspond to low production efficiency levels or technologically outdated production installations.

4.5. Energy consumption and day-ratings correlation

In paragraph 4.2, the relation between the records of past annual fuel consumption of a building and the heating degree-days in the site where it is located were presented (see Fig. 4.8). The resulting statistical correlation line is the basis of the grapho-analytical method of cumulative differences (CUSUM), which can be used to continuously monitor the gains resulting from fuel/energy saving measures applied in the building. The CUSUM method involves the following six steps:

Step 1
Plotting a graphical representation of the annual fuel consumption of a building, for a time period before the implementation of any energy saving measures, with the heating degree-days of the same period. Determinations of the consumption part that is not climate dependent (Figure 4.20).

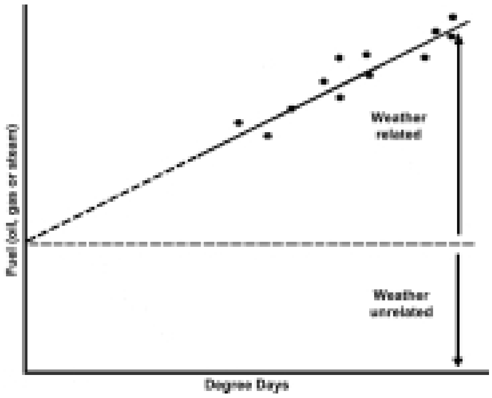

Figure 4.20. Fuel consumption and heating degree-days correlation

Step 2
Statistical assessment (i.e. with the use of “least squares” method) of the function that represents the above-mentioned graphical correlation (a linear function of the type: $y = a{\cdot}x + b$).

Step 3
Use of the above function for the theoretical calculation - forecast of monthly fuel consumption for future time periods, after the possible application of energy saving measures, based on the monthly degree-days of these periods.

Step 4
Subtraction of step 3 forecasts from the measured fuel consumption, for these future periods. Extraction of each monthly value algebraic difference for future time periods.

Step 5
Stepwise summation of each monthly algebraic difference to the next month’s one. Extraction of monthly cumulative differences (CUSUM).

Step 6
Plotting a graph showing the monthly accumulating differences for the relevant months in the chosen time periods.

Steps 3 to 5 are presented for a building application in Table 4.1, and step 6 of the same application in Figure 21.

Table 4.1. Calculation of cumulative differences in a hospital case

		Oil Consumption thousand litres Actual	Degree Days	Predicted Consumption thousand litres	Difference thousand litres	CUSUM thousand litres
		1	2	3	4	5
1983	April	417	321	425	−8	−8
	May	353	217	329	23	16
	June	200	90	213	−13	3
	July	173	22	150	23	26
	August	133	46	176	−38	−12
	September	212	107	228	−16	−28
	October	343	225	337	7	−21
	November	387	304	400	−22	−43
	December	468	389	488	−19	−62
1984	January	506	427	523	−17	−79
	February	421	415	512	−91	−170
	March	452	396	494	−42	−212
	April	360	282	390	−30	−241
	May	285	238	368	−64	−305
	June	169	95	217	−48	−353
	July	155	59	184	−29	−381
	August	122	41	168	−45	−427
	September	126	123	243	−117	−543
	October	241	199	313	−72	−615
	November	263	276	384	−120	−735
	December	330	395	493	−163	−898
1985	January	410	539	626	−216	−1,113
	February	396	429	524	−129	−1,124
	March	380	408	505	−125	−1,367
	April	309	264	360	−63	−1,430
	May	241	197	309	−69	−1,500
	June	169	137	264	−86	−1,586
	July	147	59	205	−37	−1,623
	August	155	90	228	−58	−1,681
	September	154	94	232	−62	−1,743
	October	195	195	308	−114	−1,857

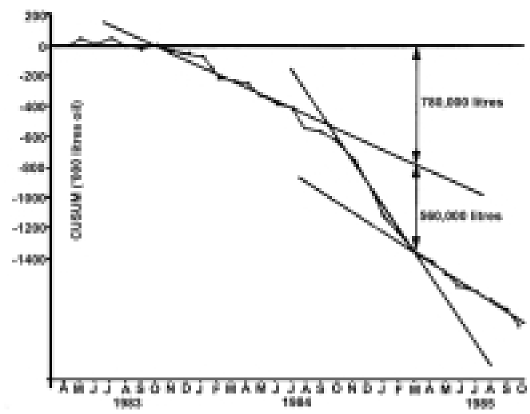

Figure 4.21. Cumulative differences graph in a hospital case

In Figure 4.21, it can be noticed that the first part of the graph covers the time period that corresponds to the base line with value equal to 0. Normally, in this part, as it was expected, cumulative differences fluctuate near 0. This trend continuous up to the point in which something changes the energy consumption profile, thus the trend gradient as well as, forming a series of intersecting straight line parts consumption trends, for a given time period.

Every intersection point represents the instance where an energy saving action has an impact on the consumption patterns, and defines the effectiveness of every such action. According to the reasoning of the CUSUM method, similar correlations are possible for electricity and fuel consumptions with other parameters that affect their values in particular time periods.

4.6. Annual energy consumption estimation

In the framework of an energy audit procedure, the past operating experience of a building/unit is the most reliable and accurate basis for predicting future requirements. In the relevant literature, one can find various methodologies for estimating energy requirements. These procedures vary considerably in degree of sophistication. A rough classification of the available methods leads to the following categories:
– Single-measure procedures, which use only one measure, such as annual degree-days,
– simplified multiple–measure methods, which are more accurate since they are using more information, such as the number of hours anticipated under particular operating conditions (the bin method), and
– detailed simulation methods, which perform energy balance calculations hourly over a given analysis period, typically one year.

5. EVALUATION OF INTERVENTIONS AND DRAWING UP OF ACTION PLAN

5.1. Evaluation criteria

When proceeding at this phase of the energy audit, the auditor has already formulated a preliminary catalogue of Energy Conservation (or Savings) Possibilities (ECP), based on the results of the in-site survey, the analyses that has performed and the measurements that has made. This catalogue should be formulated according to the audit's aims and criteria. The ECPs under consideration should be evaluated from the energy point of view, in accordance to the procedures and the requirements that are determined from the standing "Regulation of Energy Audits".

The criteria and the procedures valid for the overall evaluation and scaling of the proposed interventions or, more generally, of the Energy Conservation Measures (ECMs) are examined in the following paragraphs. The evaluation criteria are related to the energy, technical, operational, environmental, economic and financing characteristics of the measures under consideration. The most important of these criteria, that they usually also constitute a work-task of the energy audit, are those related to the energy and economic aspects of the intervention.

Apart from the criteria that are included in the energy audit's terms, the auditor has also to take into account the various criteria related to the existing financing programs, such as possible programs providing financial support, special programs for loans provision, the terms related to the purchase of initial capitals for enterprises, etc. These criteria should be also counted when an analysis of the financing options for the proposed ECMs is included in the terms of the energy audit.

5.1.1. Energy and environmental criteria

The criteria related to energy and environmental aspects that have to be taken into consideration in the evaluation of the proposed at the end of an energy audit ECMs include:
a) The fuels' quantity saved annually (expressed both in its physical quantities and in thermal energy equivalent).
b) The quantity of electricity saved in an annual base (in kWh).
c) The annual economic profit due to energy savings (or due to the energy efficiency measures taken).
d) The flattening of the monthly electric power demand, expressed as a reduction in the value of the electric load coefficient. Furthermore, the annual economic benefits due to the flattening of the electricity consumption.

The abovementioned economic benefits are closely related to the energy bills and the variations of the corresponding values. For this reason, all the criteria that are related to energy aspects should be expressed both in the form of energy and economic units. Furthermore, the programs related to the financial support of investments in energy efficiency measures usually include the following additional criteria:
e) The annual substitution of liquid fuels, which are typically imported.
f) The auto-production of energy in an annual base through the use of Combined Heat and Power (CHP) units, or with the exploitation of Renewable Energy Sources (RES).
g) The annual reduction of the most significant gas and liquid pollutants emissions, that is expressed either in an absolute value or reduced per product (or service provided) unit.

5.1.2. Technical and operational criteria

All the proposed interventions or energy retrofit projects should be based in techniques and/or technologies characterized by their technical maturity and reliability in operation (that means, to have been tested previously). The basic evaluation criteria of this kind include:
a) The operational reliability. The maturity of the relevant technology is evaluated, as well as its previous applications.
b) The technological level and the readiness of the technical support network in a local basis.
c) The operational availability in an annual basis. The guaranties provided regarding the minimum number of working hours in an annual base are evaluated in this point, together with the maintenance and stand-by mode operation programs.
d) The operational and maintenance costs, in relation to the corresponding costs before the implementation of the energy retrofit project.
e) The time required for the adaptation and full performance of the ECM. The requirements for personnel training must also be evaluated herein.

5.1.3. Economic and financing options criteria

The criteria related to economic aspects constitute the most usual criteria for the delimitation of the energy audit's work and the evaluation of the individual energy retrofit projects. These include:
a) The level of the initial capital required for covering the costs for the implementation of the measure.
b) The economic performance of the investment. Here, it is the annual profit in respect to the implementation cost of the project that is evaluated. This annual profit includes not only the net profits due to the energy use reduction, but also the profits (or the deficits) stemming from possible changes in the operational and/or maintenance costs. It is usual this profit to

include also the benefits from the reduction of the polluting emissions, as far as these emissions contribute explicitly or implicitly to the modulation of the operational costs.

c) The level of third party financing. In this point, the potential for possible financing support is evaluated, coming either from national and/or sectorial financing programs. Moreover, the contribution to the financing of the measure possibility of a capital coming from another business/venture is also examined herein (third party financing).

5.2. Basics of economic evaluation of energy retrofit projects

5.2.1. The necessity for economic evaluations

Energy audit of commercial and industrial buildings encompasses a wide variety of tasks and requires expertise in a number of areas to determine the best energy conservation measures suitable for an existing facility. On the other hand, in most applications, initial investments are required to implement energy conservation measures. These initial costs must be generally justified in terms of a reduction in the operating costs (due to energy cost savings).

Therefore, most improvements in the efficiency of energy systems have a delayed reward, that is, expenses come at the beginning of a retrofit project while the benefits are incurred later. For an energy retrofit project to be economically worthwhile, the initial expenses have to be lower than the sum of savings obtained by the reduction in the operating costs over the lifetime of the project. Moreover, the lifetime of an energy system retrofit project spans typically over several years.

Therefore, it is important to properly compare savings and expenditures of various amounts of money over the lifetime of a project. Indeed, an amount of money at the beginning of a year is worth less at the end of the year and has an even less buying power at the end of 2 years. To evaluate the cost-effectiveness of energy retrofit projects, several evaluation tools can be considered. The basic concept of all these tools is to compare among the alternatives the net cash flow that results during the entire lifetime of the project.

In the following, the basic concepts of engineering economics are described. First, some of common economic parameters are defined and, in a second step, an overview is provided of the basic evaluation methods that are typically used to determine the cost-effectiveness of various energy conservation measures, suitable for commercial buildings and industrial facilities. Furthermore, some of the advantages and disadvantages of the various economic analysis methods are discussed. Finally, a general but systematic approach to perform the economic evaluation of various alternatives of energy retrofit projects is described.

5.2.2. Basic concepts

There are several economic parameters that affect a decision between various investment alternatives. To perform a sound economic analysis for energy retrofits, it is important for the auditor to be (i) familiar with the most important economic parameters, and (ii) aware of the basic economics concepts. The parameters and the concepts that significantly affect the economic decision-making include:

- The time value of money and interest rates including simple and compounded interest.
- Inflation rate and composite interest rate.
- Taxes including sales, local, state, and federal tax charges.
- Depreciation rate and salvage value.

When money is borrowed to cover part or all the initial cost of a retrofit project, a fee is charged for the use of this borrowed money. This fee is called *interest (I)* and the amount of money borrowed is called *principal (P)*. The amount of the fee depends on the value of the principal and the length of time over which the money is borrowed. The interest charges are typically normalized to be expressed as percentage of the total amount of money borrowed. This percentage is called *the interest rate*.

The life-time (*N*) of a project is typically divided into smaller periods or interest periods (i.e., one year, three months, etc.). The interest fee is charged at the end of each interest period and is allowed to accumulate from one interest period to the next. For the economic analysis of projects for energy use and/or cost savings, the interest rate is typically assumed to be constant throughout the lifetime of the projects. Therefore, it is common to use average interest rates when an economic analysis is performed for energy retrofit projects.

5.2.3. Cash flows

In energy audits, it is important to account for the total cash receipts and disbursements due to an implementation of an energy conservation measure (such as the installation of a new boiler) for each period during the entire lifetime of the project. The difference between the total cash receipts (*inflows*) and total cash disbursements (*outflows*) for a given period of time is called a *cash flow*. Over the lifetime of project, an accurate accounting of all the cash flows should be performed.

Note that the cash flows are positive when they represent inflows (i.e., receipts) and are negative when they are outflows (i.e., disbursements). It should be noted again that the cash flows couldn't be simply added since the value of money changes from one period to the next. In the following, various factors are defined to correlate cash flows occurring at different periods. Moreover, to better visualize the evolution over time of the cash flows, *a cash flow diagram*, as depicted in figure 5.1, is used.

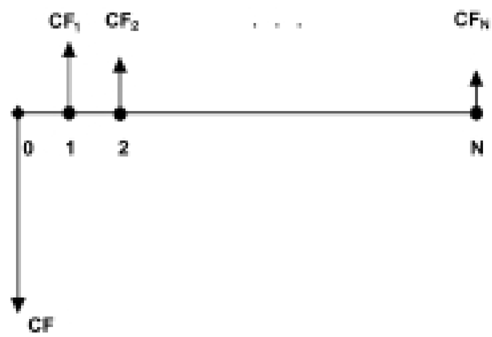

Figure 5.1. Typical cash flow diagram

5.2.4. Compounding factors

Without loss of generality, the interest period is assumed in the remainder of this text to be one year. Moreover, a nominal discount rate (*d*) is used henceforth, which can include the various effects such as inflation and taxation discussed above. In this case, an initial payment is made to implement a project by borrowing an amount of money (*P*). If this sum of money earns interest at a rate (*d*), then the value of the payment *F* after *N* years is provided by:

$$F = (1 + d)^N P$$

The ratio *F/P* is often called single payment compound-amount factor (*SPCA*). The *SPCA* factor is a function of *d* and *N* and is defined as:

$$SPCA\ (d,\ N) = F/P = (1+d)^N \quad (5.1)$$

Using the cash flow diagram of figure 5.1, the single payment represents the case where $CF_0 = P$, $CF_1 = ... = CF_{N-1} = 0$, and $CF_N = F$.

The inverse ratio *P/F* allows to determine the value of the cash flow *P* needed to attain a given amount of cash flow *F* after *N* years. The ratio *P/F* is called single payment present worth (*SPPW*) factor and is equal to:

$$SPPW\ (d,\ N) = P/F = (1+d)^{-N} \quad (5.2)$$

Consider then an amount of money *P,* which represents the initial investment, and receipt of an amount *A* that is made each year and represents the cost savings due to the retrofit project. To simplify the analysis, the amount *A* is assumed to be the same for all the years during the lifetime of the project. Therefore, the cash flows –using the diagram of fig. 5.1- are $CF_0 = P$, $CF_1 = ... = CF_N = A$. To correlate between *P* and *A,* it is noticed that for any year k, the present worth P_k of the receipt *A* can be determined using Eq. (5.2), as follows:

$$P_k = A\ (1 + d)^{-k}$$

By summing the present worth values for all the annual receipts *A*, the result should equal to the cash flow *P*. This sum can be rearranged to obtain a geometric series that can be evaluated analytically. The ratio *A/P* is called uniform-series capital recovery factor (*USCR*). This *USCR* factor can be determined as a function of both *d* and *N*:

$$USCR(d,N) = A/P = \frac{d(1+d)^N}{(1+d)^N - 1} = \frac{d}{1-(1+d)^{-N}} \quad (5.3)$$

The uniform-series present worth factor (*USPW*), that allows calculating the value of *P* knowing the amount *A*, is the ratio *P/A* and can be expressed as follows:

$$USPW(d,N) = P/A = \frac{(1+d)^N - 1}{d(1+d)^N} = \frac{1-(1+d)^{-N}}{d} \quad (5.4)$$

The values of the above compounding factors for $d = 0.05$ (5%) and $N = 10$ years are summarized below:

Compounding factor	Equation Used	Value
SPCA	Eq. (5.1)	1.629
SPPW	Eq. (5.2)	0.613
USCR	Eq. (5.3)	0.129
USPW	Eq. (5.4)	7.740

5.3. Economic evaluation methods among alternatives

5.3.1. Net Present Worth

The basic principle of this method is to evaluate the present worth of the cash flows that occur during the lifetime of the project. Referring to the cash flow diagram of fig. 5.1, the sum of all the present worth of the cash flows can be obtained by using the single payment present worth factor, as follows:

$$NPW = -CF_0 + \sum_{k=1}^{N} CF_k \cdot SPPW(d,k) \quad (5.5)$$

Note that the initial cash flow is negative (a capital cost for the project) while the cash flows for the other years are generally positive (revenues). In the particular, but common, case of a project with a constant annual revenue (due to energy operating cost savings) $CF_k = A$, the net present worth is reduced to:

$$NPW = -CF_0 + A \cdot USPW\ (d,\ N) \quad (5.6)$$

For the project to be economically viable, the net present worth has to be positive or at worst zero ($NPW \geq 0$). Obviously, the higher is the *NPW*, the more economically sound is the project. The net present worth value method is often called the net savings method since the revenues are often due to the cost savings from implementing the project.

5.3.2. Rate of Return

In this method, the first step is to determine the specific value of the discount rate (*d'*) that reduces the net present worth to zero. This specific discount rate is called the rate of return (*ROR*). Depending on the case, the expression of *NPW* provided in Eq. (5.5) or Eq. (5.6) can be used. For instance, in the general case of Eq. (5.5), the rate of return *d'* is the solution of the following equation:

$$-CF_0 + \sum_{k=1}^{N} CF_k \cdot SPPW(d',k) = 0 \quad (5.7)$$

To solve accurately this equation, any numerical method (such as the Newton-Raphson iteration method) can be used. However, an approximate value of *d'* can be obtained by trial and error. This approximate value can be determined by finding the two *d*-values for which the *NPW* is slightly negative and slightly positive, and then interpolate linearly between the two values.

It is important to remember that a solution for *ROR* may not exist. Once the rate of return is obtained for a given alternative of the project, the actual market discount rate or the minimum acceptable rate of return is compared to the *ROR* value. If the value of *ROR* is larger ($d' > d$), the project is cost-effective.

5.3.3. Benefit-Cost Ratio

The benefit-cost ratio (*BCR*) method, also called the savings-to-investment ratio (SIR), provides a measure of the net benefits (or savings) of the project relative to its net cost. The net values of both benefits (B_k) and costs (C_k) are computed relative to a base case. The present worth of all the cash flows are typically used in this method. Therefore, the benefit-cost ratio is computed as follows:

$$BCR = \frac{\sum_{k=0}^{N} B_k \cdot SPPW(d,k)}{\sum_{k=0}^{N} C_k \cdot SPPW(d,k)} \quad (5.8)$$

The alternative for the project is considered economically viable relative to the base case when the benefit –cost ratio is greater than one ($BCR > 1.0$).

5.3.4. Payback Period

In this evaluation method, the period *Y* (expressed typically in years) required to recover an initial investment is determined. Using the cash flow diagram of fig. 5.1, the value of *Y* is the solution of the following equation:

$$CF_0 = \sum_{k=1}^{Y} CF_k \cdot SPPW(d,k) \quad (5.9)$$

If the payback period *Y* is less than the lifetime of the project *N* ($Y < N$), then the project is economically viable. The value of *Y* obtained using Eq. (5.9) is typically called discounted payback period (*DPB*), since it includes the value of money.

On the other hand, in the vast majority of applications, the time value of money is neglected in the payback period method. In this case, Y is called simple payback period (*SPB*) and is solution of the following equation:

$$CF_0 = \sum_{k=1}^{Y} CF_k \tag{5.10}$$

In the case where the annual net savings are constant ($CF_k=A$), the simple payback period can be easily calculated as the ratio of the initial investment over the annual net savings:

$$Y = \frac{CF_0}{A} \tag{5.11}$$

The values for the simple payback period (*SPB*) are shorter than for the discounted payback periods (*DPB*) since the undiscounted net savings are greater than their discounted counterparts. Therefore, acceptable values for simple payback periods are typically significantly shorter than the lifetime of the project.

5.3.5. Summary of Evaluation Methods

Table 5.1 summarizes the basic characteristics of the economic analysis methods used to evaluate single alternatives of a retrofit project.

Table 5.1 Summary of the basic criteria for the various economic analysis methods for energy conservation projects

EVALUATION METHOD	EQUATION	CRITERION
Net Present Worth (*NPW*)	$NPW = -CF_0 + \sum_{k=1}^{N} CF_k * SPPW(d,k)$	$NPW > 0$
Rate of Return (*ROR*)	$-CF_0 + \sum_{k=1}^{N} CF_k * SPPW(d',k) = 0$	$d' > d$
Benefit Cost Ratio (*BCR*)	$BCR = \frac{\sum_{k=0}^{N} B_k * SPPW(d,k)}{\sum_{k=0}^{N} C_k * SPPW(d,k)}$	$BCR > 1$
Discounted Payback Period (*DPB*)	$CF_0 = \sum_{k=1}^{Y} CF_k * SPPW(d,k)$	$Y < N$
Simple Payback Period (*SPB*)	$Y = \frac{CF_0}{A}$	$Y << N$

It is important to note that the economic evaluation methods described above provide a measure of whether or not a single alternative of a retrofit project is cost-effective. However, these methods cannot be used or relied on to compare and rank various alternatives for a retrofit project. Only the life-cycle cost (*LCC*) analysis method is appropriate for such endeavour.

Example: *A building owner, after finding out that the old boiler has an efficiency of only 60% while a new boiler would have an efficiency of 85%, has decided to invest the $10,000 in getting a new boiler. The old boiler consumes 5,000 gallons per year at a cost of $1.20 per gallon. An annual maintenance fee of $150 is required for the boiler (independently of its age). Is this investment cost-effective, if the life-time of the boiler is 10 years and the discount rate is 5%? All five evaluation methods summarized in Table 5.1 will be used to perform the economic analysis.*

Solution: The base case for the economic analysis presented in this example is the case where the boiler is not replaced. Moreover, the salvage value of the boiler is assumed insignificant after 10 years. Therefore, the only annual cash flows (A) after the initial investment on a new boiler are the net savings due to higher boiler efficiency as calculated below:

$$A = FuelUse_{before} * (1 - \eta_{before} / \eta_{after}) * cost / gallon$$

Thus,

$$A = 5{,}000 * \left(1 - \frac{0.60}{0.85}\right) * \$1.20 = \$1{,}765$$

The cost-effectiveness of replacing the boiler is evaluated as indicated below:

(1) <u>*Net Present Worth*</u>. For this method CF_0=\$10,000 and $CF_1 = ... = CF_{10} = A$, d=0.05, and N=10 years. Using Eq. (5.6) with *USPW*=7.740 (see paragraph 5.2.4):
NPW=\$3,682
Therefore, the investment in purchasing a new boiler is cost-effective.

(2) <u>*Rate of return*</u>. For this method also CF_0=\$10,000 and $CF_1 = ... = CF_{10} = A$, while *SPPW* (d', k) is provided by Eq. (5.2). By trial and error, it can be shown that the solution for d' is:
d'=12.5%
Since $d' > d$=5%, the investment in replacing the boiler is cost-effective.

(3) <u>*Benefit Cost Ratio*</u>. In this case, B_0=0 and $B_1 = ... = B_{10} = A$ while C_0=\$10,000 and $C_1 = ... = C_{10}$=0. Note that since the maintenance fee is applicable to both old and new boiler, this cost is not accounted for in this evaluation method (only the benefits and costs relative to the base case are considered). Using Eq. (5.8):
BCR = 1.368
Thus, the benefit cost ratio is greater than unity (*BCR* >1) and the project of getting a new boiler is economically feasible.

(4) <u>*Compounded Payback Period*</u>. For this method, CF_0=\$10,000 and $CF_1 = ... = CF_{10} = A$. Using Eq. (5.9), Y can be solved providing:
Y = 6.9 years
Thus, the compounded payback period is shorter than the lifetime of the project (Y>N=10years) and, therefore, replacing the boiler is a cost-effective solution.

(5) <u>*Simple Payback Period*</u>. For this method, CF_0=\$10,000 and A=\$1,765. Using Eq. (5.10), Y can be easily determined:
Y = 5.7 years
Thus, the simple payback period method indicates that the boiler retrofit project can be cost-effective.

5.3.6. Life-Cycle Cost method

The Life-Cycle Cost *(LCC)* method is the most commonly accepted method to assess the economic benefits of energy conservation projects over their lifetime. Typically, the method is used to evaluate at least two alternatives of a given project (for instance, evaluate two alternatives for the installation of a new HVAC system: a VAV system or a heat pump system to condition the building). Only one alternative will be selected for implementation based on the economic analysis.

The basic procedure of the *LCC* method is relatively simple, since it seeks to determine the relative cost effectiveness of the various alternatives. For each alternative including the base case, the total cost is computed over the project lifetime. The cost is commonly determined using one of two approaches: the present worth or the annualised cost estimate. Then, the alternative with the lowest *LCC* is typically selected.

Using the cash flow diagram of figure 5.1, the *LCC* amount for each alternative can be computed by projecting all the costs (including costs of acquisition, installation, maintenance and operation of the energy systems related to the energy-conservation project) on either:

(i) One single present value amount. This single cost amount can be computed as follows:

$$LCC = \sum_{k=0}^{N} CF_k \cdot SPPW(d,k) \qquad (5.12)$$

This is the most commonly used approach in calculating *LCC* in energy retrofit projects. Or:

(ii) Multiple annualised costs over the life time of the project:

$$LCC_a = USCR(d,N) \cdot \left[\sum_{k=1}^{N} CF_k \cdot SPPW(d,k) \right] \qquad (5.13)$$

Note that the two approaches for calculating the LCC values are equivalent.

Example: *In fact, the building owner has three options to invest his money as briefly described below:*

(A) Replace only the burner of the old boiler. This action can increase the efficiency of the boiler/burner system to 66%. The cost of the burner replacement is $2,000.

(B) Replace the entire older boiler (including burner) with more efficient heating system. The old boiler/burner system has an efficiency of only 60% while a new boiler/burner system has an efficiency of 85%. The cost of this replacement is $10,000.

(C) Do nothing and not replace neither the boiler nor the burner.

Determine the best economical option for the building owner. Assume that the lifetime of the retrofit project is 10 years and the discount rate is 5%. The boiler consumes 5,000 gallons per year at a cost of $1.20 per gallon. An annual maintenance fee of $150 is required for the boiler (independently of its age). Use the life cycle cost analysis method to determine the best option.

Solution: The total cost of operating the boiler/burner system is considered for the three options. In this analysis, the salvage value of the boiler or burner is neglected. Therefore, the only annual cash flows (*A*) after the initial investment on a new boiler are the maintenance fee and the net savings due to higher boiler efficiency (these savings can be calculated as shown in the previous example). To present the calculations for *LCC* analysis, it is recommended to proceed as shown below:

Cost Item	Option A	Option B	Option C
Initial Investment			
(a) Replacement Cost ($)	2,000	10,000	0
Annual Operating Costs:			
(b) Fuel Use (gallons)	4,545	3,530	5,000
(c) Fuel Cost ($) [$1.2*(b)]	5,454	4,236	6,000
(d) Maintenance fee ($)	150	150	150
(f) Total Operating Cost ($) [(c)+(d)]	5,604	4,386	6,150
USPW factor [d=5%, N=10, Eq. (5.4)]	*7.74*	*7.74*	*7.74*
Present Worth ($) [(a)+USPW*(f)]	45,375	43,948	47,601

Therefore, the life cycle cost for option B is the lowest. Thus, it is recommended for the building owner to replace the entire boiler/burner system. This conclusion is different from that obtained by using the simple payback analysis. Indeed, the payback period for option A - relative to the base case C- is *SPB* (A) = ($2,000) / ($ 546) = 3.66 years, while for option B, *SPB* (B) = ($10,000) / ($1,765) = 5.66 years.

Note: If the discount rate was d = 10% (which is unusually high for most markets), the USPW would be equal to USPW = 6.145 and the life-cycle cost for each option will be

LCC (A) = $36,437 *LCC (B)* = $36,952 *LCC (C)* = $37,792

Therefore, Option A will become the most economically effective and will be the recommended option to the building owner.

5.4. General procedure for an economic evaluation

It is important to remember that the recommendations for energy conservation projects that stem from an energy audit should be based on an economically sound analysis. In particular, the auditor should ask several questions before making the final recommendations such as:

(a) Will project savings exceed costs?
(b) Which design solution will be most cost-effective?
(c) What project size will minimize overall building costs?
(d) Which combination of interrelated projects will maximize net savings?
(e) What priority should projects be given if the owner has limited investment capacity?

As was shown earlier, the best suitable economic assessment method is the *LCC* method, described previously. Before the application of the *LCC*, several data are needed to perform an appropriate and meaningful economic analysis. To help the auditor in gathering the required information and in the application of the *LCC* method, the following systematic approach in any economic evaluation is proposed:

1) Define the problem that the proposed retrofit project is attempting to address and state the main objective of the project. [For instance, a building has an old boiler that does not provide enough steam to heat the entire building. The project is to replace the boiler with main objective to heat all the conditioned spaces within the building].
2) Identify the constraints related to the implementation of the project. These constraints can vary in nature and include financial limitations or space requirements. [For instance, the new boiler cannot be gas fired since there is not supply of natural gas near the building].
3) Identify technically sound strategies and alternatives to meet the objective of the project. [For instance, three alternatives can be considered for the old boiler replacement: (i) a new boiler with the burner of the old boiler, (ii) a new boiler/burner system, and (iii) a new boiler/burner system with an automatic air-fuel adjustment control].
4) Select a method of economic evaluation. When several alternatives including the base case (which may consists of the alternative of "doing nothing"), the *LCC* method is preferred for energy projects. When a preliminary economic analysis is considered, the simple payback period method can be used. As it was mentioned earlier, the payback period method is not accurate and should be used with care.
5) Compile data and establish assumptions. The data includes the discount rates, the energy costs, the installation costs, operating costs, and maintenance costs. Some of these data are difficult to acquire and some assumptions or estimations are required. For instance an average discount rate over the life cycle of the project may be assumed based on a historical data.
6) Calculate indicators of economic performance. These indicators depend on the economic evaluation method selected. The indicators are the life-cycle costs (*LCC*s) for the *LCC* method.
7) Evaluate the alternatives. Simply comparing the values of *LCC* for various alternatives can perform this evaluation.
8) Perform sensitivity analysis. Since the economic evaluation performed in step 6 are typically on some assumed values (for instance the annual discount rate), it is important to determine whether or not the results of the evaluation performed in step 7 depend on some of these assumptions. For this purpose, the economic evaluation is repeated for all alternatives, using different plausible assumptions.

9) Take into account unqualified effects. Some of the alternatives may have effects that cannot be included in the economic analysis but may be a determining factor in decision-making. For instance, the environmental impact (emission of pollutants) can be important to disqualify an otherwise economically sound alternative.
10) Make recommendations. The final selection will be based on the findings of the three previous steps (i.e., steps 7, 8, and 9). Typically, the alternative with the lowest *LCC* value will be recommended.

It has to be mentioned that, once the energy retrofit project is selected, in accordance to the results of the economic evaluation presented above, it is important for the auditor to determine the financing options that will contribute to the implementation of the retrofit project. It is also important the establishment of the procedures for the realization of the ECMs that will allow the reduction of the energy costs occurred during the operation of the unit (building or industry).

5.5. Drawing-up of an energy saving action-plan

The energy auditor has to draw-up an action-plan for the in-time implementation of the proposed energy efficiency measures, if such a task is foreseen in the audit's terms, based on the time-programming principles. This planning should be made for each phase of implementation and includes:

- the targets and the measures that have to be implemented in each phase,
- the time-schedule of each phase,
- the requested organization and the budget for the implementation costs,
- the determination of the way that the work-progress will be monitored,
- the delimitation of the monitoring/measuring or/and evaluation of each phase results procedure.

For the determination of each phase's energy related targets, the energy savings expected to result from the previous phase of implementation should be taken into account. As a result, each phase's targets should be posed in respect to the objective consumption of the previous phase, and not in respect to the initial energy situation of the site. A common criterion for the delimitation of these targets is that each phase should secure such benefits for the enterprise that they will justify both the investment required for the implementation of the measure and the continuation of the energy savings action-plan.

As a conclusion, it has to be mentioned that, for drawing-up an energy savings action-plan the following items have to be taken under consideration:

a) the scaling of the proposed measures, as this results from the energy audit,
b) the combination of the various energy retrofit projects, as well as their co-ordination with other targets of the enterprise,
c) the organizational level and the technical capability of the enterprise to implement each one of the proposed measures or bundle of measures,
d) the financial capability of the enterprise to self-finance the investments required for energy efficiency projects, in respect to other priorities that might have.

ANNEX A
COLLECTION OF ENERGY RELATED DATA

PART 1: GENERAL INFORMATION

Project Title: …………………………………. **Project Number:** ………………………….
Building Type: ………………………………………………………………………………….

Location

Town: ……………………………………. **Region:** ………………………………….
Address: ……………………………………………………………………………….
Longitude: …………………. **Latitude:** …………………………….
Elevation : ……………………………. (in meters above sea level)

Construction year: ………………………………….

Building owner:	Private ( )	Company ( )	Public ( )	Other ( )
Occupants:	Private ( )	Company ( )	Public ( )	Other ( )

Contact person: ……………………………………..
Profession /Department: ………………………….
Telephone / Fax: ……………………………………

Has any ownership or usage change occurred since building's construction?
YES ( ) NO ( )

Remarks: ………

Main building refurbishments / additions

a. <u>Building envelope</u>
Year : ………………………………….
% Refurbishment : ………………………………….
Intervention(s) : ………………………………….
Cost : ………………………………….

b. <u>HVAC installations</u>
Year : ………………………………….
% Refurbishment : ………………………………….
Intervention(s) : ………………………………….
Cost : …………………………………..

c. <u>Domestic hot water</u>
Year : ………………………………….
% Refurbishment : ………………………………….
Intervention(s) : ………………………………….
Cost : …………………………………..

d. <u>Lighting</u>
Year : ………………………………….
% Refurbishment : ………………………………….
Intervention(s) : ………………………………….
Cost : …………………………………..

e. <u>Other</u>
Year : ………………………………….
% Refurbishment : ………………………………….
Intervention(s) : ………………………………….
Cost : …………………………………..

Floor Number (including ground floor) : ………………………

Total volume of the building	**:** ………………………	(m^3)
a. Volume of heating space	**:** ………………………	(m^3)
b. Volume of conditioned space	**:** ………………………	(m^3)
c. Volume of Special space (……….)	**:** ………………………	(m^3)

Total floor areas : .... (m^2)
a. Heating area : .... (m^2)
b. Conditioned spaces area : .... (m^2)
c. Special area (................) : .... (m^2)

Building inhabitants for the last 5 years (tenants, employed, customers, trainees, patients etc.)**:**

Year	19…	19…	19…	19…	19…
Persons					

Number of products or services / period for the last 5 years (i.e. meals, studies, commercial units etc.) **or**

Number of support units of services for the last 5 years (i.e. beds, tables etc.)**:**

Year	19…	19…	19…	19…	19…
"Products" ( )					
Units ( )					

Remarks: ....
....

Building operation status for the last 5 years

Year	19…	19…	19…	19…	19…
Hours/Day					
From – To					
Days/Week					
From – To					
Weeks/Year or Months/Year					
From – To					

Remarks: ....
....

Typical Building Floor Elements

(If there are other floors with complete different characteristics from the above, the next items have to be filled for those floors too)
Total Floor Area : .... (m^2)
Floor Heating Area : .... (m^2)
Floor Air-conditioned Area : .... (m^2)
Floor Volume : .... (m^3)
Number of Floor Occupants : .... (Persons)
Occupants Activity : ....

Sketch of Typical Floor Plan

N ↑

PART 2: ENERGY CONSUMPTION AND COST

Annual Energy Cost of the last 5 years (GRD/year)

(Do not include irrelevant expenditures i.e. fees. Include V.A.T. and fixed energy costs)

Year	FUEL					TOTAL
	Electricity (Energy + Power)	**Diesel**	**LPG**	**Gas**	**Solid/ Other**	
19…	(+) =					
19…	(+) =					
19…	(+) =					
19…	(+) =					
19…	(+) =					

Percentage participation of annual energy cost compared to the total average operational cost of the building:........... %

Annual Energy Consumption of the last 5 years (in kWh, lit or kg / year)

Year or Period	FUEL				
	Electricity (kWh) (Normal + off Peak Hours.)	**Diesel** (lit) - (kWh) *	**LPG** (m^3) - (kWh) *	**Gas** (m^3) - (kWh) *	**Solid/ Other** (kg,m^3) - (kWh) *
19…	(+) =				
19…	(+) =				
19…	(+) =				
19…	(+) =				
19…	(+) =				

* The lower calorific value H_u of the common used fuels in Greece are:

Diesel Oil	= 42.700 kJoule/kg = 10.200 kcal/kg = 12kWh/kg = 10kWh/lit
LPG ($CO+H_2$)	= 10.600 kJoule/m^3 = 2.530 kcal/m^3 = 3 kWh/m^3
LPG (from Naphtha)	= 34.700 kJoule/m^3 = 8.300 kcal/m^3 = 9,7 kWh/m^3
Natural Gas (Russian)	= 36.000 kJoule/m^3 = 8.600 kcal/m^3 = 10 kWh/m^3
Propane (C_3H_8)	= 46.400 kJoule/kg = 11.100 kcal/kg = 12,8 kWh/kg
Butane (C_4H_{10})	= 45.600 kJoule/kg = 10.900 kcal/kg = 12,7 kWh/kg
Firewood	= 20.100 kJoule/kg = 4.800 kcal/kg = 5,6 kWh/kg

Remarks: ....
....

Monthly Energy Consumption of the last year 19...

MONTH	FUEL				
	Electricity (kWh) (Normal + off Peak Hours.)	**Diesel** (lit) - (kWh) *	**LPG** (m^3) - (kWh) *	**Gas** (m^3) - (kWh) *	**Solid/ Other** (kg,m^3) - (kWh) *
Jan.	(+) =				
Feb.	(+) =				
Mar.	(+) =				
Apr.	(+) =				
May	(+) =				
Jun.	(+) =				
Jul.	(+) =				
Aug.	(+) =				
Sep.	(+) =				
Oct.	(+) =				
Nov.	(+) =				
Dec.	(+) =				

Remarks: ....
....

Please attach copies of electricity and fuel periodic bills and invoices of the last 5 years.

Monthly Demand of Electric Power of the last year 19...

(Where electric energy AND power bills exist)

MONTH	POWER DEMAND DATA				
	Recorded Maximum Power Demand (MPD in kW)	**Recorded Peek Hour Maximum Power Demand** (kW)	**Network Utilization Factor** (N.U.F.) *	**Power Factor** (cos ö)	**Maximum Debited Demand** (MDD in kW) **
Jan.					
Feb.					
Mar.					
Apr.					
May					
Jun.					
Jul.					
Aug.					
Sep.					
Oct.					
Nov.					
Dec.					

***** (N.U.F.) = (month's kWh) / (MPDM x 720 hours/month)

****** (MDD) = (MPD) x (F.PRS.), where: (F.PRS.) = 0.80 / cos ö (when cos ö ≤ 0.80) or
= 1 (when 0.80 ≤ cos ö ≤ 0.85) or
= 0.85 / cos ö (when cos ö ≥ 0.85)

Subscribed Power (upon utility contract) **=** .... (KVA)

Has it been any power increment during recent years?

YES ( ) NO ( ) How much ? .... (KVA)

Remarks: ....
....

PART 3: ENERGY MANAGMENT

Is building's thermal and electric energy consumption recorded?

YES ( ) NO ( )

If YES, specify recording frequency:

Weekly ( ) Monthly ( ) Annually ( )

Is there any building's Energy Management Program?

YES ( ) NO ( )

Remarks: ....
....

Is there any person Responsible for the information of the building administration / management about the energy consumption and its costs?

YES ( ) NO ( )

If YES, what is his area of expertise and occupational profile?

....

Has ever been drawn-up an Energy Balance of the building?

YES ( ) NO ( )

Remarks: ....
....

Have ever been organized sensitization actions addressing the occupants of the building (inhabitant, workers, visitors etc.), in energy conservation issues?

YES ( ) NO ( )

If YES, which are they?

....

....

....

....

....

Has any techno-economic energy study been done for the building, during the past years?

YES ( ) NO ( )

If YES, which was its subject?

....
....
....

Which were the energy conservation measures that have been implemented and when was implemented each one of them?

Energy Conservation Measure	Implementation Date
1.	
2.	
3.	
4.	

Remarks: ....
....

Which are the issues that the building administration / management needs more information on them in order to give priority to the energy efficiency measures?

Electricity Bills ( )
Building Envelope Thermal Insulation ( )
Building RES Exploitation Systems ( )
Central Heating Installation ( )
HVAC Installation ( )
Domestic Hot Water System ( )
Lighting System ( )
Energy Management Procedures ( )
Users' Sensitization Procedures ( )
Individual Building Particular Problems
1. ( )
2. ( )
3. ( )
4. ( )
5. ( )

Remarks: ....
....