Finnish Ministry of the Environment

English/Russian edition

ENERGY AUDIT GUIDE FOR BUILDINGS

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PREFACE

Interest in energy auditing is increasing in the areas of the former Soviet Union and eastern Central Europe. These countries are planning to set up an energy audit system and to promote energy auditing activities. Energy audits are one tool to improve energy efficiency. The aim of this guide is to give one view for energy audits. The guide is not in any respect an official guidebook, but a book to promote discussion on energy audits and the development of energy auditing. Until recently, very little has been published on energy audits in local languages. In addition to this English/Russian edition, similar editions are being published in Estonian and Latvian.

The number of pages of this guide has been kept to the minimum to make it easy to use. The style is not very technical so that “a layman” can understand the key message.

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1. INTRODUCTION

Energy and energy audits

Energy audit is a term used worldwide. As with all terms, the definition and the content of an energy audit differs from person to person and from society to society. In many countries like in Finland, governments subsidise energy audits. In some countries, the law may require that energy audits are carried out at regular intervals. In both cases, governments may require that energy audits are carried out in accordance with some form or regulation for obvious reasons. These regulations tend to differ from country to country.

For example in Finland there are some six different kinds of energy audit models. This diversity of models is mostly to rationalise the decisions concerning the subsidies for energy audits and to develop and control the work of auditors. Energy audits for buildings and industry should have a different emphasis. If the same subsidy scheme is applied for a school and for a paper mill, it is difficult to have a fare subsidy policy. However, the main principles of energy audits are applicable to both types of targets.

In the building sector, domestic water use and its saving opportunities are normally seen as a part of energy audits. When the phrase "energy audit" or energy in a general sense is used in this guide it includes both energy - fuels, heat and electricity - and water.

Definition of energy audit

Although there are many models for energy audits, we can give some common definitions for an energy audit. We can define the main idea of an energy audit very simply: It is a procedure to show how energy is used in a audited target, and what are the measures to save energy or to improve energy efficiency in the target. The scope and thoroughness of an energy audit depends on the audit model applied and on the available human and financial resources.

Objectives and scope of this building energy audit guide

In the ex-socialist countries governments plan to promote energy audits. The ways and the forms of the promotion are not yet clear. However, there is an urgent need for energy audit practises and procedures. How is this energy audit guide targeted? Because the financial opportunities of the governments differ and the governments have different plans to develop their energy audit schemes, the objective of this energy audit guide should be on the method side. The guide will show the main principles and the main approaches of energy auditing and how the thoroughness of an energy audit affects the procedures and methods of the energy audit. These general outlines on energy audits can be applied when energy audits are promoted. By reading this guide no one will become a qualified energy auditor. Hopefully, this guide will show what one has to do to become one.

In the ex-socialist countries, the main energy saving potential exists in the buildings built according to the ways and procedures of the socialist period.

This huge building stock will be the main target for energy audit activities in the future. The author of this guide has had a great deal of experience with energy and renovation projects of buildings from the socialist period. The buildings from the socialist period were in mind when the guide was written.

The main aim of this guide is to answer the question "What is a building energy audit?" An intention has been to write the guide so that both the clients of energy auditors and the energy auditors themselves will understand it. It is hoped that this guide will help to develop an energy audit market where the clients know what they want to order and to buy and where the energy auditors know what they should offer and sell. The guide is targeted at buildings, but it may also be useful for auditors working at industrial processes.

Energy audit models

Since the first energy crisis in 1973, the energy question has been one of the main topics in "the western world". Especially during the last couple of years, the volume of energy audits has increased remarkable due to the generous subsidy policy of governments and/or due to the requirements of law. Energy audit models deal more with the legal status and financing of energy audits as well as the training of energy auditors, administration and operating agents than practical energy audit methods and procedures. To promote and to give impetus to the discussions about the energy audit models, the energy audit models of Denmark, Finland and the Netherlands will be briefly introduced in chapter 5.

2. ENERGY AUDITS AND ENERGY AUDITORS

2.1 Why energy audits?

Energy audits can be seen as a part of building condition surveys - surveys that are targeted on the energy performance of a building. As condition surveys, energy audits are a useful tool for long term building renovation planning. Other ways to use energy audits are as follows:

- A statement of the energy quality of a building. A building energy certificate and energy labelling of the building are easily produced based on the audit reports. They are valuable for example when a building is for sale.
- One outcome of an energy audit is a list of energy saving measures and ways to increase the energy efficiency of a building. A housing owner can reduce energy and other costs by applying these measures.
- An energy audit may be advantageous when applying for a loan for a building renovation.
- In future, CO_2 emissions are very likely to become more and more important. Energy audits will be one tool to abate CO_2 emissions.

In the building sector energy saving measures are not necessary very profitable if seen only in an energy sense. However, If the energy saving opportunities of a building are seen in relation to the other improvement needs in a building, then the profitability of the proposed measures increases. For example, after additional insulation of walls heat will be saved but also cold and draught problems are decreased. The installation of additional insulation requires a new wall covering, which increases the service life of the building. Heat savings bring many other positive consequences.

2.2 Requirements of a building energy auditor

What are the requirements of energy auditors? Designers, consultants, contractors, and material and equipment suppliers should be familiar with the energy performance of the field they are experts in. Structural designers and consultants should be familiar with heat losses of walls and how additional insulation should be done. Heating and ventilation designers should be familiar with the energy performance of heating and ventilation and heat recovery systems. Designers of electrical systems should know for example the differences in energy performance between lamp types. Most of the knowledge necessary for energy audits is part of already existing expertise.

The expertise of energy auditing is not a very strict and separate field of skills, methods and procedures, but a combination of skills and procedures from different fields. The expertise of energy auditing covers the ways and the procedures how this already existing knowledge is put together to show the energy performance of a building and how the performance can be improved.

A well-grounded building energy audit should have expertise from the fields of heating, piping and air-conditioning (HPAC), structural engineering and electrical and automation engineering. Also, an “engineering thinking” architect is a valuable person for energy auditing. As can be seen, there are three kinds of expertise that are required: HPAC, structural and electrical/automation engineering. So, in principal a good energy audit requires three experts. However, in practise one experienced and motivated person can cover the three areas of expertise at the energy performance level. For example HPAC engineers have a deep understanding of HPAC technology but can after some training have a basic understanding concerning the energy performance questions of electrical and structural engineering. They can tell the scale of savings if the lamps or the light fixtures are replaced, or the savings caused by additional insulation. But if detailed energy saving proposals are required then they should consult electrical and structural engineers.

Different levels of energy audits are discussed in chapter 3.3. The more thorough the audit the wider range of skills is required. In Figure 2.1, the relations between the level of energy audits and the requirements of energy auditors is shown.

LEVEL 1

EXPERIENCED ENERGY AUDITOR

LEVEL 2

EXPERIENCED ENERGY AUDITOR.
IF NECESSARY CONSULTS WITH HPAC, STRUCTURAL AND ELECTRICAL/AUTOMATION SPECIALISTS

LEVEL 3

EXPERIENCED ENERGY AUDITOR IN CO-OPERATION WITH HPAC, STRUCTURAL AND ELECTRICAL /AUTOMATION SPECIALISTS

Figure 2.1.** **The levels of energy audits and the requirements for an energy auditor. See the levels in chapter 3.1.

The purpose of this guide is not to cover the energy saving details of each different expertise, but to show the components, the general methods and procedures and the reporting practices of an energy audit. Most of the details are normal engineering practice and a lot of books, reports and articles are published on them. Those who are planning a career as an energy auditor are strongly advised to become familiar with the details.

3. ENERGY AUDIT METHODS FOR BUILDINGS

3.1 Thoroughness of the energy audit

In the introduction, an energy audit was defined thus: “It is a procedure to show how energy is used in a audited target and what are the measures to save energy or to improve energy efficiency in the target.” When looking at the definition one can see that an energy audit has two parts: one is a study of the energy flows in the audited target and its subsystems such as air-conditioning and heating systems, and the other part covers the recommendations for efficient energy use. As with all work, you can do your energy audit more or less thoroughly.

THE THOROUGHNESS OR WORK REQUIRED BY AN ENERGY AUDIT DEPENDS ON MANY FACTORS SUCH AS:

- Type of target: for example hospitals and industrial buildings have more complicated energy systems and energy use than residential buildings. If we have the same sized hospital and residential building, the same level and the same quality of energy auditing can be achieved by less work in a residential building than in a hospital

- Experience of the auditor: If auditors are experienced and skilled, they can work more rationally and effectively and can show the energy flows and give the recommendations with less effort than a less experienced auditor. However, the thoroughness of an energy audit may be the same

- Costs of an energy audit: The quality of an energy audit depends on the number of man-days one can use for the energy audit. But more days means more costs, and after a number of days the quality of the energy audit is no longer increasing. The pricing of an energy audit may have a different basis. It may be stated that the auditing costs may be xx percentage of the energy and water costs of the audited target or the costs may be in relation to the volume and to the type of building or they may be based on an offer by the auditor

3.2 Scope and levels of an energy audit

An energy audit may include different components and activities depending on the audited target. In residential buildings, the activities and the objectives may be different than those in industrial buildings. The available resources for the energy audit as well as the available documents and statistic of the audited building provide a framework for the auditing activities.

What are the main activities of energy audits? Calculations of specific energy and water consumption are commonly used. Design and other technical documents of the audited building are necessary when the quality of the building is evaluated**,** and when proposals for energy saving measures and investments are prepared. Interviewing maintenance staff and other personnel as well as the occupants of the audited building is a very good source of information on the problems of the building. When the interviews are complemented with measurements concerning indoor air quality and thermal comfort and lightning levels, then a rather good picture on the real conditions of the audited building is achieved.

Heat balance describes how energy flows into a building (inputs) or its subsystems like air-conditioning, and how energy leaves a building (outputs). If it is possible to calculate a reliable heat balance for the audited building, then energy and water saving potentials can be reliably calculated and well-grounded energy and water saving measures and investment proposals can be presented.

The development of an energy audit market requires that clients should know what they want to order and to buy and energy auditors should make clear what they can offer and sell. It will promote the market if there are some examples and proposals for the contents of energy audits which could be used as a framework for discussions between the clients and the auditors. In Table 3.1 are three proposals for different levels of energy audits. Level 1 is a basic level and level 3 is the most thorough. *)

DESCRIPTION OF AUDITING LEVELS

Level 1

Level 1 is the basic level for an energy audit. It gives basic information on the opportunities for energy and water savings on a very draft (basic) level. This may be called a walkthrough audit

Level 2

The proposals for energy and water saving proposals are more thoroughly grounded than in level 1 and are based on some measurements

Level 3

Energy and water consumption is carefully studied and the proposals for energy and water saving measures and investments are so well-prepared that they are ready for implementation

*) If a country is planning an energy audit policy, these levels can help when guidelines are set for official energy audits

Table 3.1. The level of energy audits and auditing activities at different levels.

AUDITING ACTIVITIES	***LEVEL OF ENERGY AUDIT***		
	Level 1	***Level 2***	***Level 3***
Energy consumption and specific numbers	× [1)]	× [1)]	× [1)]
Rough evaluation of technical systems and interviewing of technical staff	×	×	×
Technical documents		×	×
Interviewing of building occupants		×	×
Measurements: light level		×	
Measurements: thorough level			×
Heat Balance		× [1)]	× [1)]
Saving potentials	×	×	×
Investment proposals: guiding		×	
Investment proposals: well-grounded			×

[1)] Possible if energy and water meters installed

3.3 Energy auditing activities

What should be the content of the components of Table 3.1 and what should be considered when the activities are carried out in practice?

3.3.1 Energy consumption and specific numbers

The main precondition for well-grounded energy saving measures are reliable energy and water meters. Meter readings tell the total energy and water consumption for certain periods, for example for one year. If there are no meters and meter readings, the presented energy saving potentials are only outlined. After the implementation of energy saving measures, a building owner will not be able to identify the savings if there are no reliable meter readings from prior to the implementation.

When comparing and characterising building energy consumption, certain specific numbers are useful. Commonly used specific numbers are the following: annual heat, electricity and water consumption per square metre or volume of building (kWh/m^2, yr or kWh/m^3, yr and litres/ m^2, yr or litres/ m^3, yr); In residential buildings water consumption is mostly specified by using water consumption per occupant and day (litres/occupant, d). These specific numbers can be easily calculated if energy and heat meters are installed and the meters are read regularly, which is the normal practice for example in the Nordic Countries.

TYPICAL SPECIFIC NUMBERS	
Heat	kJ/m^2, yr; kJ/m^3, yr; kWh/m^2, yr; kWh/m^3, yr
Electricity	kWh/m^2, yr; kWh/m^3, yr
Fuel	**oils:** litres or kg/m^2, yr; litres or kg/m^3, yr **gas:** m^3/m^2, yr; m^3/m^3, yr
Domestic water	litres/occupant, d; litres/m^2, yr; litres/m^3, yr

During the socialist period very few reliable energy and water meters were installed. After the collapse of the socialist system, meters have become more common. For those buildings which have water and energy meters a well-grounded energy saving measures can be presented, as well as the specific numbers calculated. The consumption of fuels is not necessary metered, and the recording is done in other ways. For example with oil a level gauge in the oil tank or the recording of oil tank filling are used.

Meter readings and their dates should be carefully registered. It should be kept in mind that the meters may have failures. For example if the quality of domestic water or district heating water is poor, the service life of a meter may be only one year when normally five years is easily achieved. If the readings are from longer periods, this helps to recognise the failures.

The way in which square and the cubic metres are calculated, should be made clear. The specific numbers are useless if it is not shown how square and cubic meters are calculated. The square metres and the volume of the building should be calculated in the same way as with the building stock to which the numbers are being compared. When specific domestic water consumption numbers are calculated, the number of occupants should be reliable. Care should be taken with “Dead Souls”.

If reliable specific numbers are available, they are the first indicator to show energy saving potentials. When more buildings are equipped with the meters, statistics for specific consumption numbers for different types of building stocks can be calculated. For example, in Finland the specific numbers are collected at constant intervals from a representative sample of Finnish building stock. Public organisations and societies like district heating companies and research institutes may be the collectors of the consumption data and the publishers of the specific numbers.

In case these kinds of databases are not available, experienced auditors can little by little collect a small database of their own. It is recommended that energy auditors calculate the energy and water specific numbers for every audited target whenever possible. This increases the auditor’s deep understanding of energy and water use. When auditors have a database on many similar targets, they can very soon tell something about the general opportunities for the energy and water saving potentials of an audited target.

3.3.2 Rough evaluation of technical systems and interviewing of technical staff

In the building stock from the Soviet and socialist period, there are some typical defects, which an experienced auditor can easily show. The balcony doors may be poorly insulated and leak much air. The gables of the buildings are poorly insulated and the plate between the cellar and the first floor is without insulation. The ejectors in the district heating substations are energy losses. After looking at these weak points, an auditor can get the first view of the saving potentials.

Furthermore, if an auditor interviews the maintenance and other staff of the building and also some occupants of the building, the auditor will get a lot of useful information concerning the history of the audited building and the defects in the building. However, the auditor should be critical with the comments of the interviewees because they are not necessary good experts on buildings and especially because the opinions of the occupants of buildings normally differ a lot concerning thermal comfort and the quality of indoor air.

QUESTIONS PRESENTED TO MAINTENANCE STAFF MAY BE OF THE FOLLOWING TYPES:
Are there any leaks in the roof?
Are there moisture problems with the envelope of the building?
Are there any general renovation needs for the envelope of the building? (rotten window frames, water leaks in seams of concrete plate, areas of insufficient insulation, etc.).
Are there leaks in domestic water, waste water or heating systems?
Are there cold or draughty spaces?
Are any spaces too warm during the heating season?
Are there any cooling needs?
Are there frequent interruptions in water, heat or electricity supplies?
Immediate repairs needed to domestic and waste water systems, heating and air-conditioning systems and electrical systems and how these needs should be taking into account when saving proposals are considered.

3.3.3 Technical documents

When a thorough auditing project is carried out, technical documents should be at hand. The technical documents help when the area of walls, doors and other parts of the envelope of the building are estimated. They include information on the designed structures of the envelope components, which are necessary when overall heat transfer coefficients ($W/(m^2 \cdot {}^oC)$, k-factor or U-factor) for the envelope components are calculated. They are useful when the operation of air-conditioning, heating, water servicing and electrical systems are studied and the saving opportunities of these systems considered. They are also useful when the costs of energy saving investments are calculated.

VALUABLE DRAWINGS AND DOCUMENTS FOR ENERGY AUDITS
Plan and section drawings of building
Schema of heating system
Schema of ventilation system
Schema of domestic water system
Schema of electrical and automation systems
Schema of boiler house
Specifications of main equipment and devices in different systems

The technical building documents give basic information on the audited building. However, one should be careful when these documents are used, because they are normally based on the design state. This is especially true of buildings from the socialist period where the real performance of the buildings may be something else than that indicated by the design documents.

3.3.4 Interviewing of building occupants

The occupants of an audited building are a valuable resource for finding out defects in the building and especially finding out problems with thermal comfort and indoor air quality. If the flats studied are chosen from different parts of the building for example spaces on gable sides, on the first floor and on the highest floor, etc, an experienced auditor gets a good view about the conditions in the building. Normally, in residential buildings it is enough if 10-20% of the occupants (10-20% of flats) are interviewed. Mostly it is wise to combine the interviews and measuring activities.

THE QUESTIONS PRESENTED TO OCCUPANTS MAY BE OF THE FOLLOWING TYPES:
Are there cold wall surfaces?
Are there spaces that are cold and/or draughty?
Are you satisfied with the quality of the indoor air?
Are there often interruptions in domestic water supply or in heating?
Are there leaks in taps or in toilets?

3.3.5 Measurements

The opinions of occupants on thermal comfort and indoor air quality are valuable. However, they should be supported by measurements because thermal comfort and air quality are to some extend personal opinions and may change in the course of time. If the prevailing opinion among the occupants is that the flats are too cold and the temperature measurements indicate that the indoor temperatures are 18-20 ^{o}C, then the auditor can be sure that cold is a real problem.

If 10-20% of flats are chosen representatively (see point 3.4.4), then measurements cover an audited building well. In other types of buildings, the auditor should use other grounds for the choice, but the weak points are often the same as with residential buildings. Spaces near gables are cold and in the middle of building perhaps too warm.

These systematic measurements will give a general view of the thermal conditions in a building. It is also wise to measure the spaces which occupants see as problematic in case they are not yet included in the systematic measurements. After successful energy projects, energy is saved and conditions improved. To achieve this goal, the problematic areas within an audited building should be recognised. In residential and office buildings an indoor air temperature of 21-23 ^{o}C is seen as favourable during the heating season. For manual work in industrial buildings some +15 ^{o}C may be favourable.

TYPICAL MEASURING INSTRUMENTS FOR THE ENERGY AUDITS OF BUILDINGS
Examples of basic instruments: air temperature, air humidity and air speed meters, manometers for measurements of differential air and water pressures; air flow meters for air-conditioning systems, surface temperature meters; illuminance meter for lighting level measurements; ammeter for electrical measurement
Examples of advanced instruments: CO_2 - meters; ultra-sound flow meters, energy analysers for advanced electrical system analysis, infrared camera for heat leakage detection

The humidity content of the indoor air tells something about the sufficiency of ventilation. The ventilation rate should be in a right relation to the moisture sources caused by people, washing rooms, etc. In winter, the relative humidity should be 30-70% because of health and technical reasons. If it is higher, it indicates that the ventilation rate is too low. Without a humidifier in normal flats during the coldest period of the year relative humidity easily drops under 30%. However, for a healthy person this is not a problem. If it is more than 70%, it increases moisture problems in wall structures especially in areas where insulation is insufficient. The wall structures may be destroyed and wet walls are favourable for mould growth, which causes dangerous health problems. The CO_2 - content of indoor air also tells about the sufficiency of the ventilation. Due to comfort and health reasons the CO_2 - content should not be more than 1500 ppm (part per million). Reliable CO_2 - meters are rather expensive.

In buildings with mechanical ventilation, it would be wise to measure the air flows of the main ventilation or air-conditioning units as well as the temperature of the supply and exhaust air flows.

Lightning makes up a large part of electricity consumption in office buildings and light industrial buildings. Seeking for energy efficiency does not mean worsening the lightning conditions. In these types of buildings it would be wise to measure and compare the lightning levels with the recommendations given for different kinds of activities. If the proposed energy saving measures include changes for example in light fixtures, it is important that the recommended lightning levels should be fulfilled after the improvements have been carried out.

Measurements concerning thermal comfort, air-conditioning air flows and lightning levels do not require very extensive measurements and the measuring instruments are not very expensive.

Wall surface temperature measurement gives information on the heat losses of walls. If an audited building has no electricity meter then an energy analyser can be used to measure the electricity consumption for one day or one week. The analyser also gives information on peak loads and on the quality of electricity (reactive power, etc.). An ultra-sound flow meter is useful when water flows should be measured in pipelines where there is no fixed flow meter or balancing valves offering flow metering opportunities. The measuring instruments to measure these quantities are rather expensive and require experienced persons to use them.

3.3.6 Heat Balance and distribution of energy use

Heat or energy balance is a useful tool to clarify energy use. Heat balance shows the energy inputs and outputs of a building. The balance helps to make sure that the building’s energy use is correctly understood. The inputs and outputs should be “the same”.

The main heat input is of course the heat required for space heating, air-conditioning and hot domestic water production. This means in practice district heat, heat from boiler house and electricity for heating purposes. Other than intended heat can be called free heating: Most of the electricity supplied to the building is also input because the electricity used by lightning and other equipment is transformed into heat. The people living or working in a building also release heat. In spring and autumn sunlight causes high heat inputs through windows. In a building with a well-operated control system these free heat sources will cover a large part of required heat. If the heat control of building is not working well - as it is normal with socialist based systems - then excess heating is very likely, especially in spring and autumn and the heat bills are unnecessarily high.

The outputs are the heat losses through windows and walls and other parts of building envelope and the heat of exhaust ventilation flows and air leaks. The water flows in waste pipes contain heat as well.

The equations and the procedures used in normal heating and cooling requirement calculations can also be applied when heat balance is calculated, see Annex 1. At the market there are many computer programs doing the same. The equations, databases and defaults of these programs should be clear otherwise the use of the programs is risky.

The main precondition for calculating the heat balance is that the heat inputs for space heating, air-conditioning and domestic hot water are registered, for example the amount of district heat supplied to the building is metered. Also, the domestic water meters are valuable as are the electricity meters. The meter readings should be from a period of at least one year. Sometimes it may be useful to build up a heat balance for example for one month. In this case, of course, the readings should be from this period.

Sometimes heat balance calculations require a lot of work and it is difficult to get enough similar inputs and outputs and a lot of suppositions need to be made. A difference between the inputs and the outputs indicates that something is missing. Usually, the main reason for the differences is that the annual operation times of energy systems differ from the information given by the maintenance staff or from the operation times in use when the auditor visited the building. For example, the operation times of air-conditioning units can be different: If it is expected that they are off during night times, when actually they are on, this means tens of percents more heat consumption. A good energy auditor is more or less a detective who has to be a little sceptic about all information.

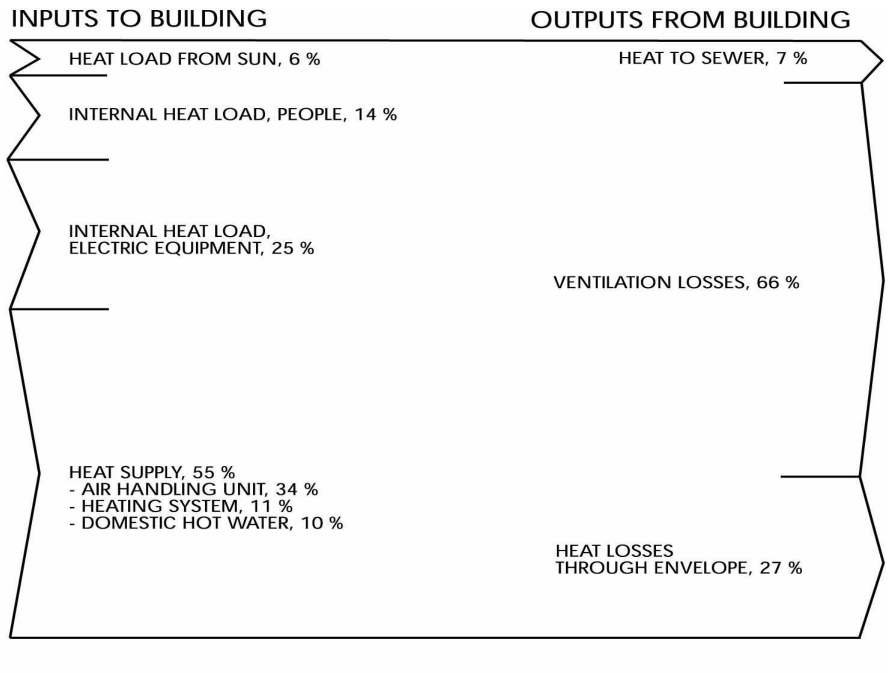
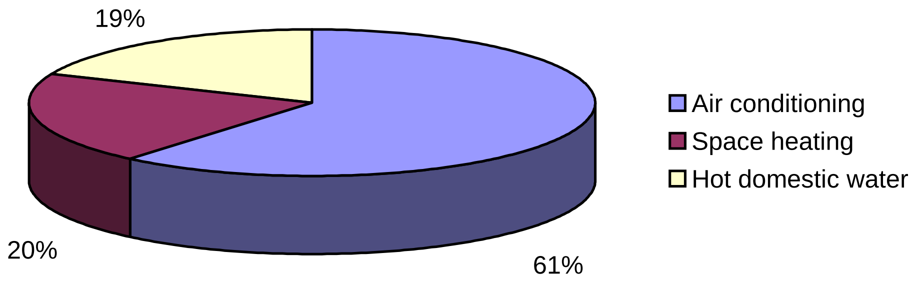


Figure 3.1. An example of the heat balance of a building.

In Figure 3.1 is shown an example of a heat balance. In Figure 3.2 is an example where electricity and heat supplied to a building are divided into components. At least at this level, energy use should be known. The most sophisticated way to express the energy flow is a Sankey-diagram as shown in Figure 3.3. This diagram is very illustrative because it also expresses the energy flows inside a building. However, it requires a lot of work and is very seldom necessary in building energy audits.

DISTRIBUTION OF HEAT SUPPLY



DISTRIBUTION OF ELECTRICITY CONSUMPTION

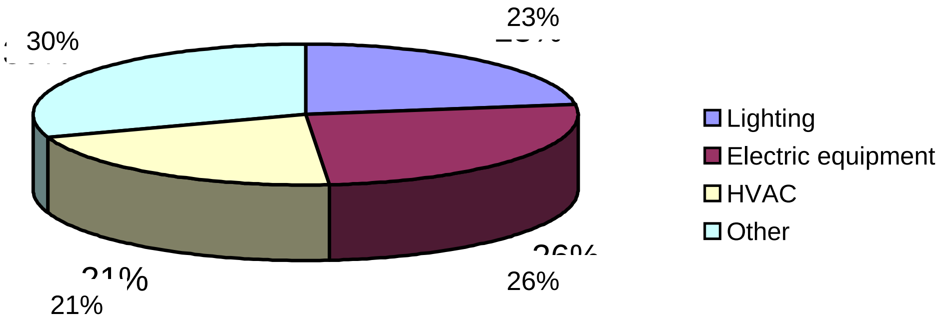


Figure 3.2. An example of the distribution of heat and electricity consumption in a building.

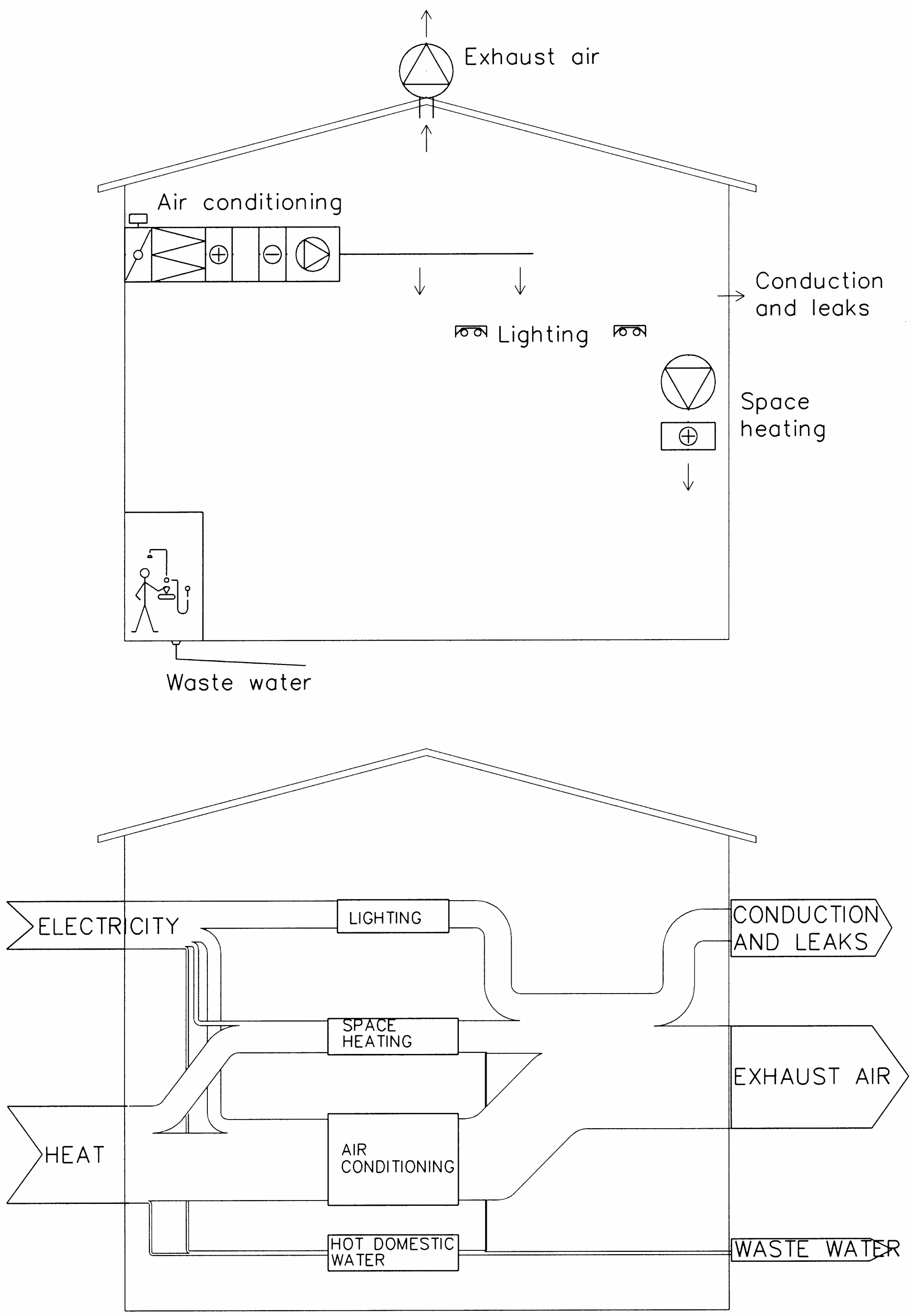


Figure 3.3. An example of a Sankey-diagram of a building.

3.3.7 Pricing of energy

In an environmental or engineering sense the physical unit kWh, kJ, or tons of CO_2 -emissions may be enough to describe the changes caused by energy saving measures. But if the profitability of the measures is considered then the physical units should be converted into monetary units. Oils and solid fuels are priced based on physical units like euros/litre, euros/ ton, etc. There may also be some conditions for the quality of fuels and for the terms of delivery. These are especially important with bio-fuels like wood chips and peat. The moisture content and the net caloric value (lower heating value) for example between loads of wood chips may differ, which means that tons of fuels are not directly comparable. The transportation costs of fuels are very important because they may cover tens of percentages of the end user price of the fuel. It is important to know whether or not the transportation costs are included in fuel pricing.

Fuels are burned in boilers that have a combustion efficiency that expresses which percentages of the net caloric value of the fuel can be converted into usable heat. With the best gas or oil fired boilers this efficiency should be instantaneously over 90%. In some cases, it may be under 90%. Especially with solid fuel fired boilers the efficiency is less than with the oil and gas fired boilers. The efficiency of gas or oil fired boilers may be less if the effect of a boiler is not correctly adjusted to the heat demand or if the burner is not working properly.

When an annual combustion efficiency is considered it will be clearly less than instantaneous efficiency. The gap is bigger the more the boiler is off or on low loads, because the off and low load periods increase the flue gas and radiation and conduction losses of the boiler in proportion to the net heat supplied for the heating system. In actual energy pricing, the combustion efficiency should be taken into account. To get the actual fuel price, price per kJ or KWh, etc, it should be divided by (annual) combustion efficiency. Also, the capital costs and maintenance costs of boiler house should be considered in energy pricing. The share of the capital costs may be even tens of percents of heat price especially with boilers working on low loads.

The energy carriers that are normally supplied through networks such as natural gas, district heat and electricity, have their own pricing. Normally when the client makes a new contract with a network company one should pay a connection charge which covers the costs of the connection. Consumption may be charged simply based on the recorded units consumed. The unit prices, euros/kWh, euros/m^3, are agreed between a supplier and its clients. More advanced rates have fixed price components which are more or less based on peak loads, for example euros/kW/month. If peak loads are charged, money can be saved by cutting the peaks. With these advanced rates the total price of energy is a sum of the unit prices and the fixed components: the number of consumed energy units is multiplied by the unit price of energy and the fixed price components are added. To get the total unit price this sum is divided by consumed energy units. Normally, the more stable the consumption the less you should pay per energy unit.

PRICING OF ENERGY, THINGS TO BE TAKEN INTO ACCOUNT
Transported fuels: net caloric value (lower heating value) of fuel, combustion efficiency of boiler (and boiler house), quality of fuel, transportation costs of fuel, capital costs, maintenance costs, internal consumption of heat and electricity in boiler house and other operating costs than energy
Energies transfer in networks: connection charges, unit pricing of energy (net caloric value of fuel), fixed costs, maintenance and operating costs

With domestic water the pricing may have two components one for fresh water and one for wastewater. Normally, the total charge is a sum of both.

Auditors should be familiar with the pricing of energy otherwise it will not be possible to implement reliable energy saving measures and to carry out energy saving investment calculations. If the audited target has a choice between different energy rates, auditors should check which one is the most economical for the target. Sometimes, it may be economical to change from the audited target's own boiler to district heat or vice verse. Auditors should be able of comparing the pricing of different heat and energy sources. However, the change from one energy source to another cannot be based on the “daily” and temporary development of energy prices, but on long-term thinking.

3.3.8 Saving potentials

The condition of a building can tell an experienced energy auditor a lot about the energy saving opportunities. Especially in the socialist based building stock there are commonly known saving opportunities, which should be familiar to an energy auditor. This is especially true for residential buildings. For example, replacing an ejector in a district heating substation with a heat exchanger with a modern control unit will give 10-30% heat savings from the total heat consumption depending on the case. Replacing poor double glazed windows with new modern triple glazed ones may decrease heat losses in windows by 50%, but may mean only some 5% reduction in the total heat consumption. One degree of overheating may mean a 5% increase in space heating. These kinds of rules of thumb can be used as a firsthand tool when saving potentials are evaluated. But as always with rules of thumb, the auditor should know their limits.

Auditors should evaluate the savings potentials based on real information from the audited target. The rules of thumb are not recommended in the final reporting. Energy saving potentials, energy saving investment and energy saving measure proposals should be reliably based. For example the expected savings caused by a modern district heating substation are not realised in a case where the building has been too cold even before the investment due to under heating.

Saving potentials include only the energy savings in energy and/or in monetary terms, but not the costs of energy saving measures. When the net costs of the measures are combined with the net saving revenues, the economy of the measures can be calculated.

3.3.9 Saving measures and investment proposals

3.3.9.1 Scope and type of proposals

Proposals for saving measures include both the saving opportunities and the costs of savings. So, they are valuable when decision-makers are planning energy efficiency projects.

Most of the energy saving measures for buildings are not very profitable in an energy sense. If the energy saving opportunities are considered together with the renovation needs, then the measures are in most cases more profitable. When the energy savings from window replacement are combined with the other effects of the measure such as the extended service life of the windows and better thermal comfort, the measure is more attractive. In many cases, these other effects may be the main reason to implement the proposed measure. In the energy audit report, these other positive or sometimes also negative effects should be mentioned, although they are not studied in depth.

In some cases, the energy auditing of a building and a condition survey of the building are combined. In a condition survey, the condition of the building is studied in depth more than in an energy audit. Energy and water saving proposals are a part of a condition survey and a building development project.

Savings proposals can be called guiding or less comprehensive if the investment costs are based on unit or specific prices: Replacing a district heating substation costs xx euros/kW, which is applied to the estimated size of the substation in kW; Additional insulation in gables costs xx euros/m^2, which is applied to the total area of the gable. So this kind of pricing is very handy and does not require much time if the energy auditor has good price databases. In most case, this kind of pricing is enough, if carefully done, for investment proposals at the decision-making level.

A saving proposal can be called well-grounded or comprehensive if they are approaching a design level of documentation. The proposals may include draft drawings of the structural changes in walls necessary for additional insulation or draft drawings of the changes in pipelines because of the installation of balancing valves and a modern district- heating substation. This kind of detailed work should be carried out if decision-makers have already made the decision to invest in energy efficiency and have resources for investment. This kind of drafting should also be done at the light level if it is presumed that there may be a lack of space for “some energy saving equipment” - for example heat recovery equipment in air-conditioning needs extra space - or additional insulation on the facade side of a building may be difficult to build. Drafting is a good way to clip the wings of unrealistic proposals.

The energy savings measures may only require changes in set values of air-conditioning or in operational practice. At the other end of the scale, there are additional insulation investments in the building's envelope and heat recovery units of the air-conditioning. So there are expensive and less expensive measures.

ENEGRGY SAVING MEASURES ARE COMMONLY DIVIDED INTO THREE CATEGORIES:

I:	Measures that do not require any investments. For example advice to decrease indoor air temperature one degree or advice to use plugs in a washbasin instead of running tap water when rinsing dishes
II:	Measures that require minor investments. For example a new control system for heating or air-conditioning or the repair costs of leaking domestic water pipes
III:	Measures that require large investments. For example replacing the whole heating system or investments in a new boiler

3.3.9.2 Investment evaluations and calculations

Energy saving measures and investments are normally based on economic factors. In the future, other aspects may also be more emphasised. A reduction in CO_2- emissions may be the main reason to invest in energy efficiency rather than profits in monetary terms. When the energy and water saving measures are based on profitability in monetary terms normal investment calculations methods are applied. Normally, concerning energy (and water) saving investments and measures, the cost components should be divided into the following:

Investment (capital) costs and costs of capital:

For example additional insulation, a heat recovery unit in air-conditioning or a new DH substation cause investment costs. Sometimes, it is possible to sell some equipment, which is being replaced or is left unused for other reasons. This kind of income can be subtracted from the investment costs due to energy saving measures. After this subtraction, one gets the net investment (capital) costs. Costs of capital include the costs of borrowing money, i.e. interest rates. If no interest rates or other financing costs are included then investment (capital) costs are the costs to be paid, for example, to a contractor for carrying out an energy saving measure.

Changes in energy and water costs:

These costs are based on the energy and water saving opportunities from the saving potential calculation. In some cases, especially when heat is saved, electricity consumption is increased. Typically, heat recovery units in air-conditioning increase the electricity consumption because fans require more pressure. The net savings are increased electricity consumption subtracted from heat savings.

Changes in other costs: This category includes changes in maintenance costs, in consumables and in labour costs. For example if a roof gets additional insulation and a new leak proof rubberised bitumen membrane, the maintenance costs are decreased because yearly leak hunting and leak repairs are not necessary. A heat recovery unit in air-conditioning may increase filter costs and other maintenance.

Other effects:

Some of the expected consequences of saving measure are difficult to express in monetary terms. For example, if the envelope of a building is renovated, heat is saved but the service life of the building also increases, the appearance of the building improves and thermal comfort in the building gets better. These consequences are of course valuable but difficult to express in monetary terms. In some cases, these other effects may be the main reason to invest or it can be said that some improvements in a building also reduce energy consumption. There may also be some negative effects that are difficult to express in monetary terms. These effects should also be on the table when decisions are made.

The first step in an investment calculation is to gather the information on the project costs and benefits in order to calculate the cash flow for the investment. This will show how much money is spent or earned in each year of the project. The difference between earned and spent money shows the net savings. If the net savings are the same (or average savings are used) for every year during the project's lifetime then the simplest investment calculation method "payback period" is easy to calculate: The net investment (capital) costs are divided by the average net annual savings. This is the most commonly used investment economical evaluation method. In Table 3.2 are some suggested examples of payback periods. Other quite often applied methods are average rate of return, net present value and internal rate of return, See Annex 2.

Investments include risks. Before implementation, it may wise to do risk and sensitive analyses, especially for large and expensive investments. For example the prices of energy may cause uncertainties for the profitability of investment or there may be setbacks with the saving investments and the investment costs are higher than estimated. Also, the inflation rate causes uncertainties. It is beyond the scope of this guide to deal more deeply with these investment evaluation and calculation methods. They are applied for all kinds of investments, and there are many books and reports on these topics.

Table 3.2. Suggestive examples of payback periods of some energy saving measures.

SAVING MEASURES	*PAYBACK PERIOD*
Replacing an ejector with a modern substation	1-4 years *)
Additional insulation of gables	7-25 years **)
Balancing water flows in heating system and new balancing valves	2-4 years *)

*) Depending on how much overheated before replacing

**) If increased service life of building and better opportunities for heat balancing are considered then shorter payback period can be justified

3.3.9.3 Reporting of measures

In the audit report, the evaluation and investment calculation methods to be used are mentioned. Also, expectations concerning energy and water prices should be made clear. The principles of how the different kinds of costs and earnings are dealt with should be mentioned (see chapter 4). For easy comparison, it is wise to present the proposed energy and water saving measures in a clear form or table. The form (see below) may include the following items: name of measures, description of measure, net capital costs in monetary terms, net savings both in monetary terms and for energy also in energy units, economy of measures means payback period, etc, ranking of measures means a scale between the most and less favourable measures, other, attachments means other effects that are difficult to express in energy or in monetary terms or things which should be considered when the measure is implemented. References to attachment concerning drawings and other background information can be mentioned here.

The measures are targeted on the envelope of the building, on the heating and air-conditioning system of the building, on the domestic water and waste water systems of the building and on the electricity systems of the building. It is wise to use these same categories when measures are reported. For example industrial, hospital and other special buildings may have special systems which may require additional categories like steam systems, pressure air systems, clean water systems, etc. On the other hand, these special systems are not necessary included in building energy audits.

In the report, the summary of energy and water saving and efficiency measures may be presented as follows:

EFFICIENCY MEASURES IN ENVELOPE OF BUILDING

Measure	Description	Net capital Costs	Net Energy Savings	Eco-nomy	Ranking In energy sense	Other, attachments
1. Addtional insulation of gables	100 mm more insulation covered by ceramic plates	30 000 euros	140 MWh 3 900 euros	Payback period 8 years	Low	Part of the savings due to lower heat losses through gables and partly because indoor air temperatures can be reduced due to better thermal comfort. Service life of building will increased because of no rainwater leaks
2. …						
n. …						

EFFICIENCY MEASURES IN HEATING AND AIR-CONDITIONING SYSTEMS

Measure	Description	Net Capital Costs	Net Savings	Eco-nomy	Ranking in energy sense	Other, attachments
1. New district heating substation	Ejector is replaced by modern substation	12 000 euros	150 MWh/yr 4 100 euros	Payback period 3 years	High	Improved control of heating will save energy and improve thermal comfort
2. …						
n. …						

EFFICIENCY MEASURES IN DOMESTIC WATER AND WASTE WATER SYSTEMS

Measure	Description	Net Capital Costs	Net Savings	Economy	Ranking in energy sense	Other, attachments
1. Pressure valve	Installing a constant pressure valve in main domestic water supply pipe	2 800 euros	2500 m^3 of water/yr 4 300 euros	Payback period 0.7 years	High	Lower pressure of domestic water means lower water consumption. Savings due to lower water and heat consumption
2. …						
n. …						

EFFICIENCY MEASURES IN ELECTRICAL SYSTEMS

Measure	Description	Net Capital Costs	Net Savings	Economy	Ranking	Other, attachments
1.: Control of outdoor lightning	Timer replaced by light detector	1 000 euros	50 MWh/yr 3 700 euros	Payback period 0.3 years	High	-
2.:						
n.:						

3.4 How building type affects auditing activities

Is there any difference between building types and auditing activities? Buildings use heat in space heating, in air-conditioning/ventilation and to produce hot water. Depending on the energy (heat) sources, these are done in different ways. However, all heat sources can be applied to all types of buildings from residential to office and industrial buildings. The same similarity is also true with electricity and water use in different kinds of building. There are differences, but it is mainly a question of emphasis.

In principle it is the same whether heat recovery is applied to air-conditioning systems in offices or in industrial buildings. Auditors should carry out the same tasks in all kinds of buildings when applying heat recovery. Auditors should consider which heat recovery system would be the most suitable for a target building – for example a fixed surface exchanger or a rotary air-to-air exchanger. Auditors should also do the energy saving and economical calculations for the various heat recovery alternatives. The auditor should check that there is enough space for the recovery units and the necessary auxiliary equipment. After these tasks are completed, the auditor can tell what is the best choice or is it reasonable to apply any heat recovery alternative at all.

Some differences that an experienced energy auditor should know are for example that in socialist style residential concrete blocks, heat recovery systems in air-conditioning units are in most cases uneconomical or/and difficult to apply but for office or industrial buildings they may be more suitable. So it is not wise to use much time for considering heat recovery in residential buildings. An experienced auditor should focus on the most promising points of the audited building.

Heat bridges - areas in the walls where insulation is poorer than in other parts of the walls - may be found in the walls of residential and office buildings. Again an experienced auditor should know where the possible weak areas in the walls maybe found. These heat bridge areas may differ between different types of buildings.

Other examples: Practically all buildings have free heat, but the intensities differ. Free heat (W/m^2) is normally bigger in industrial buildings than in office or residential buildings. This is because in industrial buildings there are normally many production machines, the connected power of which may be over 100 kW per machine. In office buildings, free heat is gained only from lightning, office machines and people; The water use habits in residential buildings differ from the ones in industrial buildings.

As a conclusion: There are of course differences, as described above, but the applied methods are the same. Only the emphasis may differ among the building types.

4. REPORTING ENERGY AUDIT

During an energy audit, a lot of technical documents and other information have been reviewed, measurements have been made and people have been interviewed. What should be reported from the energy audit? Of course well-reported energy saving proposals are the most important, but also information on the grounds and other facts on which these proposal are based is in some extent valuable to report.

The reporting practices depend on the auditor. A good audit report is also a good advertisement for the auditor. If we want to promote the development of auditing services, it is not wise to give very strict orders or advice on what the audit report should include and how it should look. If all auditors develop their own reporting, this will make sure that the product “energy audit” will also develop. Although it is favourable that there is competition among auditors, it would be good to give some good ideas. The following are titles, which are suitable for use in audit reports.

Introduction. Introduction tells why the energy audit was carried out and who was involved with the audit, what were the objectives of the audits, etc.

Technical documents and energy and water consumption data. This will briefly explain the main technical documents which the auditor has had. Energy and water metering and pricing of energy and water should be presented. Statistics concerning energy and water consumption should be reported, if possible from the last 3-5 years. Also, the volumes, the square metres and the number of occupants of the audited building should be reported and the specific numbers as well. The conclusions that can be made, especially from the specific numbers.

Description of the building. The technical systems of the building and the envelope of the building should be briefly reported especially concerning the energy performance. The pre-conclusions concerning the quality of the building.

The results of interviews and measurements. The main principle on how the interviews of the staff and the occupants as well as the measurements are carried out. The results of interviews and measurements and what conclusions can be made from the interviews and the measurements.

Energy and water saving proposals. The content of this is described in chapter 3.

General conclusions and recommendations. Here the main findings are presented and advice and recommendations on what should be done first and how to go ahead with the proposed measures are given.

Annex. Here can be draft drawings, measurement reports, interviewee comments, etc.

What these titles include depends on the level of the energy audit. If the audit has been on the light level, see Table 3.1, then for example the measurements are not included.

5. ENERGY AUDIT SYSTEMS AND MODELS

5.1 What are energy audit systems or models

The key elements or the main tools of energy audits were introduced In the previous chapters of this guide. The aim has been to introduce sound auditing practices as energy audits are carried out from initial data collection and analysis to final reporting. These sound practises can be applied in different economic and social environments. Every society has its own objectives and reasons to promote energy audits. In the past, the main objective was to save money but today the emphasis is more and more on the climate change, how to mitigate CO_2 -emissions. The circumstances define how the sound auditing practises are applied, as does the kind of energy audit systems or models that are in use.

Experience from other countries is very useful if one is analysing the possibilities for the establishment of an energy auditing system. Unfortunately, there are not very many possibilities to analyse the experience of the countries that are in the transition process, e.g. Russia, Latvia, Estonia, Poland and other Central and Eastern European countries. In the transition countries the energy auditing systems are not very strong, usually in the development or starting phase. More experience can be gained from the West European countries.

To promote the discussions on energy auditing systems in the transition economies experiences from Denmark, Finland, and the Netherlands are introduced. It is clear that the circumstances in these countries differ from the transition ones and that their experiences are not easily applicable in the transition countries. However, as a stimulus they are valuable.

In the three country presentations, the Save-project's Final Report is used as a reference. The report can be downloaded from www. motiva.fi/audit. The report, written in English, is recommended because it includes a lot of information on the energy audit models, systems and programmes in Europe.

5.2 Finland

Finland has one full-scale official energy audit programme, the Energy Audit Programme. The energy audits are voluntary. The Programme includes management procedures, 6 different energy audit models which are all subsidised, auditor training, auditors authorisation scheme, monitoring system concerning the audited targets, quality inspection of the audit reports and active dissemination of auditing practices and auditing information. The Ministry of Trade and Industry (MTI) launched the programme in 1992. The programme is targeted to industries and to buildings. The operating agent of the programme is Motiva, Information Centre for Energy Efficiency, established in 1993.

Motiva is in charge of the actives concerning the development and governing of audit procedures, training, monitoring and the dissemination of information. Motiva also has other energy related activities such as to promote the Finnish Government's Energy Strategy. Finland has 15 Regional Employment and Economic Development Centres. They assist Motiva by being responsible for handling the applications and the payments of the audit subsidies as well as the preliminary inspection of the energy audit reports.

The audit subsidy is 40-50% of the accepted auditing costs, which are based on the buildings volumes (m^3). The bigger the building the bigger the accepted costs. However, increasing volumes decrease the relative accepted costs and the relative amount of subsidy as well.

The MTI is subsidising the implementation of the following 6 Motiva Energy Audits models:

Energy Inspection: very small tertiary (=offices and service buildings, etc.) and industrial buildings.

Building Energy Audit: basic model for tertiary buildings.

Industrial Energy Audit: lighter model for industries with low energy intensity in the production process (light industries).

Industrial Energy Analysis: heavier model for industries with medium energy intensity in production processes.

Process Industry Energy Analysis: two-step audit model for industries with high energy intensity in production processes.

Post-acceptance Energy Audit: model for new and renovated tertiary and industrial buildings.

As can be seen, not all the models are for buildings but also for industrial processes. The tools applied by these various models are in principle the same as described in this guide's chapters 2-4. The differences between the models are more or less a question of thoroughness and scope.

5.3 Denmark and The Netherlands

In Denmark the energy auditing system is on a more obligatory basis than in the Netherlands. In the case of the Netherlands, the energy auditing system is more voluntary but it is also on a very strong basis.

In April 1996, the Danish Government realised the fourth plan of action in the field of energy. The Danish plan of action - Energy 21 includes a number of new initiatives to secure the fulfilment of the goal of reducing the national CO_2 emissions during the period up to 2005. The goals of the energy policy in Denmark are:

- To contribute to a sustainable development;
- To meet the international challenges;
- To maintain economy, employment and competitiveness;
- To enhance the utilisation of renewable energy sources;
- To increase efficiency in all energy services.

There are different kinds of audits in Denmark. The energy audits are depending on the kind of buildings, the use of buildings and the size of buildings. Based on energy audits, buildings have an energy labelling which tells the energy performance of buildings. Three major schemes of energy audits are:

- Energy labelling in small buildings (less than 1 500 m^2 total floor area). The energy labelling has to be done when the building is sold and should be done during the previous three years.
- Energy labelling in large buildings or energy management (more than 1 500 m^2 total floor area). The energy labelling has to be done annually.
- The CO_2 scheme for industry. Voluntary energy audit for the production sector.

Because the audits are more or less obligatory in Denmark, the annual audit volumes are high.

The energy auditing system in the Netherlands is completely different to Denmark - mostly it is on a voluntary basis and there are a lot of governmental programmes for the stimulation of the auditing process. One of these programmes is described in more detail below.

Recently, the Dutch government has taken a number of initiatives to intensify energy-saving and environmental policies. For example, the CO_2 reduction plan, the Sustainable Construction action plan and the Third White Paper on Energy Policy were published, many aspects of which are already being realised. The environmental issue has also been given a high priority in the Netherlands.

The EMA programme aims to stimulate companies and organisations to make a systematic and complete research of measures leading to energy savings and less environmental pollution. In addition to being an individual Energy Audit Programme, EMA is the main host programme of the most commonly used Energy Audit Model within the Long Term Agreements. These agreements are voluntary agreements between the Ministry of Economic Affairs and a particular business sector regarding efforts to improve energy efficiency by a specific percentage within an agreed period.

Besides that, the EMA-audits also meet the audit criteria that are being used by the government to give permits under the environmental laws. Every small and medium sized company can apply for support to undertake an EMA audit on a voluntary basis. The audit has to be carried out by an external independent advisor, and the maximum support is 50% of the costs, with a maximum of 15 000,- guilders (7000 euros).

The goal of the EMA programme is to stimulate small and medium sized companies and non-profit organisations with residency in the Netherlands to make a systematic and complete research of measures leading to energy savings and less environmental pollution. In 1994, more than 500 projects were subsidised through the programme. Both small and large enterprises participated in the programme. Since the EMA programme was transferred to SENTER in 1998, the objective has been to assist 600 companies and non-profit organisations a year. There is no formal procedure for authorising the auditors. However, relevant information with regard to experience, competence, etc. is informally gathered on new consultants and auditors joining the scheme.

ANNEX (APPENDIX) 1

HEATING AND COOLING LOADS AND ENERGY CONSUMPTION IN BUILDINGS

For the sake of clarity, a short description of some of the concepts used in this report is presented. The definitions are very general and are meant only to clarify the substance of the concepts.

HEATING LOAD

Generally, the heating load of a building can be calculated according to the following equation:

$$Ø = (Ø_{loss.} + Ø_v + Ø_i + Ø_{dw} - Ø_{int.}) / \eta$$

where

$Ø$	heating load	kW
$Ø_{loss.}$	heat losses through envelope	kW
$Ø_v$	heating load of ventilation	kW
$Ø_i$	heating load of infiltration	kW
$Ø_{dw}$	heating load of domestic water	kW
$Ø_{int.}$	net utilized internal heat gain	kW
η	efficiency of heat generation	

Heat losses through envelope

$$Ø_{loss.} = \Sigma[k \cdot A \cdot (t_i - t_a)]$$

where

$Ø_{loss.}$	heat losses through envelope	kW
k	overall heat transfer coefficient of element of envelope	$W/(m^2 \cdot °C)$
A	area of element of envelope	m^2
t_1	indoor air temperature	°C
t_a	surrounding air or soil temperature	°C

Heating load of ventilation

$$Ø_v = \rho \cdot c_p \cdot q_v \cdot (t_s - t_a) - Ø_{HR}$$

where

$Ø_v$	heating load of ventilation	kW
ρ	density of air	kg/m^3
c_p	heat capacity of air	kJ/(kg · °C)
q_v	ventilation air flow (ventilation rate)	m^3/s
t_s	supply air temperature	°C
t_a	outside air temperature	°C
$Ø_{HR}$	utilized heating effect recovered from exhaust air by heat recovery equipment	kW

Heating load of infiltration

$$Ø_v = \rho \cdot c_p \cdot q_{vi} \cdot (t_s - t_a)$$

where

$Ø_v$	heating load of infiltration	kW
ρ	density of air	kg/m^3
c_p	heat capacity of air	kJ/(kg · °C)
q_{vi}	infiltration air flow	m^3/s
t_s	supply air temperature	°C
t_a	outside air temperature	°C

Internal heat gain

In defining the heating load of a building, the internal heat gain must be taken into account as much as it can be utilized in heating. The utilized heating effect recovered from exhaust air by heat recovery equipment $Ø_{HR}$ is part of the internal heat gain. The internal heat gain consists of heat released from equipment, lighting, other electrical loads and persons. In defining the net internal heat gain, the heat gain through the building envelope must be taken into account.

The internal heat gain must also be calculated when estimating the cooling load of the building.

In office buildings the internal heat gain varies for example as follows

- lighting 10…20 W/m^2
- persons 3…12 W/m^2

In the following table, measured internal heat gains in industrial premises are presented.

INDUSTRY	*INTERNAL HEAT GAIN W/m^2*
Manufacturing of bakery products	80-200
Textile, wearing apparel industries	70-230
Manufacturing of furniture	45
Printing and publishing	40-120
Manufacture of glass and glass products (furnace department)	500-1000
Manufacture of concrete and concrete products	20-40
Manufacture of metal fabricated products, machinery and equipment	40-100

COOLING LOAD

The cooling load of a building consists of heat released from internal and external sources.

External factors:

- solar radiation through fenestrations and other parts of the building envelope
- heat transfer through the building envelope because of warmer surrounding air
- infiltration due to wind and temperature differences
- ventilation air flow (ventilation rate)

Internal factors:

- industrial processes such as machining, drying, baking, etc.
- electric motors
- equipment
- steam or hot water pipes, hot water tanks, etc.
- lighting
- people

Cooling load of ventilation

If cooling is carried out by ventilation, the cooling load of ventilation (cooling coil load) is calculated according to the equation:

$$Ø_c = \rho \cdot q_v \cdot (h_s - h_a)$$

where

$Ø_c$	cooling load of ventilation	kW
ρ	density of air	kg/m^3
q_v	ventilation air flow	m^3/s
h_s	required supply air enthalpy	kJ/kg
h_a	outside air enthalpy	kJ/kg

ENERGY CONSUMPTION

HEATING ENERGY CONSUMPTION

Generally, the heating energy consumption of a building can be calculated according to the following equation:

$$Q = (Q_{loss.} + Q_v + Q_i + Q_{dw} - Q_{int.}) / \eta$$

where

Q	heating energy consumption	kWh
$Q_{loss.}$	heat energy losses through envelope	kWh
Q_v	heating energy consumption of ventilation	kWh
Q_i	heating energy consumption of infiltration	kWh
Q_{dw}	heating energy consumption of domestic water	kWh
$Q_{int.}$	net heating energy utilized by internal heat sources and solar radiation	kWh
η	efficiency of heat generation	

Heat energy losses through envelope

$$Q_{loss} = \Sigma[k \cdot A \cdot 24 \cdot S] / 1000 + q_s \cdot A$$

where

Q_{loss}	heat energy losses through envelope	kWh
k	overall heat transfer coefficient of element of envelope	$W/(m^2 \cdot °C)$
A	area of element of envelope	m^2
24	coefficient converting degree days to degree hours	
S	heating degree days	°Cd
1000	coefficient converting Wh to kWh	
q_s	energy flow density through elements of envelope adjacent to soil	kWh/m^2

Heating energy consumption of ventilation

$$Q_v = \rho \cdot c_p \cdot q_v \cdot t \cdot 24 \cdot S \cdot r \cdot t_w - Q_{HR}$$

where

Qv	heating energy consumption of ventilation	kWh
ρ	density of air	kg/m^3
c_p	heat capacity of air	kJ/(kg°C)
q_v	ventilation air flow	m^3/s
t	operation time of ventilation/day	h/24 h/d
24	coefficient converting degree days to degree days	
S	heating degree days	°Cd
r	coefficient taking into account the daily operation time of ventilation	
t_w	operation time of ventilation/week	d/7 d
Q_{HR}	utilized heating energy recovered from exhaust air by heat recovery equipment	

Heating energy consumption of infiltration

$$Q_i = \rho \cdot c_p \cdot n_v \cdot V \cdot 24 \cdot S / 3600$$

where

Q_i	heating energy consumption of infiltration	kWh
ρ	density of air	kg/m^3
c_p	heat capacity of air	kJ/(kg°C)
n_v	infiltration air flow, air exchanges per hour	exchanges/h or $(m^3/h)/m^3$
V	building volume	m^3
24	coefficient converting degree days to degree hours	
S	heating degree days	°Cd
3600	coefficient converting times/h to m^3/s	

COOLING ENERGY CONSUMPTION

$$Q_c = 24 \cdot BLC \cdot CDD \cdot /COP$$

where

24	coefficient converting degree days to degree hours	
BLC	building loss coefficient	W/°C
CDD	cooling degree days	°Cd
COP	coefficient of performance of air conditioner	

ANNEX 2

INVESTMENT CALCULATION METHODS

Here are summarised the most commonly used investment calculation methods: Payback, Net Present Value (NPV) and Internal Rate of Return (IRR). See also chapter 3.3.9.2 in this report.

Payback

The most commonly used and easiest method is simple payback. The simple means that there is no interest rate expected for the investment costs. Example: If it is calculated that net savings per yr are 4300 euros and the net investment costs 2800 euros, the simple payback period is

$$\frac{\text{Net investment costs}}{\text{Net annual savings}} = \frac{2800}{4300} = 0.7 \text{ yr}$$

The example shows that it takes less than one year when the investment will be paid back in savings caused by the investment. If the payback period is more than 5 years - valid for most savings measures of the building envelope (walls, windows etc.) - then care should be taken. The social and economic conditions may change so much that the profitability of the investment is in danger. As a rule, with longer payback periods investments should include other positive effects that cannot be evaluated in monetary terms, like better indoor climate and longer service life of building. These effects will be achieved although the energy savings may be partly lost.

Net Present Value (NPV)

For every year is calculated a net cash flow, i.e. savings less expenditures cause by a saving measure. These cash flows may differ year by year, for example during the first years the investment cannot be used in full-scale. These cash flows from each year can be added.

For the investor, the sum invested will grow because of the interest paid. The longer one must wait for the savings the more the capital costs will be. Discounting means that the interest rate and the point of time when the cash flows and investment costs are generated is taken into account. In most cases, the cash flows are discounted for the year(s) of investment, it is called the Present Value. If net cash flow is used then one gets the Net Present Value (NPV). Discounting is done by using a discounting factor which can be taken from tables (example below) or by calculating the factor.

Year	***Discount (interest) rate***		
	5%	***10%***	***15%***
1	0.952	0.909	0.870
2	0.907	0.826	0.756
3	0.864	0.751	0.658
4	0.823	0.683	0.572
5	0.784	0.621	0.497

The cash flows are discounted to the present year by multiplying the cash flow by the discount factor. If it is supposed that every year the cash flows are the same, then we get the NPVs for the example above (Lifetime is 5 years and discount rate 10%):

1 yr	0.909 × 4300 euros	=	3909	
2 yr	0.826 × 4300 euros	=	3552	
3 yr	0.751 × 4300 euros	=	3229	
4 yr	0.683 × 4300 euros	=	2937	
5 yr	0.621 × 4300 euros	=	2670	
∑			16297	euros

During its 5 year lifetime the investment will bring Net Present revenues that are 5-6 times the investment costs (16297/2800).

As can be seen from the example table and the example calculations, the higher the discount rate and the further in the future the revenues will be generated the less valuable they will be. This shows that if the costs of capital are high (i.e. interest rates are high) and one has to wait long for the revenues of a energy saving measure the less profitable the measure will be.

<u>Internal Rate of Return (IRR)</u>

The Internal Rate of Return (IRR) is the discount rate for which the total income from the investment, once discounted, equals the initial investment. For the investment should be expected a lifetime. The IRR is the discount rate at which the Net Present Values are zero.

The IRR is a tool to compare investments. The higher the discount rate the more profitable the investment.