Shared training program for energy auditors -
Manual for Energy Audits

About project

The EU today finds itself in conditions where Energy Efficiency (EE) investments have become strategically important due to the high level of energy imports required by the EU block, energy price instability and the need for transition to a competitive low carbon and resilient economy. In addition, energy efficiency investing has a fundamental and beneficial role to play in the transition towards a more competitive, secure and sustainable energy system with an internal energy market at its core.

Notwithstanding the "win-win" characteristics of EE investments, existing investment flows in EE are sub-optimal. Currently, with the exception of buildings constructed in the last decade, Albanian buildings have no insulation. According to the EED (Directive 2012/27/EC), Albania will have to achieve an annual 1.5 percent energy sales savings compared to the recent three-year period through the use of a utility obligation scheme or other alternative approach. Montenegro has also been implementing the EE Programme in Public Buildings since 2012 and is planning to complete the programme by the end of 2020. Montenegro plans to invest EUR 6 million in the implementation of energy efficiency measures at 18 health care facilities by 2023, as part of the Montenegro Energy Efficiency Project 2 (MEEP 2). Partners of the project share the idea that public buildings should be an example of best practise to energy saving, improving energy efficiency through innovative techniques and good habits and consumers' behaviour. According to this goals, they would like to propose "REEHUB +". HUBs will be get stronger in REEHUB +, capitalizing results of REEHUB and connecting experience with similar Mediterranean regions, as a network, to increase EE awareness at regional levels. REEHUB+ will boost new energy policy and energy efficiency approach for future building local rules.

The main overall objective of the project is:

Partners of the project share the idea that public buildings should be an example of best practise to energy saving, improving energy efficiency through innovative techniques and good habits and consumers' behaviour. HUBs will be get stronger in REEHUB +, capitalizing results of REEHUB and connecting experience with similar Mediterranean regions, as a network, to increase energy efficiency awareness at regional levels. The main results of REEHUB was the energy efficiency audit model for public building sector. This will serve as an input for REEHUB+, as a tool to boost new energy policy and energy efficiency approach for future building local rules. REEHUB+ aims to strengthen the role of HUB as an "agora" where local policy maker of Italian and Balkan coasts can have open dialogue with citizen, building material industry, designer and green SMEs for the implementation of local energy plan.

Project Specific Objectives are:

Pilot actions on energy efficiency audit as a best practice – Albania and Montenegro have adopted the EED Directive in the last years and the energy performance diagnosis is not applied yet. For this reason Partners believe that through a demonstrative action we can show to local and national government how to audit a building in the best way and using the necessary instrumentation.

Raise awareness on RES and RUE application in public and private sector – The objective is to promote the integration of renewable energy and energy efficiency technologies in old and new buildings in the project countries. Undertaking RES and RUE measures will contribute to overcome the lack of information which is still one of the prevailing obstacles for new technologies integration into buildings.

The project main result is:

The project result is that the audit methodology identified and published in the REEHUB project should be used wider for the energy performance of public buildings in order to demonstrate to local administration and other stakeholders how to reduce the energy consumption through guaranteeing human comfort, health and safety, according to the cost effective opportunities for energy savings.

Project partnership is made of 5 partners with a Lead partner Barleti Institute for Research and Development from Tirana.

Barleti Institute for Research and Development	BIRD	Albania
Ministry of Infrastructure and Energy	MIE	Albania
National Energy Technological Cluster Scarl	DiTNE	Italia
University of Montenegro, Faculty of Architecture	UoM	Montenegro
MUNICIPALITY OF AGNONE	MoA	Italia

Total value of the project is 718,200.00 EUR.

Duration of the project: 18 months (01/09/2020-28/02/2022).

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This Manual results from the tender no REEHUB Plus – T02, the expected result of which is connected to the activities of the REEHUB Plus project:

- A.T.1.1. Energy performance diagnosis of public buildings in each region
- A.T.1.3. Manual for Energy Efficiency in Old and New Buildings
- A.T.2.1. Shared training program for energy auditor
- A.T.2.2. Training organization

The company **Expeditio Architects** d.o.o. has been selected to carry out the stated activities.

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Energy Audits

Energy audit of a building entails an analysis of the energy properties of the building envelope and its technical systems in order to establish the present energy consumption, and provide conclusions and recommendations for improving its energy efficiency.

The main goal of an energy audit is to obtain a detailed insight into the existing energy condition of the building through collecting and analyzing a set of data about the building construction characteristics related to thermal protection, and energy properties of different energy and water consuming systems, after which practical measures for increasing energy efficiency are proposed. These measures refer to:

- Improving the thermal properties of the external envelope;
- Replacing or improving the heating system;
- Replacing or improving the ventilation system;
- Replacing or improving the cooling system;
- Replacing or improving the air conditioning system;
- Replacing or improving the domestic (sanitary) hot water preparation system
- Improving the lighting system and the system of electric appliances (consumers);
- Replacing fuel in cases when it is economically and environmentally cost-effective;
- Introducing renewable energy sources;
- Using water rationally;
- Improving the control and management system.

All the proposed packages of measures include the data on the technical characteristics of the implementation of measures, energy savings that can be achieved by them, evaluation of investment, and possible economic savings. Based on the comparison of the obtained results, a report is prepared with recommendations for an optimal selection of measures.

The purpose of a detailed energy audit

The main goal of an energy audit of the building is to obtain, through collecting and analyzing the data about technical systems in the building, insight about the energy properties of the building regarding:

- construction characteristics related to thermal protection,
- energy properties of air conditioning, heating, cooling, ventilation and lighting systems,
- the presence and energy properties of certain groups of appliances,
- the building's management structure and users' approach to energy issues.

Based on the collected data analysis, practical energy, economically and ecologically optimal energy efficiency measures for the given building are selected.

The energy audit serves two basic purposes:

• to analyze conditions and possibilities for implementing measures to improve the energy performance of the building and increase its energy efficiency,

• it is a basic tool for determining an energy consumption class in energy certification of buildings.

Types of energy audits

Depending on how detailed research is, there are two types of energy audits:

- Preliminary energy audits
- Detailed energy audits

A preliminary energy audit (often called a walkthrough audit) involves a brief insight into the energy state of the building to establish the potential for increasing its energy efficiency. That includes a visual survey of the envelope condition and energy infrastructure in the building, energy analysis of those elements, followed by recommendations for increasing energy efficiency. The site visit takes one day and may include some minor measurements. Based on the preliminary energy audit, a decision is made if a detailed energy audit is needed.

A detailed energy audit entails a detailed energy analysis of the construction and technical systems in the building. Compared to a preliminary energy audit, a detailed audit includes additional measuring to fully evaluate the energy performance of some building systems and a more detailed analysis of the applicability and cost-effectiveness of some energy efficiency measures. A report on the detailed energy audit proposes measures accompanied by both business and financial plans.

According to buildings age, energy audits can be:

- Energy audits of new buildings
- Energy audits of the present buildings

Energy audits of new buildings are not the subject of this manual because the primary purpose of such analyses is the certification of buildings. That process is more simple than energy audits of the present buildings because it uses, to a large extent, the data from the project documentation and does not provide a detailed analysis of measures for improving energy performance. This manual primarily deals with analyzing energy characteristics of the present buildings providing explanations on how such features could be improved by implementing adequate energy efficiency measures.

Energy audits of the present buildings are carried out following the legislation of each country. An important starting point for a detailed energy audit of an existing building is the data about the time of its construction and the knowledge of construction characteristics of the given period. An energy audit aims to provide, following a current situation analysis, recommendations on how to reduce energy needs by improving the thermal characteristics of the external envelope and typical energy-consuming systems in the building, as well as on the possibilities for using alternative energy sources.

This Manual mainly focuses on Detailed Energy Audits because they are a more complex type of audits. Once you master the methodology of their development, it is easy to conduct a preliminary energy audit.

It is important to note that each country has its legislative framework governing this area. It primarily refers to calculation methodology, reference data on energy consumption, climate characteristics, and the minimum approved amounts of electrical and thermal energy classes, nationally approved software for the calculation of energy performance of buildings, etc. Before undertaking an energy audit, you should acquaint yourself well with the national legislative framework so that the detailed energy audit you perform is valid. Detailed energy audits are always carried out by authorized persons. Rules and conditions on performing energy audits and adequate trainings of energy auditors are also important.

Phases of the detailed energy audit

An energy audit can begin after signing a contract with the energy audit client, defining, among other things, the goal and scope of the audit.

All the activities related to energy audit can be divided into three phases:

Phase 1: Activities before the site visit

Phase 2: Activities during the site visit

Phase 2: Activities after the site visit

Phase 1: Activities before the site visit

Step 1 Initial meeting with the energy audit client

An energy audit begins with an initial meeting with the energy audit client, during which the client is acquainted with the activities to be carried out as part of the planned energy audit. For an auditor to be prepared for the site visit and to form a first picture of the building and its energy performance, the client should provide the following data/documents:

The existing technical documentation;
Data about energy and water consumption in the building, i.e., the copies of bills for all consumed fuels and water (preferably for the 3 last years, and at least for last 12 months);

A completed questionnaire with basic information about the energy state of the building. It would be very useful to have the completed questionnaire before the planned site visit.

Step 2 Analysis of the existing technical documentation

Technical documentation that preferably should be available to the auditor **before the site visit** concerns the following preliminary or main projects:

- Architectural project;
- Project of Construction structure and other Building constructions;
- Project for a water supply system and sewerage system;
- Project for high and low voltage electrical installations;
- Project for HVAC systems (heating /ventilation /cooling /air conditioning);

Other projects and studies, such as a landscaping project, environmental impact assessment, fire protection, thermal and sound protection of the building, energy efficiency, etc. depending on the purpose of the building.

*When the mentioned project documentation is missing, **any drawings or sketches of the site**, schemes of installations distribution, equipment specifications, etc., can be of great use.*

In addition, measurement books, contractors' building diaries, and building maintenance projects can be very useful.

When technical documentation for the existing building is not updated or is completely missing, the auditor should use the present documentation and subsequent visual survey, possible measurements, and photo documentation to make assumptions important for further analyses. It might be useful if the building is built in a typical style so that necessary information can be obtained from the data on another building of the same type.

If the engineering physics of the building external envelope cannot be precisely determined from the present documentation and the site survey, this information can be assumed from the engineering physics of the external envelope characteristic of the period when the building was built and the corresponding heat transfer coefficient.

If the project documentation is completely missing, such a situation requires additional work that is very important to be defined when contracting an audit. The absence of project documentation can be overcome by the building survey conducted by the auditor or the survey commissioned independently of the energy audit.

Step 3 Analysis of the building's energy and water consumption based on the existing bills

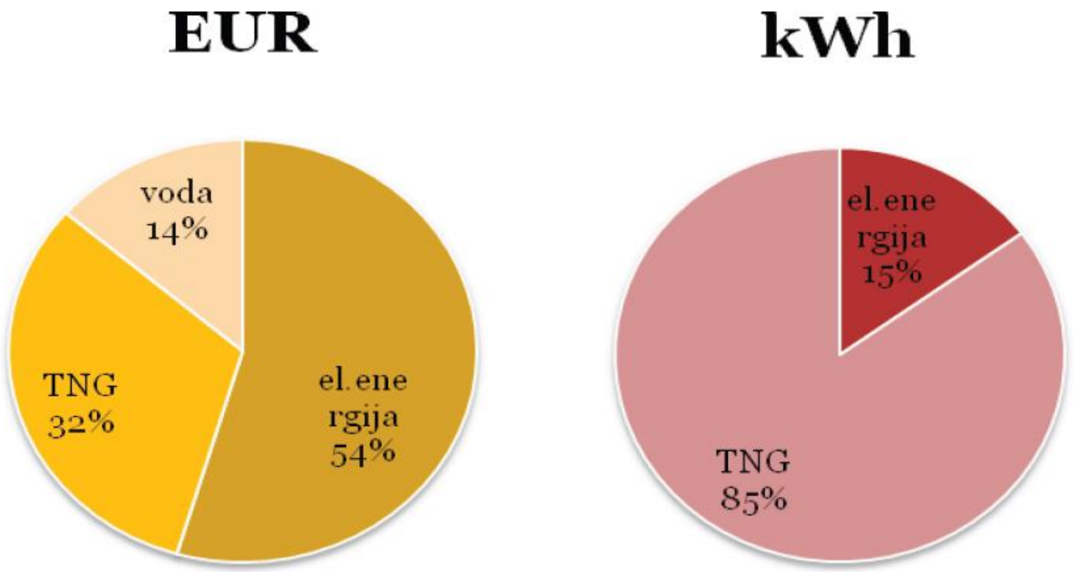
It is most effective if the data on energy and water consumption in the building is analyzed through a period of **3 years**, enabling thus energy consumption modeling and assessment of the energy needs of the building.

Based on the available bills for all the types of fuel and water, **energy balance** and **cost balance** are calculated. The energy balance represents the consumption of individual energies in the total annual energy consumption, while the cost balance includes costs for energy/fuels and water in a given building. These balances should be linked to the activities in the building in order to form an idea of energy and water consumption.

Presentation of data in that way emphasizes the importance of certain types of fuels/energies in the total energy consumption in the building.

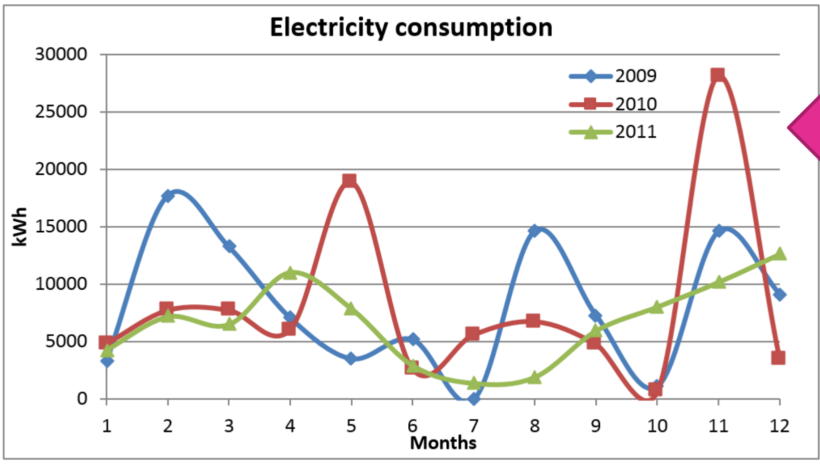
The consumption of each type of fuel/energy and water should be shown **separately**. The consumption data can be presented in a graph and a table.

The graphic presentation of energy consumption by months can point to some obvious conclusions, such as shown in the examples in image below (peaks in winter and summer periods refer to the consumption of electricity for heating or cooling).



Cost balance and energy balance

By comparing the consumption of fuels/energy or water over the years, we can find out whether the monthly and annual consumption is balanced or if there are any irregularities that point to a possible malfunctioning of one of the systems, an error in the bill for a given fuel, etc..



Monthly electricity consumption (kWh) for the years 2009, 2010 and 2011

Year	Jan	Feb	Mart	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Total
2009	3.345	17.726	13.271	7.100	3.540	5.205	0	14.663	7.290	1.134	14.628	9.165	97.067
2010	4.830	7.740	7.740	6.061	18.892	26.37	5.622	6.750	4.768	690	28.115	3.421	97.266
2011	4.295	7.185	6.514	11.040	7.886	2.951	1.395	1.934	5.969	8.041	10.189	12.631	80.030

The analysis of energy and water consumption based on the available bills is very important in order to compare the consumption and energy needs of the building determined by calculation. For that purpose, it is necessary to establish **referential annual energy or water consumption**. Usually, the consumption in the last year during which no disturbances in activities on the site, in energy and water supply, were recorded and for which bills for the consumed fuels/energy and water are available is taken to be a referential consumption. In addition, it is necessary to consider the changes in the energy performance of the building and its technical systems (taking into account the last year after introducing the changes).

If the monthly and annual consumption during the period for which the data are available (preferably 3 years) is balanced, an average consumption over the last 3 years (or the period for which the bills are available) can be taken as referential consumption. When the monthly and annul consumption is unbalanced, those months or the whole year in which the consumption is unrealistic (deviates from the usual one) should be excluded, and only the data compatible with the realistic use of the building should be included in an average to establish the referential consumption.

The annual consumption costs in the referential year are calculated using the latest available market prices for energy or water. **The same prices will be used to calculate the cost-effectiveness of energy efficiency measures**.

When there are major discrepancies between the calculated and actual consumption (the consumption according to the available bills) in the building, these discrepancies need to be explained. For example, the reason for the discrepancy may be how the building is used during the heating season. When the actual (referential) consumption is much higher than the calculated one, the cause may be the unnecessary overheating or excessive ventilation of the rooms, the absence of nightly and daily mode of operation, etc. If the actual consumption is lower than the calculated one, it is necessary to check whether this happens because the thermal comfort in the building has not been maintained.

Some important indicators that need to be calculated include:

The energy/water consumption indicator *is the ratio of energy/water used to satisfy a need in the building and the corresponding measurable quantity which affects the consumption.*

Electricity consumption indicator – a total electricity consumption expressed in [kWh/year] used to meet the needs of a given building comes down to the surface of usable area of the building AK expressed in [m^2] and the number of occupants.

Thermal energy consumption indicator – a total thermal energy consumption expressed in [kWh/year] used to meet the needs of a given building comes down to the surface of usable area of the building AK expressed in [m^2] and the volume (gross, net) of the heated part of the building expressed in [m^3].

Water consumption indicator - water consumption in buildings comes down to the number of occupants and is expressed in m^3/(person × year) and L/(person × day) or to the surface of usable area of the building AK expressed in [m^2]

Step 4 Energy audit preparation and organization

After you have analyzed the data collected by a questionnaire and have been partially acquainted with the building through present technical documentation and energy/water consumption analysis based on the available bills, it's time to start planning the site visit and energy audit.

Below you can find several useful proposals and suggestions on how to prepare for the site visit in the best way:

- Prepare **questions** for the building owner/technical staff regarding any doubts that have arisen during the analysis of energy/water consumption based on the existing bills (unexpected peaks in the graphic presentation of energy/water consumption, unexpected consumption in some periods, the bills accuracy, etc.);
- It would be useful to prepare **drawings** (of the ground plan and façade, if they exist), in several copies to take notes during the site visit, and record the types of walls and windows, spotted damages, locations of thermal installations equipment, conditioned spaces, level of lighting and elements of other technical systems in the building;
- Make a **plan of visit and plan of necessary measurements** to be carried out;
- Prepare the **necessary instruments** and equipment for carrying out the planned measurements: thermometer, temperature data logger, lux meter, thermographic camera, flue gas analyzer, anemometer, ultrasonic flow meter, network analyzer, etc.;
- You should also bring a meterstick, a long tape measure, a compass, etc. (especially in cases when the project documentation is missing);
- Don't forget the **camera**! Prepare the camera, making sure it is set to the highest resolution to get the best quality photos, the card has enough memory, the battery is charged, etc.

Phase 2: Activities during the site visit

Step 5 Survey of the existing state of the building

The preparatory activities are followed by the site visit and energy audit. The site visit aims to provide more information about activities in the building, engineering and energy characteristics of the building, how the building is managed and maintained, and the occupants' habits.

The site visit should begin with a short introductory meeting with the director/energy audit client, who is the owner or user of the building. At this meeting, the person in charge of the building's maintenance, who possesses technical and operational data about the equipment and systems in the building, should be made available to the auditor during the energy audit. In addition, a person should be appointed, who will be in charge of providing information about the building even after the visit, if needed.

During the building survey, it is necessary to check the data collected by the questionnaire, and obtain other important information and data not collected in that way or those that can be collected only at the site. Some common data about the building that are checked or collected at the site include the floor area and layout of the rooms, details of the building envelope elements, technical data on energy and water supply systems, conditions and parameters used when designing the building, conditions and parameters in building's operation, the mode/regime of use, etc.

Photo documentation collected during the site visit is very important for preparing a report on the energy audit in the best possible way. In addition, photo documentation is of great help in later additional analyses and surveys of details of the building's technical characteristics.

A survey of the building's present state includes the collection of data about:

The building envelope characteristics related to **thermal protection**;
Energy properties of the **heating** system;
Energy properties of the **ventilation** system;
Energy properties of the **air conditioning** system;
Energy properties of the **cooling** system;
Energy properties of the system for **domestic (sanitary) hot water preparation**;
Energy properties of the **lighting** system;
Energy properties of **other electric appliances**;
Energy properties of **drinking and domestic water consuming systems**;
Energy properties of **specific systems**

While surveying the above systems, attention should be paid to the following elements for which the data need to be collected (in order of the listed systems):

The external envelope of the building

Building

- Compare whether the constructed and designed states match;
- Identify places and details that do not match;
- Record any additions/extensions, or changes to the building;
- Check measures if the documentation is of poor quality;
- Establish orientation of the building on the site;
- Establish whether the building is dug in the ground

External walls

- Identify layers of the wall and their thickness;
- Establish if there is thermal insulation and indicate its type;
- Record all types of walls and their orientations;
- Establish if there are any damages to the walls and record them;
- Record all fasteners, girders, canopies, awnings, ...;
- Establish if there are any places damaged by water penetration
- Identify any specific stylistic and other details on the facade;
- Identify any specific design elements (bay windows, drains, brackets, curved surfaces, passages, etc.);
- Check the parapet walls, if their thickness is reduced, materials changed, etc.;

- Identify all cold (thermal) bridges (linear and point thermal bridges)

Roof

- Identify all types of roof (flat or sloping);
- Identify the roof structure;
- Identify layers of each roof's type and their thickness;
- Establish if there is thermal insulation and indicate its type;
- Establish if a roof is passable (in case of a flat roof);
- Establish if there are any damages to the roof and describe them;
- Record how the atmospheric water drainage is solved and note any damages;
- Establish if there is waterproofing and if it is adequate;
- Establish if there are any damages in the building caused by water penetrating from the roof;
- Indicate the type (lying, hanging) and state of gutters and vertical pipes;
- Establish if there is an attic (if the roof is flat)
- Analyze the junction between the roof and wall plane;
- Identify all penetrations through roof surfaces (vertical chimney, various girders, etc.);
- Identify if there are roof windows, skylights, etc.

Windows and doors

- Identify all types of windows and their orientation;
- Divide windows into different types if they differ in dimensions, kinds, number and thickness of glasses, frame material, type of frames, type of windows, type of sun shading ;
- Record the state of windows according to their types, with brief descriptions;
- Mark in the sketch the windows with damages and describe the damage;
- Mark the windows in a way that it is clear what measures will be proposed for each type of window;
- Mark the windows that fulfill thermal requirements;
- Identify the recently replaced windows ;
- Identify all kinds of sun shading and their characteristics

Floor

- Identify all types of floors (depending on their finishing and layers);
- Check actual and constructed surfaces according to floor types;
- Establish if there is thermal insulation

Heating system

- Make a note of the data on the boiler plate;
- Describe the condition of boiler, its casing, insulation, installations;
- Describe the condition of safety equipment;
- Make a note of the data from the burner plate;
- Describe the condition of the chimney and the connection to chimney;
- Check if chemical treatment of water exists;
- Indicate the temperature regime of the heating system;
- Provide information about the boiler room and mark its position in the drawings/sketches

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- Indicate the type of fuel and how it is supplied;

- Make a note of the data from the nameplates of the fuel storage and the fuel supply system;
- Describe the condition of installations for the fuel storage and supply;
- Describe the condition of safety equipment for the fuel storage and supply;
- Determine the fuel consumption based on the tank filling data

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- Describe the general condition of pipework and fittings;
- Describe the condition of pipeline insulation;
- Provide information on circulating pumps and their regulation;
- Check if the hydraulic balancing of the system exists

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- Specify the type of heating emission bodies, their total number and installed heating capacity by types, and mark their locations in the drawings/sketches;
- Describe the condition of heating emission bodies
- Check if the heating emission bodies have regulation valves

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- Indicate the type of the regulation system and it's compatibility with the heating system, i.e., characteristics of the building;
- Establish if there are zones with different heating temperatures;
- Record the locations of temperature sensors;
- Make a note on possibility of monitoring of physical quantities to be regulated

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- Specify the regime of operation of the heating system (on/off, set-back temperature);
- Describe the maintenance of the system;
- Check if the consumption of fuel and delivered energy is monitored;
- Check the availability of the documentation for the boiler and its equipment, as well as the connection schemes;
- Check if there is a book on boiler inspection and maintenance;
- Register the data on periodic inspections if they exist

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- Check if there are individual heating appliances in the building;
- Specify the types, number, installed capacity, operating mode, and general condition of the individual heating appliances in the building

Ventilation system (heating)

- Specify the data about the ventilated space (description and size);
- Provide information about the requirement for air exchange and quality (temperature, humidity);
- Make a note of the data on the air handling unit plate (number of units, type, year of production, total installed electrical power and capacity of the system);
- Mark the location of the air handling units in the drawings/sketches;
- Describe the condition of the air handling unit

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- Specify the type and capacity of the air heater;

- Describe the condition of the air heater
- Indicate the source of thermal energy used by the air heater (data from the boiler nameplate);
- Describe the state of the boiler, the casing, insulation, installations;
- Provide information on circulating pumps (type, power, condition) and their regulation;
- Check if there are filters, humidifiers, cooling coils and specify their type and capacity;
- Provide information about fans (type, power, condition) and their regulation

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- Describe the ductwork (material, cross-section, insulation);
- Describe the condition of ductwork;
- Indicate if there are regulating flap valves;
- Identify the elements for air distribution (grilles, diffusers, etc.);
- Identify the inlets for fresh air supply and the outlets for the exhaust air discharge;
- Indicate the proportion of fresh air;
- Indicate the quantity and temperature of the exhaust air;
- Indicate the quantity and temperature of the supplied air;
- Check if air recirculation is used;
- Check if there is a heat recovery system and indicate its type and efficiency;
- Describe the regulating system and its condition;
- Make a note on possibility of monitoring of physical quantities to be regulated

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- Indicate the regime of operation of the ventilation system;
- Describe the maintenance of the ventilation system;
- Indicate the age of the system and its general condition

Cooling/air conditioning system

Indicate the type of cooling/air conditioning system (local or central)

Local cooling system

- Specify the type of system (mono-split, multi-split, compact units);
- Specify the number of units (indoor and outdoor) and mark their locations in the drawings/sketches;
- Indicate the total installed cooling capacity;
- Specify individual cooling capacities;
- Check if there is an option for heating as well;
- Specify the average cooling/heating factor (EER/COP);
- Specify the type of cooling agent;
- Describe the regulation of the cooling system;
- Indicate the regime of operation of the cooling system (on/off);
- Describe the maintenance of the system;
- Indicate the age of the system and its general condition

Central cooling system

- Specify the total installed cooling capacity;
- Specify the type of chiller (compressor or absorption);

- Specify the number of chillers and mark their locations in the drawings/sketches;
- Make a note of the data on the chiller's nameplate (type, power, efficiency, temperature regime);
- Specify the type of refrigerant;
- Specify the age and describe the condition of the chiller;
- Specify the energy source used by the chiller;
- Check if there are cooling towers (specify their number and mark their location in the building);
- Check if free cooling is used;
- Check if evaporative cooling is used (specify airflow, saturation effectiveness);
- Check if the availability of the heating option

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Check if there is a heat pump (specify the source and sink, number of pumps and their locations in the building);

Make a note of the data on the heat pump nameplate (type, cooling/heating capacity, EER/COP);

Specify the age and describe the condition of the heat pump

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- Check if the air handling unit exists (specify the number of units, type, year of production, total installed electric power and capacity of the system);
- Check if there are filters, humidifiers, heaters, cooling coils and specify their type, capacity, and energy source;
- Provide information on circulating pumps (type, power, condition) and their regulation;
- Provide information about fans (type, power, condition) and their regulation;
- Check if there is a heat recovery system and specify the type and efficiency of the system;
- Mark in drawings/sketches the location of the air handling unit within the building;
- Describe the condition of the air handling unit

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- Specify the type of energy carrier (water, air);
- Describe the ductwork (cross-section, material, insulation, regulating flap valves);
- Describe pipe distribution (two-pipe or four-pipe, the material, insulation);
- Specify the age and describe the condition of the duct/pipe distribution;
- Identify terminal units (specify their type, number, installed power, and mark their locations in drawings/sketches)

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- Describe the regulation system of chillers and terminal units;
- Check if there are zones with different cooling temperatures;
- Make a note on possibility of monitoring of physical quantities to be regulated

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- Indicate the regime of operation of the cooling system;
- Describe the maintenance of the cooling system

System for domestic hot water (DHW) preparation

- Indicate how DHW is prepared (decentralized, central system)

Decentralized DHW preparation

- Specify the type of device (storage or flow heater), number, type of fuel, total capacity, and capacity by types;
- Specify the amount of water consumed in the building;
- Specify the water consumption locations in the building (type and number, the way of use and number of uses);
- Specify the operating regime of the device;
- Describe how the device is maintained;
- Indicate the age of the device and describe its condition;

Central DHW preparation

- Specify the heat source (existing boilers used for heating of the building, separate DHW boilers);
- Make a note of the data on the boiler nameplate;
- Describe the condition of the boiler, casing, insulation, installation;
- Make a note of the data on the tank nameplate (volume, etc.);
- Describe the condition of the tank and the insulation;
- Describe the pipe distribution system (material, insulation);
- Check if there is a leakage in the system;
- Specify the temperatures of water (hot/cold);
- Check if the hot water consumption is measured;
- Describe the regulation of DHW preparation system;
- Specify the quantity of water consumed in the building;
- Specify the water consumption locations in the building (type and number, the way of use and number of uses);
- Specify the regime of operation of the system;
- Describe the maintenance of the system;
- Indicate the age of the system and describe its condition;

An electric power system and consumption measuring

- Check the condition of the main distribution cabinet in the building, and the local distribution cabinets;
- Make a note of the results of IR camerawork of the distribution cabinets which indicate the unwanted heating of cables, circuit breakers, fuses, and other elements;
- Indicate the type, cross-section, and state of the main electrical power cable;
- Indicate the age of installations, the latest date when the electrical installation system or its parts were repaired or reconstructed;
- Indicate the voltage level, location, and method of power supply of the building;
- **Establish if regular maintenance is carried out and if the contracts for maintenance** of electrical installations in the building exist;
- Establish if a certificate of proper functioning of electrical installations has been issued in the last three years;
- Indicate the place of measurement, and the voltage level;
- Specify the method of measurement (direct or indirect);
- Check if the consumed reactive energy and power demand have been measured;
- Indicate the type, manufacturer, and serial number of the meter;
- Indicate the current phase and intermediate voltages in the main distribution cabinet, and the phase currents in the main power cable;
- Check if there is a device for reactive power compensation in the building;

- Check if there is a system for peak power management the building

Lighting system (indoor and outdoor)

- Specify the type and number of luminaries, their individual and total installed power;
- Describe the condition of luminaries and indicate their age;
- Specify the kind of ballasts used in fluorescent lamps (magnetic or electronic);
- Indicate the method of lighting control (central, local, automatic);
- Check if there are any timers, impulse relays, light sensors, presence sensors/motion sensors, etc.
- Check if there is an intelligent control system and if the lighting is integrated into a “smart house” system (in case it is used in the building);
- Check if the lighting system in the building is regularly maintained;
- Check if the maintaining illuminance meets the standards for that type of building;
- Describe how the outdoor lighting is managed;
- Indicate the regime of use of indoor and outdoor lighting (daily, weekly, annual)

System of other electric appliances

- Specify the type of appliance, and its manufacturer;
- Specify the declared energy class of each appliance;
- Specify the number of appliances, their individual and total installed capacity;
- Specify the age, i.e., the year of production of appliances;
- Describe the condition of appliances;
- Describe how the appliances are regulated;
- Specify how many hours the appliances are used per day, on average, and how many days during the year;
- Check if there is an intelligent appliance control system and if the appliances are integrated into a “smart house” system or a peak power control system, if such systems are used in the building;

Drinking and domestic water supply system

- Indicate the water consumption locations in the building (type and number, the ways of use and number of uses);
- Check if water is consumed by certain technical systems in the building (e.g., cooling towers, humidifiers, etc.);
- Describe how drinking water is supplied;
- Describe the condition of the water supply system and network;
- Record possible losses and unwanted leakages;
- Check if there is a pressure regulation system;
- Check if there is a hydrant network, describe its condition and potential losses;
- Describe the maintenance of the system

Specific subsystem: Compressed air system

- Indicate the purpose of the system;
- Provide information about compressors (type, manufacturer, number, age);
- Specify the total capacity and individual capacities;
- Specify the operating pressure in the network;
- Specify the operational parameters of the compressor;
- Indicate the installed electrical power of the electric motor per compressor;
- Provide the data about the compressed air tank (volume, number)
- Describe how the system is regulated;

- Describe how the compressor is cooled;
- Specify the operating regime of the system;
- Describe the general condition and efficiency of the system

Specific subsystem: Steam preparation system

- Indicate the purpose of the system;
- Make a note of the data on the steam boiler nameplate (manufacturer, type, age, installed capacity);
- Describe the condition of the boiler, casing, insulation, installation;
- Describe the condition of safety equipment;
- Make a note of the data on the burner nameplate (manufacturer, type, age, maximum burner power);
- Specify the type of fuel and the method of its supply;
- Indicate the inlet and outlet temperatures of the steam boiler;
- Specify the outlet steam pressure of the boiler;
- Specify the amount of water added to the system;
- Specify the inlet temperature of the boiler feedwater
- Describe how the condensate is recovered and how it is processed;
- Describe the general condition of the pipework and fittings;
- Specify the regulating system (especially the end consumers control);
- Specify the regime of operation of the system;
- Describe how the system is maintained

Specific subsystem: Kitchen equipment

- List the groups and types of kitchen appliances and fuels they use;
- Indicate the installed carrying capacity of appliances;
- Specify the periods of use (daily / monthly);
- Describe the general condition of appliances

Specific subsystem: Laundry room

- List the groups and types of devices in laundry rooms and fuels they use;
- Indicate the installed carrying capacity of devices;
- Specify the periods of use (daily / monthly);
- Describe the general condition of devices

Step 6 Carrying out the necessary measurements

The analysis of data collected during the previous steps is accompanied, if needed, by some **measurements**.

Measurements carried out to identify the building users' behaviour and regime of operation of the appliances can provide information about the degree to which certain comfort conditions are met in the building. These are simple control measurements, and they include measuring temperature and humidity in the conditioned part of the building, measuring lighting in standard rooms of the building, measurements of basic performance parameters of power supply.

Without good preparation, the measurement results tend to be flawed and therefore unusable. Measurement preparation must include developing a measurement plan. The measurement plan is the key document that the client must be acquainted with in order to ensure optimum conditions for its implementation. Usually, before making the plan, a short site visit is made to determine the exact locations where the measuring equipment will be placed to eliminate any possible surprises. For instance, when the measurement plan is made using installation sketches or diagrams, some unpleasant surprises may happen when placing measuring equipment, e.g., the main distribution cabinet is too narrow to accommodate the planned measuring equipment. The measurement plan must answer the following questions:

- Who performs the measurement?
- Where is the measurement carried out?
- How long does the measuring take?
- Who, on the part of the users, approved the measuring?
- What equipment is used for measurement?
- Who controls the measurement?

The measurement plan must be an integral part of the documentation submitted to the user/client alongside the measurement results. All possible changes of conditions during the measurement process must be recorded to accurately interpret the obtained results.

Measuring temperature and humidity in the rooms in the conditioned part of the building

Measurement goal: assessing the level of fulfillment of indoor conditions in the building, collecting data needed to calculate energy consumption in the building

Measurement results: the data on indoor and outdoor temperatures and/or humidity presented in an MS Excel format

Measuring illumination of typical rooms in the building

Measurement goal: assessing the level of fulfillment of comfort conditions related to lighting

Measurement results: the data on the level of illumination at measuring points

Basic Measurements of basic performance parameters of power supply

Measured values: consumption of active and reactive energy, current power, peak power, power factor, phase, and intermediate voltages, phase current, frequency

EE measures: Peak load is managed by regulating the regime of operation of the largest consumers. The goal is to avoid simultaneous work, i.e., to schedule the periods of a full load of different consumers, so they do not overlap. Reactive energy compensation is used in order to improve the power factors, reduce consumed electricity costs and achieve some positive technical effects.

The second group includes measurements to ascertain more precisely the energy properties of the building that could not be determined in previous phases or when there are reasonable doubts about the accuracy of some parameters important for calculating the energy needs of the building. These measurements refer to determining the energy state of the envelope, measuring heating, cooling, ventilation, and air conditioning systems, and measuring the basic performance parameters of power supply.

The most common measurements to determine the energy state of the external envelope include identifying the heat loss places by using infrared thermography, measuring the air permeability of the building (Blower Door Test), measuring the U-value of the in-situ building elements.

Identifying the places where heat is lost through the building's external envelope

Measurement goal: analyzing and assessing the energy state of the building's external envelope by using infrared thermography

Measurement results: a thermogram

Measuring air permeability of the building (Blower Door Test)

Measurement goal: analyzing and assessing the state of the external envelope concerning its air permeability

Measurement results: the amount of air exchanged per hour

Flue gas measuring

Measurement goal: controlling the combustion process, establishing whether the heat source meets the limited levels of harmful substances emissions into the environment

Measurement results: the contents of O2, CO, NO, NO2, flue gas temperature, and temperature of the surroundings

Measuring a working fluid flow rate by an ultrasonic flow meter

Measurement goal: determining the technical characteristics and efficiency of individual parts of the heating/cooling/ventilation / air conditioning system

Measurement results: velocity and flow of working fluid

Measuring the air velocity and flow with an anemometer

Measurement goal: determining the technical characteristics and efficiency of the ventilation and air conditioning systems

Measurement results: the air velocity and flow, air temperature

Phase 3 Activities after the site visit

After visiting the site, the auditor needs to examine all the data obtained from the activities during the preparation and building survey phases, upon which he/she identifies places of inefficient energy consumption and proposes energy efficiency-improving measures, which together with measures analysis are presented in an energy audit report.

Step 7 Analysis of the collected data

Immediately after the site visit, the auditor needs to interpret his/her records and fill in the data in the checklists they did not have time to complete during the survey.

In addition, all the drawings, sketches, and schemes made during the survey should be organized, together with completed checklists and photo documentation, by categories (external envelope/heating system/ventilation/DHW preparation/cooling/lighting/different consumers) for better understanding the technical and energy properties of the building and further data analysis.

- **Analysis of thermal characteristics of the building's external envelope**

- **Analysis of energy characteristics of the heating system**
- **Analysis of energy characteristics of the air conditioning and cooling systems**
- **Analysis of energy characteristics of the system for preparation of domestic hot water**
- **Analysis of energy characteristics of the electricity appliances/consumers**
- **Analysis of energy characteristics of the systems for producing thermal and electrical energy from alternative energy systems**
- **Calculating the amount of thermal energy required for heating**
- **Analysis of domestic water consumption**

Step 8 Selecting appropriate measures for increasing EE of individual energy systems

As part of this analysis, it is necessary to identify and propose adequate measures that can be divided into 3 groups:

Energy efficiency measures aimed at saving energy and/or water while maintaining or improving comfort conditions that result in savings in energy and/or water consumption, energy and/or water costs, and reducing greenhouse gas emissions;

Economic efficiency measures are aimed at saving money, although they do not result in energy savings;

Measures aimed at **increasing the degree of comfort and fulfilling the minimum technical conditions** defined by regulations and rulebooks that may result in increased energy and/or water consumption and do not necessarily represent energy and economic efficiency measures.
Each type of building, depending on its purpose, has some specific features of its energy systems that are crucial for understanding the whole building's functioning concept.

Below are some possible measures for increasing the energy efficiency of the building's external envelope elements and individual energy systems.

Building's envelope

Thermal insulation of external walls

This measure is always implemented when external walls are without any thermal protection. Savings by introducing this measure can range from 15-25%. In addition to thermal protection, this measure prevents the negative consequences of cold bridges and significantly improves the indoor comfort. See Measure 1, Chapter Typical measures for increasing energy efficiency.

Thermal insulation of the roof

This measure involves applying thermal insulation on flat or sloping roof surfaces, depending on the roof structure. More heat is lost through roof surfaces than through walls, which means that the thermal insulation of the roof, if of the same properties as the wall insulation, should be thicker than that applied on the walls. The correctly insulated roof surface can yield up to 25-40% of savings. See Measure 2, Chapter Typical measures for increasing energy efficiency.

Replacing windows or improving their thermal characteristics

Windows are the segment of a building's envelope that requires special attention. Heat losses through windows can be transmission or ventilation losses. These two types of heat losses combined can amount to more than 50% of the total heat losses of the building. Heat losses through windows are usually more than 10 times higher than those through the walls. That is why the windows are a very important segment that must be treated through efficiency measures. See Measure 3, Chapter Typical measures for increasing energy efficiency.

Thermal insulation of the floor

Heat losses to the ground amount to up to **10%** of the total heat losses of a building. When the ground floor of an existing building is concerned, it is not cost-effective to undertake its insulation due to a significant scope of works.

Thermal insulation of the ground floor is not the same as thermal insulation of the floor towards the unheated space of the lowest floor. In the latter case, the intervention is cost-effective, so that such a measure should be recommended. In addition, it is necessary to thermally insulate the floor structures above the open passages to ensure the continuity of thermal protection of the whole external envelope of the building.

Thermal insulation of the ground floor should be at least 10 cm thick. Although losses through the ground floor are relatively small compared to those through other parts of the building's structure, the floor temperature similar to indoor temperature contributes to occupants' comfort.

Heating systems

Replacing old conventional boilers with the low-temperature and condensing boilers (with or without fuel changing)

Most conventional boilers between 10 and 30 years old are with damaged insulation, damaged furnaces, and their operation is not regulated, which significantly contributes to unnecessary energy consumption. The level of energy efficiency of old boilers is usually between 60-75%, depending on the type of fuel they use. Compared to standard boilers, the newer low-temperature and condensing boilers, which have a high level of energy efficiency, can save about 15-40% of fuel. See Measure 4, Chapter Typical measures for increasing energy efficiency.

Replacing old conventional boilers with biomass–pellets boilers

The level of energy efficiency of biomass boilers (briquettes, pellets) is not higher than in heating oil and gas boilers; the fuel price, however, is significantly lower so that by using biomass boilers, up to 60% of savings on heating can be achieved. In addition, the use of biomass boilers considerably contributes to environmental protection. See Measure 5, Chapter Typical measures for increasing energy efficiency.

Replacing old conventional boilers with heat pumps that use air, ground, or groundwater as a heat source

Heat pumps use up to 75% of free energy from the environment, so that by using heat pumps, some important results can be achieved: considerable savings on heating costs, reduced amount of fuel for producing the same amount of heat, increased energy efficiency of a heating system, as well as reduced negative impact on the environment. In addition to space heating, heat pumps can be used for cooling and domestic hot water preparation. See Measure 6, Chapter Typical measures for increasing energy efficiency.

Chemical treatment of water for heating systems

Inadequate preparation of water in heating systems causes limescale formation, which reduces heat transfer, obstructs proper water flow due to a reduced cross-section, causing corrosion, lower operational safety, increased maintenance costs, and, consequently, reduced efficiency and life span of the boiler plant. This problem can be overcome by preparing the boiler feedwater adequately and keeping all the parameters within the standard limits.

Balancing the heating system

When heating systems are not hydraulically balanced, the thermal comfort conditions in some rooms are often unfulfilled. Some rooms are overheated (those closer to the circulator pump), while the more distant ones often have a temperature lower than optimal even after a long time of heating. This problem can be overcome by balancing pressure and flow in the heating system networks, i.e., by installing balancing valves.

Fitting thermostatic valves to the existing heaters

By fitting thermostatic valves to radiators, it is possible to regulate the temperature in the room, as well as thermal energy consumption. See Measure 9, Chapter Typical measures for increasing energy efficiency.

New automatic regulation system

Continuous regulation of the performance of heating emission bodies in accordance with the energy needs (depending on the outdoor temperature, wind speed, intensity of solar radiation, internal heat sources, etc.) can be successfully maintained only by automatic regulation. That reduces energy consumption, as well as heating costs.

Installing variable speed pumps

Variable flow pumps have a built-in frequency regulator, which changes the speed of the electric motor, therefore changing the pump flow. The pumps are equipped with electronics that, based on the measured velocity of the pump motor, the power that drives the motor, and the set piping parameters, regulate the pump speed and maintain the operating point of the pump in an optimal regime. In addition to optimizing the flow in heaters, variable speed pumps reduce electricity consumption from 70% to 90%.

Thermal insulation of the non-insulated parts of the system

Thermal insulation of the non-insulated parts of the system prevents condensation occurrence, reduces heat losses, and increases system efficiency.

Setback temperature

Setting the temperature to a lower value in periods when the building is unused or when the heating is reduced (e.g., during the night, weekends, holidays) contributes to energy savings. According to some rough estimates, these savings amount to about 1% of the consumed heating energy for each centigrade lower than the temperature set for regular operation for a reduced period of 8 hours. Typical setback temperatures range from 12 ° C to 15°C, depending on the building's thermal capacity and the desired comfort level.

Boiler cleaning

By cleaning the boiler firebox from soot and unburned deposits caused by poor and incomplete fuel combustion, it is possible to increase the boiler efficiency. Keeping the firebox walls clean contributes to improving the heat transfer and reducing fuel consumption. The boiler can be cleaned from the smoke-flame side and the water-steam side (descaling the inner walls of the boiler).

Ventilation systems

Installing a system for recovering heat from the exhaust air in ventilation and air conditioning systems

In order to increase the outdoor temperature before the air enters the reheater in a ventilation/air conditioning systems, it is possible to use the heat contained in the exhaust air of the system. In that way, hot water from the boiler room is not used for preheating, reducing thus the primary fuel consumption, and contributing to preserving the environment. The reduction in primary fuel consumption is equivalent to the heat recovered from the exhaust air. See Measure 7, Chapter Typical measures for increasing energy efficiency.

Balancing ventilation ducts

In a system that is not well-balanced, the amounts of air vary in different parts of the ventilated space, i.e., some areas have more, and others less air than needed. Consequently, the temperatures in those areas are too high or too low, while the air gets stagnant. Balancing the system can overcome this problem, and save energy, in addition to fulfilling the thermal comfort conditions.

Frequency-controlled fans

Variable-frequency drives as an alternative to conventional constant-speed drives and damping devices enable the “soft” starting and stopping of electric motors, preventing thus mechanical stress and prolonging the life span of motors. They allow a wide range of speed and power change, enabling precise control and greater energy efficiency of electric motors and contributing to energy savings. See Measure 10, Chapter 4.

Heat exchanger cleaning

When magnesium, calcium, and silicon dioxide from the feed water deposit on a heat exchanger, they act as its insulation, slowing down heat transfer, which causes overheating of the heat exchanger or weakening of its function, reduced energy efficiency, and the system decay.

Filter replacing/cleaning

Dirt and dust that accumulate on the filters can affect the temperature registered by sensors in the ventilation system.

Cooling systems

Replacing the existing chiller with a more efficient one

High-efficiency chillers come with improved regulation, increased and improved condenser sections, and high-efficiency compressors. Air-cooled systems eliminate the need for cooling towers, reducing thus installation and maintenance costs. On the other hand, water-cooled chillers are more efficient than air-cooled chillers.

Chiller optimization

Optimizing chillers to improve their control is mainly achieved in two ways: by regulating the supply water temperature by setting it to the highest possible value under the given heat load conditions, and by reducing the condensation temperature, which results in increased condensing efficiency and reduced energy consumption.

Evaporative cooling

The amount of electricity needed for mechanical cooling can be reduced by using water in evaporative cooling systems. The energy of warm outside air encourages evaporation of water dispersed in chambers with specially designed slope, whereby the water takes over the heat from the air, and the air escapes from the device cooled. Evaporative coolers do not require additional energy for water evaporation, nor chemical reagents such as freon for cooling, but only a powerful ventilator and a small pump.

Using waste heat from the chiller condenser for heating

In buildings that have simultaneous needs for heating and cooling, the waste heat from condensation can be used to preheat or heat the working fluid, which serves as the heating fluid. In a cooling system with a water-cooled condenser, the heated water that has taken the heat from condensation can be directly used in a closed heating circuit (e.g., in a preheater). In a chiller system with an air-cooled condenser, an additional heat exchanger (an air to water recuperator) can be used to utilize the condensation waste heat.

Using inverter cooling devices

Inverter technology consumes less energy and increases energy efficiency (energy savings of up to 50%), achieves the desired temperature faster, and allows for more precise temperature control.

Optimizing multiple-chiller operation

The annual flow of heating load, the curve of outdoor temperatures frequency, and the duration of daily operation form the basis for dividing the total cooling capacity, i.e., for using several chillers to better adapt to the cooling system present load. Through proper division and appropriate electronic regulation, it is possible to achieve energy savings and increase operational safety.

Systems for domestic hot water (DHW) preparation

Replacing individual electric boilers for DHW preparation with solar thermal systems

The DHW preparation systems that use solar collectors can save up to 100% of energy in the summer, or from 15% to 50% in the winter (depending on the building purpose). One of the most cost-effective options is the combination with an additional electric and water heater. During the winter, a water heater is used as an additional source, while in the summer an electric heater is used for additional heating. See Measure 8, Chapter Typical measures for increasing energy efficiency.

Using waste heat from the chiller condensers for DHW preparation

There is an increasing number of cooling units that, partly or completely, use condensing heat for DHW preparation. In a cooling system with a water-cooled condenser, the heated water that has taken the heat from condensation can be directly used in a DHW boiler heater. In a chiller system with an air-cooled condenser, an additional heat exchanger (an air to water recuperator) can be used to utilize the waste heat from condensation.

Preheating water by waste heat

It is estimated that about 80% of the heat used for DHW preparation goes to the sewer unused. If the water from bathtubs, showers, and washbasins is drained separately from the fecal sewage, it is possible to recover the heat from the water used during washing and showering. That is convenient for big consumers (e.g., hotels, large residential buildings, etc.), and such devices are cheaper to install in newly constructed buildings than in the existing ones. Care should be taken to build the system in such a way as to ensure reliable operation, keeping in mind that wastewater contains dirt and grease.

Energy-saving fittings

The new faucets found on the market are increasingly produced with a built-in device that reduces the volume of water flowing through the faucet, saving thus water. Some of such faucets can reduce water consumption by up to 40%.

Improving the insulation of a hot water tank and pipes

If they are not factory insulated, a hot water tank and the complete piping must be insulated to reduce heat losses.

Timer control

A timer installed on the hot water cylinders allows for water heating at an exact period when hot water is needed. That prevents unnecessary overheating of water, which, unused, will cool down faster or slower, depending on the quality of the tank insulation.

Lighting systems

Replacing classic light fittings with those of newer generation with a higher level of energy efficiency

Today, 70% of lighting in commercial buildings consists of older generation fluorescent tubes, so there is a great potential for savings by replacing the existing light fittings with the new, more energy-efficient ones.

With the development of fluorescent lighting technology, the diameter of fluorescent tubes is being reduced, which produces greater efficiency of the lighting system (the light source is closer to the point source).

By replacing the classic fluorescent light fittings with those of the latest generation, in addition to the already mentioned advantages, the classic magnetic ballasts are eliminated and replaced with electronic ballasts. Electronic ballasts reduce electricity consumption, improving at the same time the power factor, which in turn further increases the energy performance of the building. The savings achieved in this way can be considerable, amounting to up to 70%.

Incandescent lamps (classic light bulbs), which are still widely used in Montenegro, belong to light fixtures with the lowest degree of efficiency (only up to 5% of energy is used for lighting, while the rest gets lost as heat). Replacing such lamps with compact fluorescent (the so-called energy saving) light bulbs is one of the common energy efficiency measures, with a payback period of only a few months. See Measure 12, Chapter Typical measures for increasing energy efficiency.

Improving the lighting system control by installing different types of sensors, timers, and controllers

Very often, in typical commercial buildings of the older generation, lighting is directly controlled using classic switches, leaving the care of rational use to the conscience of employees (when lighting control is local) or persons taking care of the facility (if control is centralized).

By installing the light level sensors separately or in different combinations with motion sensors and/or timers, considerable savings can be achieved, depending on the type and purpose of the building and its separate units.

Intelligent lighting, i.e., integrating the lighting system into a “smart house” system

This measure, combined with the already mentioned ones, can achieve even greater savings, up to 85%, compared to classic systems of the older generation. Additional information on this topic can be found within the measure for replacing the standard light fixtures.

Replacing the classic light fixtures with those using the latest generation LED lamps

LED lighting is the most energy-efficient form of lighting. However, the disadvantage of this technology is that it is still expensive, so the payback period is relatively long compared to other measures. However, the price of LED lamps is constantly falling, while their performance is being further improved, so this measure can be expected to become very attractive, i.e., cost-effective in the future.

The great advantage of LED lighting over fluorescent lighting, apart from a significantly higher energy efficiency class, is that it does not produce increased electromagnetic radiation and mercury alloys, which are the disadvantages of fluorescent lighting.

Today, there is a wide range of colors emitted by LED lamps, unlike the first LED lamps that could emit only blue-whitish light. It can be selected between warm white, neutral white, and cool white, as well as RGB (combinations of red, green, and blue) that produce up to 16,000,000 different color shades.

The LED lamps emit much healthier, more comfortable, and more even light compared to classic lighting. LED lamps do not emit ultraviolet or infrared radiation; they do not produce buzzing, flickering or stroboscopic effect to which many people are sensitive.

Replacing the outdoor light fixtures with those using the latest generation LED lamps and contain built-in photovoltaic panels with batteries

That s is a very interesting measure that can maximally reduce the electricity consumption for outdoor lighting, especially in the summer. The disadvantage of this technology is that it is still expensive, so the payback period is relatively long compared to other measures. Furthermore, this technology requires additional maintenance measures (e.g., periodic battery replacement).

Electric system

Reactive power compensation

The monthly costs for reactive energy can be considerable depending on the number and size of reactive energy consumers. Reactive energy compensation not only achieves the economic effect of reducing energy bills but also increases available power, reduces losses in transmission lines and voltage drops, increasing equipment lifespan. See Measure 11, Chapter Typical measures for improving energy efficiency.

Peak power management

For large consumers, peak power is measured in addition to active and reactive energy. For such consumers, peak power, or peak energy management is a very interesting and cost-effective measure for energy efficiency.

The peak power costs make, on average, about 30% - 50% of the total costs for the consumed electricity, and the price we pay for the power demand may exceed the price of the consumed active power.

Peak load management is achieved by installing an advanced central system that controls the operating regimes of the largest consumers. The goal is to avoid simultaneous work, i.e., to sequence the periods of a full load of different consumers so they do not overlap

It has been proved in practice that such systems can reduce peak load costs by over 50%. See Measure 13, Chapter Typical measures for increasing energy efficiency.

Electric appliances/consumers

Replacing electric appliances that have energy efficiency class C or lower with the new ones with energy efficiency class A

Until a few years ago, the price of electricity in Southeast Europe was relatively low, so not much consideration was given to the energy efficiency class of an electric consumer. Today, with relatively high electricity prices and a clear tendency of their increase in the coming years and decades, this energy efficiency measure is becoming more and more important, as substantial savings can be achieved by purchasing devices of the highest energy efficiency class.

To replace all existing electric appliances in a commercial building or a household can be a huge investment that might make this measure unattractive due to a long payback period. However, given the appliances are often replaced (usually once every few years), it is recommended to buy appliances of the highest EE class. The difference in price between class A and class C of the same type of appliance is usually not higher than 25% and it pays back very quickly through energy savings.

Connecting all the electric appliances into a "smart house" system

Advanced control systems employed in some or all the appliances in households or commercial buildings include different, usually advanced, sophisticated, and highly integrated electronic systems. They allow that all the devices are controlled by a single central processing unit that has, in newer versions, a remote control option via TCP/IP, GPS, GPRS, and GSM networks, or in other ways, such as voice command.

For example, it is possible to control all the electrical devices in a home or a commercial building regardless of their location by using a specific application on a mobile phone or a laptop connected to the Internet.

Such systems usually have sensors, so when you open a window or leave the room, the air conditioning system gets automatically turned off, which, naturally, eliminates unnecessary electricity consumption and increases the energy efficiency of the building.

In addition, it is possible to integrate electric roller blinds and curtains into a lighting system in order to utilize as much daylight as possible and reduce the use of artificial light while achieving the set level of illumination.

Step 9 Entering data into software for calculating the energy performance of a building

Software selection

The software to be used to calculate the energy performance of buildings depends on national legislation and the choice of each country. See videos below:

7_Audit_Calculation >>>

8_Audit_Software-example MEEC >>>

Step 10 Preparing an energy audit report

The following outlines the basic components of a well-organized audit report:

Executive Summary

The Executive Summary should be a simple, straight forward and to the point explanation of the current situation, recommended improvements, and advantages of taking recommended actions. Include a brief introduction to the facility and describe the purpose of the audit and overall conclusions. An executive may read no further than this one or two-page introduction so make sure that you have expressed very clearly what specific actions you want them to take.

Building Information

This section provides a general background of the facility, its mechanical systems, and operational profile. It should include a description of the building envelope, age and construction history, operating schedules, number of employees and occupancy patterns, and a discussion of the operation and maintenance program. It is also useful to include a floor plan, selected photos of the facility and mechanical systems, a description of energy types used in the plant, and a description of the primary mechanical systems and controls.

Utility Summary

Energy Accounting information for the last two years is included in this section. Attach selected charts and graphs that were developed for analysis that are easy to understand and demonstrate the overall consumption patterns of the facility. Choose the information for each graph to suit each target audience. For example, actual monthly consumption by fuel type may be of more interest to the engineering and maintenance staff while annual costs or money-savings information may be more appropriate for administrative personnel. Pie charts of energy use and cost by fuel type can offer compelling documentation of overall energy uses and expenses.

Include a summary of overall facility benchmarks, energy use indices, and comparisons with industry averages. You may also want to include a copy of the utility rate schedules and any discussion or evaluation of rate alternatives for which the facility may qualify.

Energy Conservation Measures (ECM's)

Begin this section with a summary list of Energy Conservation Measures that meet the financial criteria established by the facility owner or manager. For each measure, include the measure name, estimated cost, estimated savings, and simple payback in a summary chart. A one or two page description of each energy conservation measure and support calculations should follow this summary chart. Include the ECM description, energy use and savings calculations, and the simple payback, net present value or life cycle cost analysis. It's also a good idea to discuss any assumptions that were made regarding operation or equipment efficiency. ECMs that were considered but fell out of current financial criteria should also be listed and identified as have been evaluated.

Operation and Maintenance Measures (O&Ms)

This section will address operational and maintenance issues observed during the site visit. Include descriptions of specific low-cost operational and maintenance items that require attention. Include items that will reduce energy consumption and costs, address existing problems, or improve practices that will help prolong equipment life of systems not being retrofit. It is also useful to the owner to include cost and savings estimates of O&M recommendations.

Appendices

Support material and technical information not included elsewhere in the report can be added to the appendices. Typical information in this section includes, floor plans and site notes as appropriate, photos, audit data forms, motor, equipment, and lighting inventories, and equipment cut sheets of existing or recommended systems.

Typical measures for increasing energy efficiency

Measure 1: Thermal insulation of external wall or a wall adjacent to an unheated space

An essential step of the audit, for it to be carried out properly, is to determine the types of walls. If the walls consist of different layers or have different thicknesses, they should be divided into separate types.

> *It should be noted that most heat is lost through windows and external walls, which means that the improvement of those elements can result in huge savings. By enhancing the roof above a heated space, i.e., the top floor ceiling adjacent to an unheated attic, heat losses can be considerably reduced, as well. It is often not cost-effective to improve the floor to the ground due to a relatively small reduction in total heat losses compared to the scale of such an investment.*

Step 1: Ascertain if the external wall has any thermal insulation

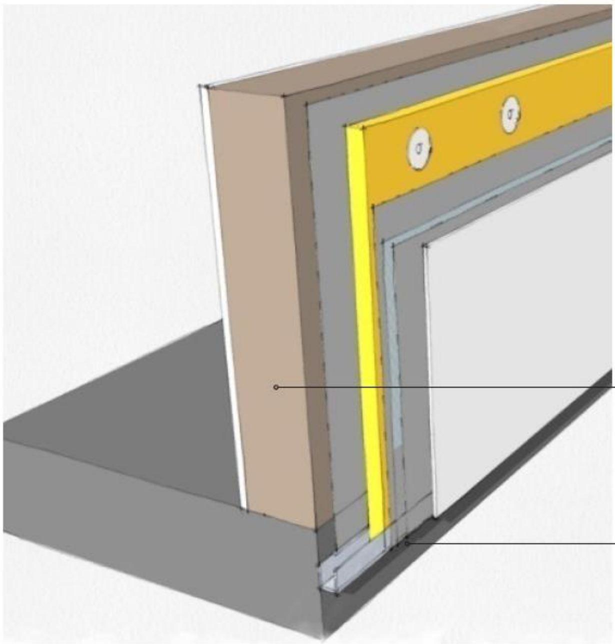
Thermal insulation of the outer wall or the wall adjacent to an unheated space should always be proposed as a measure when no thermal insulation exists.

Step 2: Identify any specific elements on the façade

That refers to details of junctions between the gutter and the wall, the details around the openings, canopies, terraces, or other elements projecting from the wall surface, covered passages if there are any, etc. The subsequently proposed measure should describe how such areas should be treated when it comes both to applying thermal insulation or reducing its thickness, etc.

Step 3: Decide on thermal insulation materials and their thickness, type of façade, and method of its installation

Thermal insulation of an external wall usually involves adding a thermal insulation layer on the **outside surface of the wall**. Thermal insulation on the inner surface of the wall should be applied only in specific cases, in the buildings of architectural and historical importance, where the application of thermal insulation on the outer surface would impair their authentic stylistic values.



An example of thermal insulation of the outer wall by applying a “demit” façade

Installing thermal insulation on the inner surface of the wall is unbeneficial both from the point of view of engineering physics and finances for several reasons: it is necessary to address an additional problem of water vapour diffusion, stricter fire safety requirements need to be fulfilled, useful space is lost, etc. In addition, when applying thermal insulation on the inner surface of the wall, the wall loses its mass that is useful in retaining the heat after heating the space. In that way, instead of being protected towards the colder side, the outer wall remains thermally unprotected; therefore, its temperature gets reduced, and the wall gets cold. That’s why special attention should be devoted to building a vapour barrier to prevent condensation and the appearance of molud.

> *The thermal conductivity coefficient λ [W/mK] is the amount of heat transferred during a unit of time through a layer of material with a surface area of 1 m^2, 1 m thick, at a difference in temperature of 1 K. The heat transfer coefficient (U) is the amount of heat that a building element loses in 1 second per 1 m^2 of the surface area at a difference in temperature of 1 K, expressed in W/m^2K.*

Characteristics of thermal insulation added on the inner surface of the external wall:

- It can be applied in new or existing buildings
- Inner space gets reduced
- It is not easy to apply because of built-in furniture, wall decorations, sockets, plugs, etc.
- Low thermal capacity and inertia, but fast heating and cooling of space
- It does not prevent thermal bridges

Note: When adding thermal insulation on the inside, pay attention that parts of the partition wall at junctions with the outer wall should also be insulated.

Thermal insulation can be installed on the outside surface of the wall in two ways: as a **compact unventilated façade** and a **ventilated façade**.

A compact unventilated façade (also known as a compact or “demit” façade) involves “gluing” the final protective layer onto thermal insulation. Depending on plaster, it can be a thin-layer or thick-layer façade. As for ventilated façade, its final layer is fastened to the load-bearing part of the wall by an appropriate substructure. That creates an air layer between the protective coating and thermal insulation, serving as a ventilation layer. The advantage of this type of façade is that the circulating air dries the excess moisture from the wall and additionally cools the wall in summer. In winter, its effect is not so beneficial because the air circulation can further cool the walls.

Deciding on the type and thickness of thermal insulation material

Factors that influence the choice of thermal insulation are the same as when choosing any other building material: local micro and macro climatic conditions, traditional building solutions and popularity of some products, the desired comfort level, specific requirements, and, naturally, the price the investor is willing to pay. However, the most important is that the product fulfills the task envisaged by the project, which in modern construction involves a wide range of requirements:

low thermal conductivity - the main property of thermal insulation materials
low water and moisture absorption – given that water is a better conductor than air, a water-soaked material allows considerably more heat/cold to pass through it than dry material, so manufacturers use hydrophobes which reduce absorption
vapour permeability /breathability - one of the particularly important properties thanks to which moisture does not accumulate in the multi-layer façade construction, preventing thus thermal resistance collapse (vapour permeability of layers should increase from warm to the cold side of the wall, i.e., from inner to outer side)
fire resistance - an exceptionally important factor in modern buildings, so the non-flammability of thermal insulation is one of the basic requirements by customers.

A good choice of thermal insulation materials requires that one is well acquainted with their properties. Heat losses through a building element depend on its layers, orientation, and thermal conductivity coefficient.

λ value is different in different materials, and it depends on the density, size of pores, and their connectivity and moisture of the material. Materials with low thermal conductivity provide better thermal insulation. The thermal resistance of the material increases with its thickness.

The U coefficient is a significant characteristic of external elements of the structure and is important in the analysis of total heat losses [kWh/m^2] and energy used for heating.

The lower the heat transfer coefficient is, the better the thermal protection of the building is.

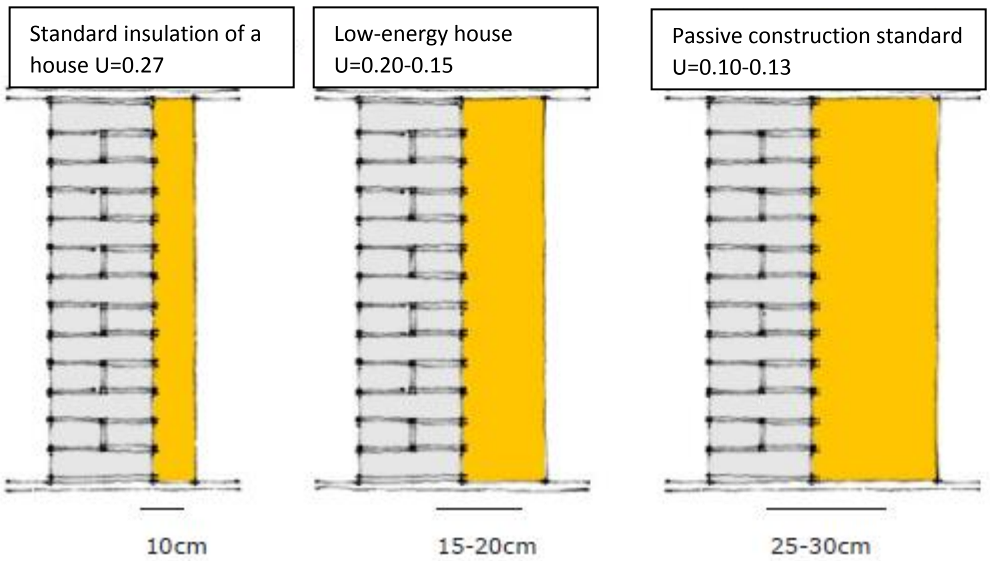


Image 4: Comparing U values for the same wall with different thickness

When choosing thermal insulation materials, in addition to thermal conductivity, their other characteristics should be considered, such as fire resistance, water vapour diffusion resistance factor, compressibility, durability, moisture resistance, etc. Also important are the material production method, the use of energy in its production, and the price. The type of structure where we install the material also influences its choice, so it is not the same if we insulate a floor, basement wall, overhead wall, flat or sloping roof.

The primary division of thermal insulating materials is into inorganic and organic. The most well-known inorganic insulation materials are stone and glass wool, while polystyrene, expanded and extruded, and polyurethane, i.e., polyurethane foam, are organic materials.

The table below gives an overview of thermal insulation materials with their main characteristics, such as the U-value of thermal conductivity, water vapour diffusion resistance factor, as well as a comparative analysis of relative costs of their installation taking a wall with the U-value of 0.35 W/m^{2}K as an example.

Thermal insulation material	**Density ρ [kg/m3]**	**Thermal conductivity λ [W/m K]**	**The needed thickness (cm) for U=0,35 [W/m^{2}K]**	**Water vapour diffusion resistance factor μ**	**Relative cost for U=0,35 [W/m^{2}K]**
Mineral wool (MW)	10-200	0.035-0.050	9-11	1	1
Expanded polystyrene (EPS) "Styrofoam"	15-30	0.035-0.040	9-10	60	0.80
Extruded polystyrene foam (XPS) "Styrofoam"	25	0.030-0.040	8-10	150	2.5
Rigid polystyrene foam (PUR)	30	0.020-0.040	7-9	60	5-8
Wood wool (WW)	360-460	0.065-0.09	16-20	3/5	4-6
Expanded perlite (EPB)	140-240	0.04-0.065	10-16	5	1.5-2.0
Expanded cork (ICB)	80-500	0.045-0.055	11-14	5/10	2.0-3.0
Sheep wool	15-60	0.040	10-11	1-2	-
Straw	-	0.09-0.13	20-35	-	-

The data in the table above refer to the thermal insulation of an external wall. To achieve the stated U-value, it would take, on average, 10 cm of stone wool, or 9 cm of polystyrene, depending on the material thermal conductivity. For the same U-value, about 16-20 cm of wood wool or 7-9 cm of polyurethane insulation is needed. If we compare the market prices of materials and assume that the stone wool price is 1, we can conclude that polystyrene insulation EPS is slightly cheaper, i.e., priced 0.80, whereas the extruded polystyrene XPS is 2.5 times more expensive. Polyurethane foam has a cost factor of 5-8, while, for example, that factor of wood wool is 4-6. The actual price of thermal insulation materials depends on their characteristics, thickness, and method of installation.

The recommended thermal insulation must be installed in the right way to achieve the planned coefficients and duration.

Description of the existing state

Description of the existing state of the building external walls should include the following:

- Identify all types of external walls according to their layers and describe them (presence of certain types can be expressed in percentages depending on the façade orientation), specifying each layer's thickness and the total wall thickness;
- Associate wall types with the façade orientation;
- Description of the state of external walls;
- U-value of all wall types and an average U value;
- Identify and describe possible damages to the façade;
- Record all specific details and elements, such as different canopies, balconies, bay windows, etc.

Description of the measure

This section should contain:

- Information on whether thermal insulation will be applied on the outer or inner surface of the external wall
- Type of insulation material and its thickness, and a short description of the main characteristics of the material, including its thermal conductivity coefficient λ
- Note that the selected thermal protection system should have a European Technical Approval (ETA) according to ETAG 004 (European Technical Approval Guideline 004);
- Description of installation characteristics provided in more detail in Table 3, pointing out that the thermal protection system will be installed following recommendations from the selected material producer
- Description of the façade finishing that has the required characteristics, such as waterproofing, etc., and a note on how to select the colours, etc.;
- Typical details of the facade, and if the auditor finds it necessary, some specific details;
- The emphasis that all the present damages to the façade must be repaired and their description;
- Note that all the elements dismantled to install thermal insulation should be put back in their position

Assessment of the investment

Assessment of the investment depends on the type and thickness of insulation proposed by the measure, current market offer and price of insulation material, cost of installation works, including additional works (dismantling and assembling the elements on the façade,...) and equipment needed for the successful implementation of the measure.

Potential saving

15%-25%

Investment payback period

The payback period for this measure is not easy to determine in advance as it depends on a number of parameters, such as the type and thickness of the external wall, heating system, fuel type, market fuel price, etc.

Duration of the measure

20 years

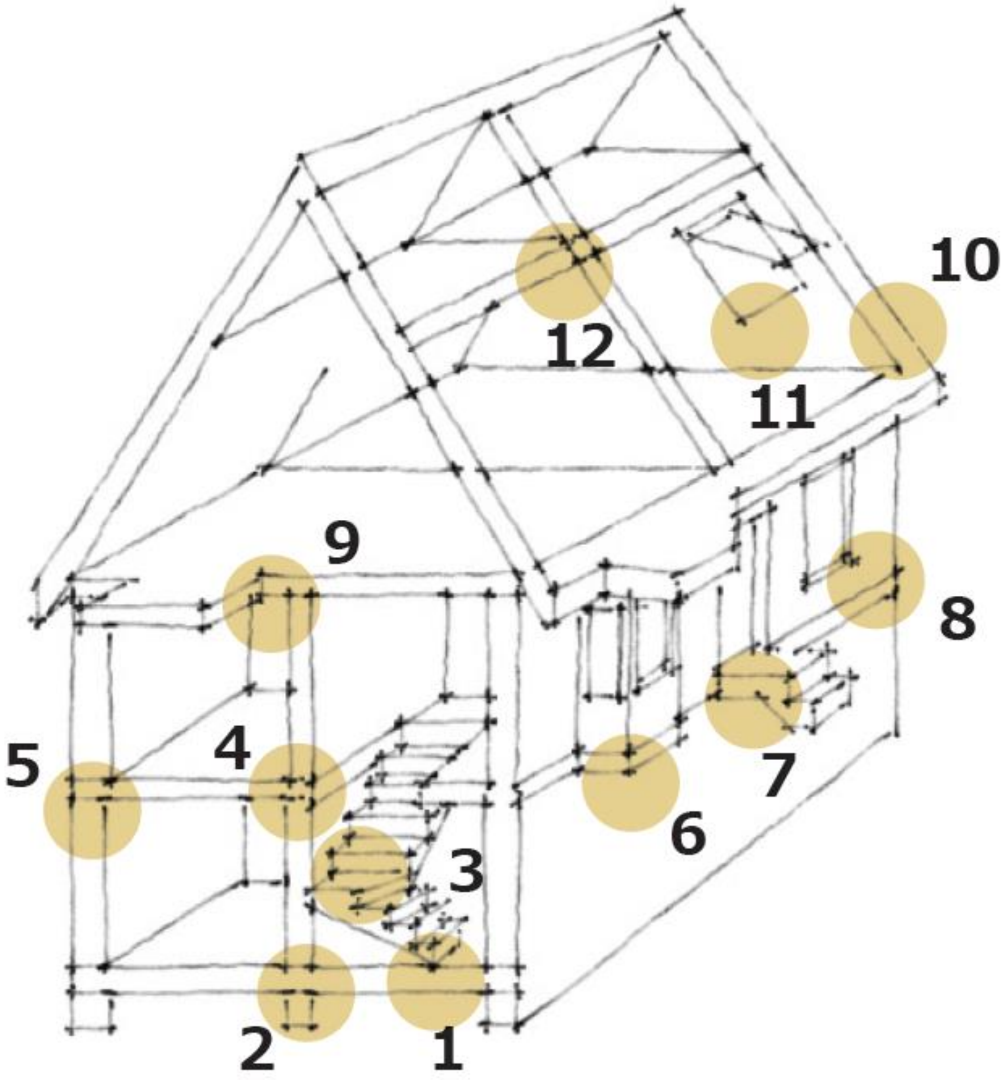
Mineral - stone, and glass- wool is an excellent thermal insulator with thermal conductivity ranging between λ = 0.035 and 0.045 W/mK, ranking it among the best thermal insulators. It is an insulating material of mineral origin used for thermal, sound, and fire insulation. In addition, mineral wool has high fire resistance; it is vapour permeable and partially waterproof and resistant to aging.

Thermal bridges (known as “cold” bridges)

Thermal insulation of the building must be applied continuously, with no interruptions, on the external envelope in order to reduce the negative effects of cold (thermal) bridges.

Thermal bridges always occur on structural parts of the building envelope. Their impact on occupant comfort, structure durability, and stability must be reduced by adequate design and construction of specific envelope elements.

The most common locations where “cold” bridges occur are shown in the drawing below:

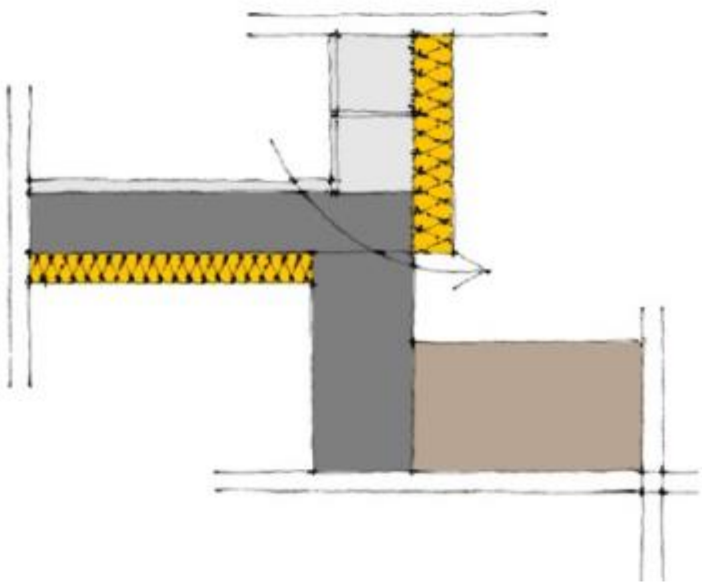


Locations in a building most susceptible to cold bridges occurrence /Source: “Energetski efikasna gradnja i sanacija građevinskih objekata” Holzcluster/

1. The junction between the basement stairs and the slab
2. A contact point between the stairs wall and the floor slab
3. Side junction between the basement stairs and the basement wall
4. The junction between the basement wall and ceiling and the partition wall adjacent to the ground floor
5. The junction between the basement wall and ceiling and the external wall of the ground floor
6. Projecting floor stab of the bay window

7. Projecting entrance landing
8. Window edges and window sills
9. Projecting balconies, canopies
10. Overhangs serving as protection from the outside air
11. Protection of the roof window from the outside air
12. Interior walls that rise to the cold floor

If these criteria are taken into account, the necessary continuity of thermal insulation can be achieved, which can be additionally checked by a thermographic survey when the construction is completed.



Possible occurrence of thermal bridge on the part of plinth

A thermal bridge is a small area in the envelope of the heated part of a building that has higher thermal conductivity due to differences in material, thickness, or geometry of the construction part. Because of the reduced resistance of thermal conductivity compared to a typical cross-section of the structure, the inner surface temperature of the barrier on the thermal bridge is lower than on the rest of the surface, which increases the risk of water vapour condensation.

Depending on the cause of increased thermal conductivity, there can be two types of cold bridges:

Structural thermal bridges – occur when different kinds of materials are combined;
Geometrical thermal bridges – depend on the shape of the structure, e.g., corners of the building.

In practice, combinations of these two types of cold bridges are very frequent.

Consequences of cold bridges are:

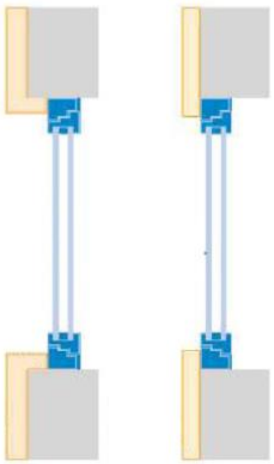
- Increased heat losses;
- Changes in inner surface temperature of the wall;
- Reduced level of comfort in the room;
- The danger of mould appearance;
- Threat to a wall structure

Condensed moisture, present for a long time, can cause damage to a building.

Naturally, the best way to prevent the occurrence of cold bridges is to install thermal insulation on the outer surface of the wall. Although it is almost impossible to build a building without cold bridges, when the elements of thermal insulation of the building envelope are adequately designed and installed, the negative impact of cold bridges can be minimized.

Potential places where cold bridges can occur are cantilevered balconies, projecting roof eaves, junctions between structural elements, junctions between walls and windows, roller shutter boxes, radiator niches, foundations, etc. That's why the structural details should be devoted special attention. It is recommended that the mentioned elements should be designed in as much detail as possible.

A very efficient way to detect cold bridges is to survey by an **infrared camera**, which clearly shows the areas and zones of excessive heat losses.

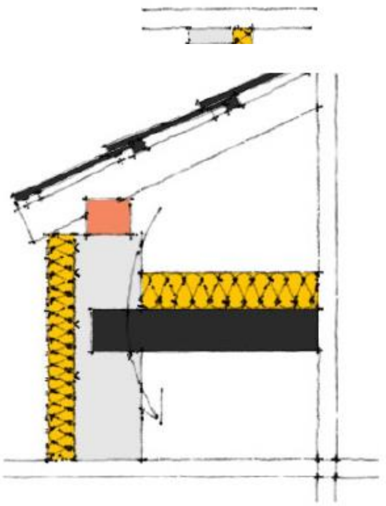


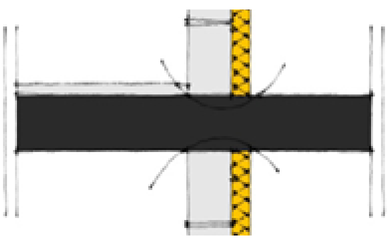
Windows, exterior doors. For static reasons, the ring beams/girders (lintels) are usually made of reinforced concrete with poorer thermal insulation than insulation on external walls. That's why those elements should be additionally insulated. The roller shutter boxes must be well insulated as a whole to avoid the occurrence of thermal bridges. Care must be taken to thermally insulate the window overhang and install windows in the right way. Exterior doors and doors leading to unheated rooms should be well insulated on all sides**.**

Ceiling. Given that concrete has poorer thermal insulation properties, the ceiling junctions must be well insulated. An insulating grille should be installed on the outside. When insulating the top floor ceiling, care should be taken that the insulation does not finish on the wall beam but is spread over it.

Balcony. It is difficult to prevent the occurrence of thermal bridges on projecting balcony slabs. That's why the balcony slab should be coated in thermal insulation. A good solution, in that case, is a complete thermal separation of the balcony on a new load-bearing structure.

Roof. When flat roofs are concerned, the attic (the wall on the front side) should be well insulated on the outside and inside.





Detail of thermal bridge on the part of floor structure adjacent to an unheated attic

Image 7: Thermal bridge on the part of junction between the balcony slab and the floor structure

Measure 2: Thermal insulation of the roof

Thermal insulation of the roof is of great importance not only for thermal protection but also because this measure contributes to maintaining or improving additional roof functions, such as protection from rain and snow. The total heat losses through the roof amount to **10-20%** of the total heat losses of the whole building.

Thermal insulation of the roof, like insulation of external walls, reduces heat losses in winter and prevents overheating of space under the roof structure in summer.

Materials for thermal insulation of the roof

Non-flammable and vapour-permeable thermal insulating materials, such as mineral wool, should be used for the thermal insulation of pitched roofs. In addition to classic materials for insulating sloping roofs, especially those covering the halls used for different purposes, sandwich panels filled with polyurethane (Polyurethane Sandwich Panels) are also suitable. As for passable roofs, the strength of their thermal protection should be considered to ensure they can bear the moving load.

Attention should be paid to the possibility of a cold bridge occurrence at the junction between the roof and the façade in order to avoid it.

The recommended thickness of the roof thermal insulation is usually bigger than for the walls, ranging, depending on the climate zone and material, from 16-20 cm.

Installation of thermal insulation depends on the type of roof structure and type of roof. As for a sloping roof and wooden structure, it is best to apply thermal insulation in two layers, one between the rafters and the other underneath them, to prevent the occurrence of cold bridges. The lower thermal insulation layer underneath the rafters is protected by gypsum plasterboards or wooden laths ("wood paneling"). As for flat roofs, which are more exposed to atmospheric influences, it is important to insulate them well and to explain well and in detail the installation process, including some specific details such as gutters or a slope. The final layer of a flat roof can be passable, impassable, and the so-called "green" roof.

Green roof

If the flat roof is "green", it is necessary to provide a sufficient layer of soil for the plants, to prevent the penetration of roots lest they damage the waterproofing, to address the atmospheric water drainage in the right way, and prevent the penetration of water or moisture towards thermal insulation.

The green roof retains heat well; it accumulates the heat in soil layers, maintaining a constant temperature of the final layer, both in summer and winter. A sloping roof can also be built as "green", paying attention to the allowed slope, etc.

Description of the existing state

Description of the existing state of a flat or sloping roof, for the roof thermal insulation measure, should include:

- Type of roof, flat or sloping, and separate descriptions of the two types;
- Description of the state of the roof;
- State if the roof is thermally insulated; if so, specify the type and thickness of insulation;
- Description of roof layers, indicating each layer's thickness;
- Description of specific details, outlets, overhangs, gutters, chimneys, etc.;

- Description of damages to the roof, if any;
- Indicate if the roof is passable or not

Description of the measure

Description of the measure for thermal insulation of the roof should contain:

- The recommended type of thermal insulation and its thermal conductivity coefficient λ;
- A list of all roof layers, present ones and those envisaged by the measure, with their thickness;
- U-value after the implementation of the measure;
- Description of the roof finishing; whether the roof is passable or not;
- Urging to pay attention to the roof's final layer and atmospheric water drainage, as well as a protective layer, usually made of lightweight concrete or cement screed and used to protect the installed waterproofing and thermal insulation;
- Urging to apply an additional layer of waterproofing above thermal insulation; its description, type, and manner of application;
- Description of specific details such as outlets, overhangs, gutters, chimneys, skylights, etc.;
- Description of standard details;
- Description of specific details, if the auditor finds it necessary;
- Notes about the places of contact between the secondary structure and the roof, when the installation of solar panels or air conditioning plant of some kind, etc., is planned.

Potential for saving

10-20%

Investment payback period

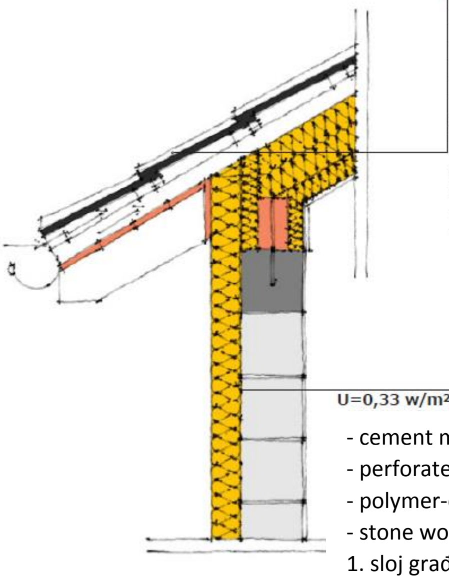
The payback period for this measure is not easy to determine in advance as it depends on a set of parameters, such as the type and thickness, i.e., the layers of the roof structure, heating system and fuel type, market fuel price, etc.

Duration of the measure

20 years

77 Priručnik za sprovođenje energetskih pregleda zgrada

Properly installing thermal insulation on a sloping roof and junction with the wall's thermal insulation in lightweight roof structure



U=0,22 W/m²K

- tiles 2 cm
- laths 5/3 cm
- counterlaths 8/3 cm
- waterproofing foil
- stone wool/glass wool/expanded polystyrene laid between the rafters ≈10 cm
- stone wool/glass woo /expanded polystyrene laid askew under the rafters ≈6 cm
- vapour barrier -
- gypsum plasterboard 2.25 cm

U=0,33 w/m²k

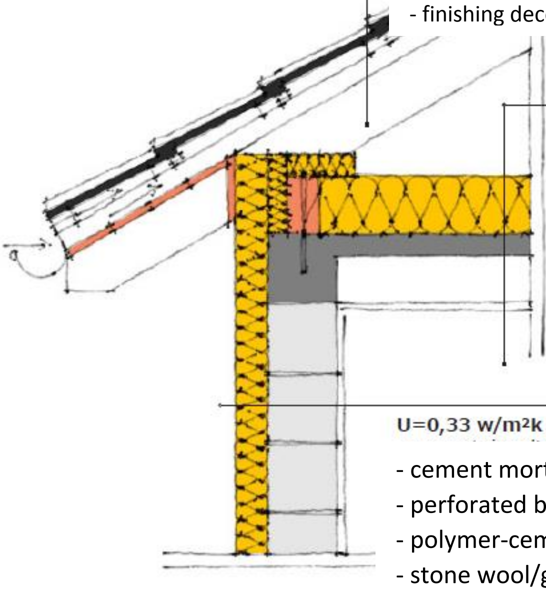
- cement mortar 2 cm
- perforated brick 19 cm
- polymer-cement adhesive
- stone wool/glass wool/expanded polystyrene ≈10 cm

1. sloj građevinskog ljepila sa armaturnom mrežicom - a layer of construction adhesive with wire mesh
2. sloj građevinskog ljepila sa armaturnom mrežicom - a layer of construction adhesive with wire mesh

- impregnated coating
- finishing decorative layer

Properly applying thermal insulation on the ceiling adjoining an unheated attic and the junction with the wall's insulation

- clay tile 2 cm
- counterlaths 8/3 cm
- wooden rafters



U=0,22 w/m²k

- cement mortar 2 cm
- slab ≈6 cm
- vapour barrier, according to need-estimate
- stone wool/glass wool/expanded polystyrene ≈10 cm

U=0,33 w/m²k

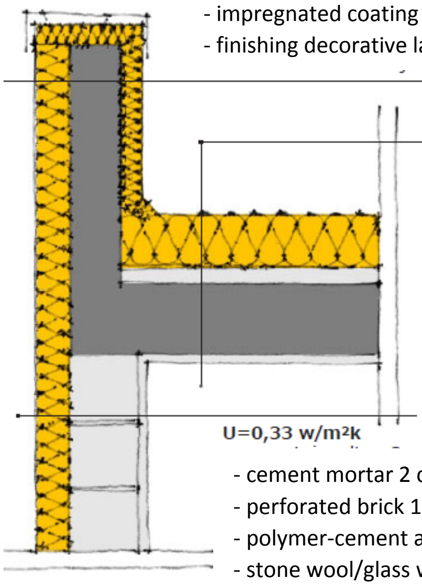
- cement mortar 2 cm
- perforated brick 19 cm
- polymer-cement adhesive
- stone wool/glass wool/expanded polystyrene ≈10 cm

1. a layer of construction adhesive with wire mesh
2. a layer of construction adhesive with wire mesh

- impregnated coating
- finishing decorative layer

- waterproofing
- stone wool /glass wool /expanded polystyrene ≈5 cm
- Concrete wall ≈15 cm
- stone wool /glass wool /expanded polystyrene ≈5 cm
1. a layer of construction adhesive with wire mesh
2. a layer of construction adhesive with wire mesh
- impregnated coating
- finishing decorative layer

Priručnik za sprovođenje energetskih pregleda zgrada 78



Properly installing thermal insulation on a flat roof and junction with the wall's insulation

$U=0,20\ w/m^2k$

- cement mortar 2 cm
- floor slab
- concrete for slope ≈4 cm
- vapour barrier (according to need-estimate)
- stone wool/glass wool/expanded polystyrene ≈10 cm
- waterproofing
- geotextile

$U=0,33\ w/m^2k$

- cement mortar 2 cm
- perforated brick 19 cm
- polymer-cement adhesive
- stone wool/glass wool/expanded polystyrene ≈10 cm
1. a layer of construction adhesive with wire mesh
2. a layer of construction adhesive with wire mesh
- impregnated coating
- finishing decorative layer

Measure 3: Replacing or improving the present windows

Measures to improve the properties of windows, no matter if they involve enhancing the present windows or replacing them with new ones are among the most common and cost-effective energy efficiency measures. On the one hand, good-quality windows reduce heat losses and enable optimal heat gains, but, on the other, they require additional shading elements to protect the rooms from overheating, especially when the openings are on the south side.

For the audit to be as effective as possible, it is necessary to determine the type of windows and divide them according to different parameters.

The windows should be divided into different types if:

- they have different types of glass;
- the glass is in a different state (in good condition, broken, cracked, not sealed, ...);
- their frames are made of different materials;
- some have, and others do not have a coating or a filter
- they are of different types (single, double, ...);
- some have, and others do not have sun shading;
- they are situated at characteristic locations, because of which, for example, their solar gains are significantly lower;
- they are skylights.

Heat losses through windows can be transmission or ventilation losses. Combined, these two types of heat losses can amount to more than 50% of the total heat losses of the building. Usually, over 10 times greater than losses through the walls, losses through windows make the windows a very important element that needs to be treated by energy efficiency measures.

The U-value coefficient of an old building window is around 3.00-3.50 W/m^{2}K and even higher (heat losses through such a window average 240-280 kWh/m^2 per year). However, European legislation prescribes lower and lower U-values, usually ranging from 1.40 to 1.80 W/m^{2}K. In modern low-energy and passive houses, that coefficient ranges between 0.80 and 1.40 W/m^{2}K.

Both glass and window profiles contribute to total heat losses through windows. Window profiles, no matter what material they are made from, must ensure good sealing, breaking of a cold bridge in the profile, easy opening, and low heat transfer coefficient.

Glasses can be insulating, double or triple glazed, with different gas filling or coatings that enhance their thermal characteristics.

The following factors contribute to lowering the U-value of the glass:

- **Thickness and number of interspaces**. The U-value decreases if there are more interspaces with greater distances between them. The U-value can be reduced by using double or triple glazed insulation glasses, e.g., 4 + 10 + 4 + 10 + 4, which means 3 layers of glass that is 4 mm thick at intervals of 10 mm;
- **The filling of interspaces**. If interspaces between the panes are filled with a gas (argon, krypton, etc.), the U-value will be significantly lower;
- **Glass selection**. The thickness of the glass has a negligible impact on the U-value, but the Low-e glass considerably reduces it. The low-emissivity glasses are coated on an inner surface, touching the interspace with a specific metal film that lets short-wavelength radiation (sunlight) pass through it and reflects long-wavelength radiation (infrared radiation).

The U-value of standard window glass is 1.0 W/m^{2}K, while special types of glass can have a U-value of 0.5 W/m^{2}K. The U-value of the frame material is usually less favourable than the U-value of the glass. The U-value of window frames ranges from 1.2-1.5 W/m^{2}K (standard frames) up to 0.7 W/m^{2}K (high level of insulation). Crucial, however, is the U-value of the entire window ($U_w = U_g$ (glass) + U_f (frame)). Besides U-value, the level of energy transmittance (g-value) of the window glass is also important. G-value describes the amount of light, i.e., solar heat, allowed in through the window glass. It should exceed 50%.

Window frames are usually made from the following materials and a combination of materials:

- Plastic frame;
- Plastic frame with the aluminium front protection;
- Wooden frame;
- Wooden frame with the aluminium front protection;
- Aluminium frame.

Frames differ considerably: plastic frames (and multi-chamber frames) are often thermally inferior to wooden frames or wood/aluminium combinations. The depth to which the glass enters into the frame can also be an important factor, considering that the edge of glass surfaces represents a thermally weak spot.

In general, it can be said that wooden frames are most thermally efficient and also easiest to repair.

Thermal characteristics of windows and other glass surfaces can be improved by:

- Sealing windows and exterior doors;
- Inspecting and repairing window and door furniture/hardware (check if they work correctly or are damaged);
- Insulating radiator niches and roller shutter boxes;
- Reducing heat losses through windows by installing blinds, hanging curtains, etc.;
- Replacing windows and exterior doors with those of higher thermal quality (recommended U <1.40 W/m^{2}K)

Description of the existing state

Description of the existing state of windows and external door should include the following information:

- Kinds and types of existing windows, frame material, number of glasses, etc.
- U-value of the existing windows according to their kinds;
- Description of windows state, specifying their orientation
- Spotted damages to the windows
- Other specific features that can be important for selecting and defining the measures

Description of the measure

Description of the measure for windows replacing or repairing should contain:

- Description of new types of windows to be installed, specifying frame material, number of grasses, glass thickness, and width of interspace;
- U-values of windows;
- The amount of solar gains;
- How windows open;
- Investment estimation

Installing roller blinds, shutters, and similar sun shading elements

Solar heat gains play an important role in the overall energy balance of the building. On the one hand, solar radiation results in heat gains, while, on the other, it threatens to overheat the building. That's why this topic should be given careful attention when analyzing both the building and proposed measures to achieve energy efficiency.

If the sun shading system is well suited to the external conditions, siting, and orientation of the building, and good internal functional scheme, it can significantly improve not only energy characteristics but also the comfort and ambient characteristics of the building.

The main functions of a good sun shading system are to:

- Protect from overheating in summer;
- Enable additional heat gains in winter

During the summer months, sun shading is used to limit the heating of rooms by sunlight entering through windows to a level ensuring a pleasant indoor climate. During the same period, thermal protection depends on the rooms and window size, type of glasses and sun shading, ventilation, internal heat sources (e.g., heat radiating from human bodies, computers, or lighting), as well as the capacity of building materials (used for inner and external walls, ceilings, insulation material in roof structures) to accumulate heat.

Measure 4: Replacing old conventional boilers with the low-temperature and condensing boilers

Replacing an old conventional boiler with a low-temperature or condensing one always brings energy savings due to the higher efficiency of new boilers.

Criteria for evaluating and replacing old conventional boilers:

- Old boilers that are using different types of fuel or can switch to a different type of fuel, with a constantly high boiler water temperature (above 70°C)
- Boilers are oversized because of oversizing the heating system in the design and installation phase (wrongly assuming that this will ensure better flexibility in the future), or subsequently implemented measures of the building's thermal envelope insulation
- Boilers are insufficiently thermally insulated so that the boiler room gets heated due to high surface losses
- Boilers have high flue gas losses (flue gas temperatures often exceed 200°C)

Fuel choice

When choosing the fuel, the following aspects should be considered:

- Price
- Fuel market supply
- The trend of the fuel market supply in the next 10 years
- Storage
- Environmental impact (air pollution)

Thermal/heat capacity (boiler power)

Given that a low-temperature or condensing boiler will replace an existing boiler in the building, the data on previous fuel consumption can be used to calculate future fuel consumption and the nominal (rated) capacity of a new plant.

If the project of the building's present heating system is available, thermal capacity (boiler power) can be established based on the calculated amount of required heat, using calculations of the building heat losses and the heat required for domestic hot water preparation (if any). The boiler heat losses (1-5%) and the heat losses in the distribution network, if it includes longer pipelines (5-15%), should also be considered.

If, in addition to a heating system modernization, measures for thermal insulation of the building envelope are undertaken, it is recommended to estimate, in percentage terms, the reduction in the building's heat losses after implementing the measures. For example, choose certain characteristic rooms in the building and calculate their thermal properties by using new U-values of the envelope elements. By comparing calculated heat losses with the old data, i.e., the percentage of their reduction, the heat capacity of a new boiler can be roughly estimated.

Special attention should be paid to:

1. Compliance with other system components:

Regulation technique: advanced regulation is used for a low-temperature and condensing boilers, which regulates the optimal supply flow temperature according to the outdoor and set indoor temperatures.

Chimneys: existing chimneys often have too large cross-sections to be suitable for modern low-temperature boilers. Because of the poor thermal insulation of chimneys, the flue gases condense on their inner surface due to lower exhaust gas temperatures. To modernize the heating installations without restoring the chimney, a combined device for additional air can be used.

Radiators: a lower water temperature in the distribution system requires larger surface radiators, so the radiators should be provided with additional ribs or smaller radiators should be replaced with bigger ones.

Potential installation of a solar system: if a solar thermal system is envisaged for domestic hot water preparation and a new boiler is planned as an additional energy source, the calculation of required thermal energy should include, in addition to heating capacity, thermal capacity for domestic hot water preparation, thus determining the required boiler capacity.

2. Boiler room:

It should be determined if the existing boiler room is big enough to accommodate the planned equipment (new boilers and other elements, and possibly equipment for domestic hot water preparation). If it is necessary to expand the existing boiler room or find a new location for a new technical /boiler room, the factors such as the chimney position, the possibility of fuel delivery, etc., should be considered.

If a new location is to be determined for a boiler room, the most convenient position is the central part of the building (if possible). In that way, distribution lines will be shorter, thus making the fluid temperatures in heating installations more uniform.

In addition, the boiler room should have at least one external wall to ensure reliable ventilation.

Description of the existing state

→ Description of the existing heating system

- *Heating generator* – indicate the manufacturer's name, type, age, energy carrier, total nominal heating capacity of the boiler (displayed on the boiler nameplate or found in the technical documentation), fuel type and method of its supply, specify if there is a system for chemical water treatment, describe the existing boiler room - its characteristics and location in the building, indicate technical features and location of the chimney, if any,

- *Distribution system and heating emission bodies* – describe how the heat is distributed, indicate the type of heating emissions in the rooms, specify the total installed capacity of heating emissions (calculated by summing up the individual capacities of all emission bodies or found in the technical documentation),
- *Method of regulation* - describe the heating system regulation with all its characteristics, separately central regulation (the heat generator regulation, e.g., regulation of the supply flow temperature according to the outdoor or indoor temperature), and separately local regulation (regulation of heating emissions, e.g., thermostatic valves),
- *Safety devices and equipment* – indicate the equipment intended to protect the boilers and system from the excessive pressure and temperature increase (a safety valve, an expansion vessel),
- Assessment of the general condition of the system by visual inspection, and based on possible measurments (e.g., flue gases analysis to estimate the boiler efficiency),
- In case that individual heating devices are used for additional heating, specify their type, capacity, manner and period of use.

→ Information on indoor temperature conditions

The results of measurements by data loggers at characteristic locations in the building, readings from control settings in the rooms, or subjective feelings of the occupants.
Indicate if the set-back temperature is used in the building. If so, specify the periods when it is active and how it is controlled (manually, automatically).
List the heated areas in the building.

→ Information on the heating system operating regime (daily, weekly)

Indicate when the heating system is switched on to a set indoor temperature during the day and when it is switched off or set to a “set-back” mode

→ Information on the duration of the heating season

Indicate the beginning and the end of the heating season, as well as possible interruptions.

Description of the measure

Indicate the manufacturer’s name, type, and total nominal capacity of the proposed low-temperature/condensing boiler, fuel type, and how the fuel is stored.

List all the changes that need to be made on other components of the existing heating system to make it compatible with new boilers.
When there is a need to expand the existing boiler room or build a new space for the boiler plant, indicate the proposed location, and include all the construction and electrical works needed to build a new system and put it into operation.

Investment estimate

40-700 €/kW (a unit price per kW of boiler power)

A higher price per kW refers to boilers with lower capacity (up to 5 kW), and it decreases with the increase of boilers’ capacities towards the upper limit (400 kW).

Potential saving

15-30% reduction in thermal energy consumption

Procedure and period of maintenance

It is recommended to have installations inspected and serviced annually by an authorized service technician (burner inspection, furnace cleaning, automatic regulation system inspection).

It is also recommended to have the flue gas discharge installations inspected once a year.

Investment payback period
2-5 years (depending on consumption)

Duration of the measure
15-20 years

Measure 5: Replacing old conventional boilers with biomass–pellet boilers

The present central heating system using old conventional fossil fuel boilers should be replaced by a system that uses biomass-pellet boilers. That can bring multiple benefits, such as increased energy efficiency of the heating system, considerably reduced heating costs, and reduced environmental pollution.

The investment costs of pellet boiler heating systems are generally higher when compared to conventional heating systems, while their operating costs are lower. In any case, quick payback can be expected, given the low fuel price. In addition, unstable prices of electricity and fossil fuels go in favour of using pellets as fuel.

There are 5 steps to estimate possibilities for introducing this measure.

STEP 1	Preliminary assessment if there is enough room to accommodate the boiler plant and pellet storage
STEP 2	Check out if the fuel (pellets) is available
STEP 3	Check out if access to the cistern (a specific purpose silo vehicle) is possible
STEP 4	Determine the capacity of the boiler
STEP 5	Determine the size of the space needed for pellet storage

Step 1. – Ascertain if there is enough room to accommodate the boiler plant and pellet storage

A pellet boiler requires more space for the boiler plant and fuel storage than the oil and gas boilers. The pellet boiler is much bigger than the fossil fuel boiler of adequate capacity, requiring, in addition, much bigger access space for cleaning and maintenance.

The following should be assessed:

if the pellet boiler, given its size, can fit into the existing boiler room or if the present boiler room should be expanded or a new one built,

if there is a space near the boiler room that can be converted into pellet storage or where the storage can be built,

if there is access to the cistern.

Step 2. – Check if the pellet fuel is available on the market

Before making a decision, research potential pellet suppliers and check the pellet quality.

The best guarantee for pellet quality is a certificate. One of them is the ENplus certificate. ENplus is a certification scheme most commonly used in Europe, which guarantees the quality of pellets through controlling the entire chain of production and supply, from manufacturers to retailers. This standard offers pellets of classes A1 and A2.

The distance from the place of pellet supply has a considerable influence on the price of pellet heating. According to some estimates, it is not recommended to use pellets if bought in a place more than 150 km away.

Step 3. - Check if access to the cistern is possible

Consider the possibility of access for a specific purpose silo vehicle (cistern). In principle, an access road at least 3 m wide and a passage at least 4 m high are the necessary preconditions. When storing the pellets, take care that the road is no longer than the hose, which is 30 m.

Step 4. - Determine the capacity of the boiler

A precondition for the optimal operation of a pellet boiler plant is the adequate selection of boiler.

Boiler capacity is determined similarly as in the measure "Replacing old conventional boilers with the low-temperature and condensing boilers".

Step 5 - Determine the size of the space needed for pellet storage

The size of the storage space depends on the required amount of thermal energy. If bigger pallet storage is available, the pellet procurement is organized only once for the whole heating season. Otherwise, the procurement must be organized several times during the heating season.

Anyway, for the plants in existing buildings, it is more cost-effective to adjust fuel delivery to the existing storage than to build a new storage facility.

A rough estimate of the storage area needed for the estimated annual energy needs

for 1 kW of thermal energy = 0,9 m^3 of space
usable storage area = 2/3 of the total volume
1 m^3 of pellets = 650 kg
1 m^3 of pellets = 3200 kWh

A rectangular shape is recommended as the best for the storage area.

Please, pay attention to:

- → It is convenient that the pellet store has one external wall. It is necessary to provide a 230 V power supply for the pellet supplier's suction fan, as well as a boiler switch off
- → Pellets are not convenient for long-term storing, so it is not recommended to store them outside the heating season. Because of a long storing and gravitational force, the pellets may decompose and create dust.
- → Pellets used as boiler fuel must meet the requirements specified by the boiler manufacturer, referring primarily to the moisture content and dimensions.
- → Storing of wood pellets requires special safety requirements (given the pellets are highly susceptible to moisture, the store must be dry, with fireproof doors and walls, and without electrical installations).

Description of the existing condition

The same as in the measure "Replacing old conventional boilers with the low-temperature and condensing boilers"

Description of the measure

Specify the name of the manufacturer, the type, and the total nominal capacity of the proposed pellet boiler.

Provide a description of the whole pellet combustion plant: burner, digital regulation (automated process), pellet storage, conveyor.

Describe the boiler plant room and the space used as pellet storage. Specify their location in the building and how the pellet is delivered (an access road for the cistern).

Indicate all other changes that need to be made on other parts of the existing heating system to make it compatible with new boilers, like in the measure "Replacing old conventional boilers with the low-temperature and condensing boilers".

Investment assessment

70-1200 €/kW (unit price per kW of boiler power)
The higher price per kW refers to boilers with lower capacity (up to 5 kW), and it decreases with the increase of boilers' capacities towards the upper limit (400 kW).

The investment includes the existing boiler dismantling, procurement, and installation of a new pellet boiler with a burner, conveyor, pellet storage, digital regulation.

Potential savings

40-60% reduction in heating costs

Procedure and period of maintenance

The pellet boiler requires a greater engagement by the user when it comes to fuel supply, cleaning, and disposing of combustion products compared to oil or gas boilers. Every 5-10 days, it is necessary to check the quantity of ash and remove it. Twice a year, it is needed to clean the burner, grilles, and fan, empty and clean the pellet tank, inspect the flexible connecting pipe and electrical cables. It is recommended that the annual maintenance be entrusted to an authorized service provider. The smoke extraction installations should be inspected once a year.

Investment payback period

2.5-5 years (depending on consumption)

Duration of the measure

15-20 years

Measure 6: Replacing old conventional boilers with heat pumps

Replacing an old conventional boiler with a heat pump using air, ground, or groundwater as a heat source can bring multiple benefits, such as increased energy efficiency of the heating system, less fuel used for the same amount of produced heat, considerably reduced heating costs, and reduced negative impact on the environment.

An obstacle to introducing heat pumps is the higher investment cost compared to conventional heating systems. However, the total operating costs are much lower. The investment costs depend on the heat source utilized and the heat pump efficiency, while the operating costs mainly depend on electricity price.

The main preconditions for the efficient use of heat pumps are:

→ sufficiently high and relatively constant temperature of the heat source for a long period (e.g., the whole heating season),
→ a short distance between the heat source and the sink,
→ a heat sink of moderate temperature level,
→ use over a large number of hours during the year (greater cost-effectiveness),

→ high prices of other energy sources (to achieve higher savings).

Selecting a heat source

Air, water, and ground as heat sources for heat pumps have both advantages and disadvantages. Which of them will be used depends, among other things, on local conditions and connection charges. In any case, the heat source that provides the highest temperature with minimum connection charges should be given preference.

Table below (*Comparing different heat sources used in a heat pump*) can help make a decision.

	Ground collector pipes	**Deep ground probes**	**Groundwater**	**Air**
Availability / possibility of installation	Preferably free surfaces	Anywhere	Depends on local availability	Anywhere
The need for space	Great	Minor	Minor	Minor
Average winter temperatures	-5 do +5°C	0 do 10°C	8 do 12°C	-25 do +15°C
If permission for use is required	No	Most of the times	Always	No
Typical heat pump energy efficiency ratio (EER)	4.0	4.5	4.5	3.3
Connection charges	High	Very high	Very high	Low

The heating system sizing

The thermal load of a building is determined in a similar way as in the measure “Replacing old conventional boilers with the low-temperature and condensing boilers”.

For the heating of buildings, a heat pump can be used in two main system configurations: monovalent and bivalent. In a monovalent system, the heat pump is the only heat source that supplies the energy required for the heating of building during the whole heating season, regardless of external conditions. The main characteristic of monovalent heat pump systems is that they are low-temperature systems. That’s why it is necessary to use underfloor, panel, or low-temperature heating with radiators. A bivalent heating system comprise another heat generator (using fossil or some other fuel) in addition to the heat pump. The bivalent heating system provides a higher water temperature in the distribution system, enabling thus the use of high-temperature heating with radiators.

The majority of existing heating installations are those with radiators using water with a temperature of 90°C/70°C, while a small number of them use feed water whose temperature is below 70°C. In heating systems with radiators having water temperature of 90°C/70°C, the heat pump can be used in bivalent mode.

In existing buildings, a heat sink is defined by old installations. After the type of heat pump (by the heat source) has been selected, and the building thermal load determined, it is necessary to define what is the proportion of the heat pump as the main heat source, and the proportion of the existing additional source, which was the only source before reconstruction. When deciding whether the heat pump will take part in the parallel or alternative operation, its size has also been defined. The ratio of the share of energy supplied by the heat pump and the additional source is derived from these data.

The heat pump operates with temperatures lower than those in conventional fossil fuel boilers, so to provide the required amount of heat for a building, it is necessary to increase the present surfaces of radiators.

A heat pump utilizing air as the heat source is the most common type, used in combination with a back-up heating system.

Please, note:

Thermal insulation of the building has a high impact on the efficiency of the heat pump. That's why heating by heat pumps is not recommended in poorly insulated buildings.

The use of heat pumps is especially cost-effective when utilized for DHW preparation and/or cooling.

Description of the existing state

The same as in the measure "Replacing old conventional boilers with the low-temperature and condensing boilers".

Description of the measure

Recommend heating of the building by a heat pump utilizing energy of the ambient air/ground /groundwater. Indicate the heat capacity of the heat pump in kW and its basic parameters (coefficient of performance - COP, annual coefficient of efficiency - Heating Seasonal Performance Factor HSPF). Indicate where the heat pump is located in the building.

Describe the envisaged concept of a heat pump heating system: monovalent/bivalent. For a bivalent mode, indicate an additional energy source and specify its characteristics. In addition, specify the proportion of the heat pump as the main energy source, and the proportion of the additional source.

If the ground is selected as a heat source, specify the required surface area of collector pipes in m^2, i.e., the total depth of the ground probes.

When the groundwater is selected as a heat source, specify if the system has one or two wells for collecting and returning the used water.

Indicate if the permission needs to be obtained from the competent institutions for utilizing the proposed heat source (groundwater, ground probes).

Specify all other changes that need to be made on other parts of the existing heating system to make it compatible with heat pumps.

Given that the installation is very complex, recommend that the project documentation should be prepared.

Plan for all the necessary construction and electrical works, including works needed to put the new installation into operation.

Investment assessment

720-1,200 EUR/kW of the heat pump capacity (for the device and its installation), with an additional cost of 150 EUR/kW for surface excavation or 720 EUR / kW for ground probing.

Potential for saving

50-60% reduction in heating costs

Savings depend on several factors, such as local climatic conditions, the present heating system efficiency, fossil fuel and electricity price, as well as the size and parameters (COP, HSPF) of the heat pump that will be installed.

Procedure and period of maintenance
It is recommended to have the system serviced by an authorized service technician once a year.

Investment payback period
10-20 years (depending on the heating system and the type of heat pump)

Duration of the measure
15-20 years for the heat pumps using air as a heat source

20-25 years for the heat pumps using groundwater or ground as a heat source

Measure 7: Installing a system for recovering heat from the exhaust air in ventilation systems

Rather than using hot water from the boiler room to preheat fresh air in the ventilation system and thus consume the primary fuel, the heat of the ventilation system exhaust air can be used for that purpose. That contributes to the primary fuel saving, equivalent to the heat recovered from the exhaust air, and environmental protection.

When and how to use the heat recovery systems in existing buildings?
The answer depends on several factors, and for each case, an analysis of its economic justification should be carried out:

- → spatial needs and distance between the system elements,
- → temperature and quantity of the waste heat,
- → airflow,
- → efficiency of energy recovery equipment,
- → additional energy needed for the operation of the energy recovery system, and
- → possibilities for adaptation of the existing systems.

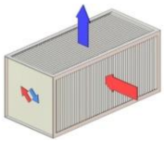
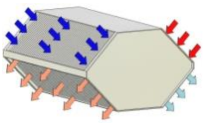
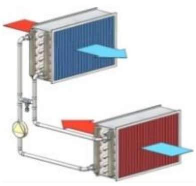
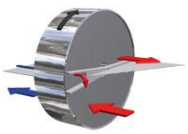
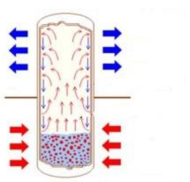
Cost-effectiveness of using a heat recovery system in ventilation systems

An analysis of the cost-effectiveness of a heat recovery system includes four important steps:

1. Determining the operating parameters for the flow and temperature of air (fresh and exhaust air), the system operating time, type and price of fuel used by the ventilation system, and the selected equipment efficiency;
2. Selecting the type of energy recovery system, establishing its efficiency and the amount of recovered energy;
3. Calculating the amount of fuel saved over a set period (one year);
4. Assessing how much it costs to introduce the system.

The table below provides information that might help determine the above parameters to evaluate a heat recovery system.

	Supply and exhaust air are carried together	A change of matter is possible	There are moving mechanical parts	Degree of heat recovery	Total costs including installation in EUR per m^3/h	A specific volume of the heat exchanger in m^3 per 10,000 m^3/h of air

Plate heat exchanger with cross flow  with countercurrent flow 	yes	no	no	45-65 %	0.35-0.65	1.00-1.80
A water circulation system 	no	no	yes	40-70%	0.70-1.40	0.80-1.40
Rotary heat exchanger  without a hygroscopic layer	yes	yes (to a certain degree)	yes	65-80%	0.50-0.80	1.00-1.60
with a hygroscopic layer	yes	Yes	yes	65-80%	0.60-0.90	1.10-1.60
A heat pipe 	yes	no	no	35-70%	0.70-1.20	0.80-1.40

The highest degree of heat exchange does not always have to be the most favourable. The higher the degree of heat recovery is, the higher the investment and operating costs are. Operating costs increase because more energy is needed for fans, pumps, or compressors.

Description of the existing state

→ Description of the present ventilation system

- description and size of spaces that are ventilated, and the requirements for air exchange,
- total installed power [kW] and capacity [m^3/h] of the ventilation system, number and type of air handling units,

- designed amount of air in [m^3/h] – supplied (fresh) air and exhaust air (the data can be found in the technical documentation, if any)
- the measured amount of air in [m^3/h] – supplied (fresh) and exhaust air, if measured,
- heating energy generator - specify the name of the manufacturer, type, age, heat carrier, total nominal capacity of the generator supplying heat to the ventilation system, and the fuel type,
- heating battery for fresh air heating - specify the type (electric or hot-water battery) and capacity [kW],
- fans - exhaust and supply, indicate the type, age, and installed capacity [kW] of the fan,
- humidifiers, filters, cooling coils - if any, specify the type and capacity [kW] of cooling coils,
- ductwork - describe the duct system for delivery of prepared air and removal of the exhaust air, and the condition of thermal insulation of the ducts,
- air distribution elements – outlet and exhaust vents (grilles, diffusers, etc.), indicate the number and type of elements,
- inlets or outlets for supplying fresh air, i.e., removing exhaust air and their location in the building,
- type of automatic control/regulation - describe the ventilation system control with all its characteristics,
- assess the general condition of the system by visual inspection and by possible measuring

→ Information on the operating regime of the ventilation system
Specify when the ventilation system is switched on to a set indoor temperature during the week (weekdays and weekends).

Description of the measure

Specify the type and main characteristics (degree of recovery) of the proposed device for recovering heat from the exhaust air.

List all other changes/preparations that need to be made on other parts of the existing system in order to install a heat recovery device.

Calculate investment and future operating costs for the proposed heat recuperator. Pay attention to additional electric appliances/consumers (higher load on the existing fans, a new circulating pump).

Calculate possible heat savings achieved by installing a recuperator and the payback period.

Investment assessment

0.35-1.40 EUR/m3/h, depending on the type of heat recovery system (installation included)

Potential saving

40-80% of the energy used for ventilation

Procedure and period of maintenance

Periodically (at least once in 2 years) dust and dirt should be cleaned off the surfaces of the heat exchanger

Investment payback period

1-5 years (the payback period is shorter for larger systems, the life span of the drive is longer, and the climate is colder)

Duration of the measure

15 years

Measure 8: Replacing individual electric heaters for DHW preparation with solar thermal systems

One of the most economical ways to prepare domestic hot water (DHW) throughout the year is to use a combined solar system with an additional electric water heater. In winter, in periods of inadequate insolation or increased consumption, a heat exchanger is used as an additional source that uses hot water from the existing building heating boiler (utilizing heating oil, gas, electricity, or biomass). During the summer period, when the central heating system is not used, an electric heater built into the hot water tank is utilized for water heating.

Basic parameters of the solar systems sizing

In the audit phase, it is necessary to define the type of solar system and calculate approximately the required collector area and volume of the heating water tank and determine their locations in the building. A more detailed analysis of the solar system (additional calculation of the collector surface and tank, the sizing of the heat exchanger, pump, expansion vessel, and piping system) is to be carried out during the design phase.

When surveying the locations for the planned installations, the following should be established:

Step 1

→ Roof:
  type of roof (flat roof/sloping roof)
  roof condition and access to it
  available area for installation (length, width) in m^2
  roof slope in degrees (recommendation: 25° to 50°)
  orientation, i.e., deviation from a southerly direction towards an east/west direction in degrees (recommendation: ± 20°, max 45°)
  existence of shelters /shading

→ Possible location for a tank – a hot water accumulator

→ Information on the heating system::
  boiler (age, power in kW) and other components
  fuel (heating oil, LPG, electricity, biomass)

Step 2

If possible, the profile of DHW consumption, daily, weekly and monthly, and information on possible interruptions in the operation of the DHW preparation system should be obtained from the technical staff.

If there is no information on DHW consumption, the need for hot water should be calculated based on an assessment of the required amount of water in different buildings, depending on their purpose.

In addition to the daily hot water consumption, water temperature should be specified (45°C, 60°C).

Furthermore, information on cold water temperature (from the public water supply network) should be obtained.

Step 3

An appropriate type of collector should be selected and its efficiency specified.

Step 4

For the correct estimation of the solar installation intended for a particular climatic area, it is very important to know the daily solar radiation expressed in Wh/m^2 per day.

Step 5

Determine the solar coverage rate - the percentage of energy for DHW preparation provided by the solar system.

Designing an optimal solar system always entails finding a good compromise between the amount of obtained heat (yield) and solar coverage, which also means a compromise between investing in a solar system and saving energy obtained from conventional sources.

A percentage between 30% and 40% is recommended for larger systems.

Sizing the collector surface and volume of the hot water tank

The software models for solar systems simulation (T * Sol, Transol, Polysun, etc.), if available, are the best way to examine the impact of all the DHW consumption-related parameters and user behaviour on the operating state of the solar system, especially in larger solar systems.

To calculate the collector surface required for DHW preparation, the following simplified method can be used:

The energy required for DHV preparation [kWh, day]:

$$Q = V \cdot \rho \cdot c_w \cdot \Delta t$$

where:

Δt [°C] – is a difference in temperature between hot and cold water,

V [m^3, day] – is an average amount of hot water consumed per day that needs to be heated by Δt,

ρ [kg/m^3] – is the density of water at a medium temperature,

c_w = 4,182 KJ/kg K – is the thermal capacity of water,

Required energy of incident solar radiation [kWh, day]:

$$Q_{sol} = \frac{Q}{\eta_k}$$

where:

η_k – is the collector efficiency (a ratio of useful energy transferred to water and energy of incident solar radiation)

The average solar flux on a horizontal surface [kWh/m^2] in the climatic zone where the solar system is installed is calculated using the available climatic data (e.g., data on the monthly average global solar radiation provided by Meteonorm software). The total solar flux is calculated as the sum of average monthly values during the months when the solar system is used (G_{sol}).

The daily solar flux [kWh/m^2, day] is determined using the monthly average solar flux, taking into account the number of days during the period when the system is used (n):

$$Q_{sol,d} = \frac{G_{sol}}{n}$$

The required collector area for DHW preparation [m^2]:

$$A_{kol} = \frac{Q_{sol}}{Q_{sol,d}}$$

Take into account the degree of solar coverage, i.e., the percentage of energy for DHW heating obtained from the solar system (x [%]).

$$A_{kol,uk} = \frac{x}{100} \cdot A_{kol}$$

The volume of a hot water tank – an accumulator can be determined based on the recommendation that the collector area of 1 m^2 requires a volume of 50 l in flat-plate collectors or 70 l in vacuum tube collectors.

Description of the existing state

Describe the present method of decentralized DHW preparation. Indicate the number and power of individual electric boilers that are used. Furthermore, specify locations of boilers in the building and the purpose of the prepared hot water.

Description of the existing measure

Propose solar thermal system to be introduced for DHW preparation.

Indicate the type and total absorbing surface of the proposed solar collectors and their location on the selected roof surface.

Indicate the type and volume of a hot water tank – an accumulator and its location in the building.

List other parts of the solar system that will be elaborated on in more detail in the design phase (heat exchangers, circulator pumps, expansion vessel, piping system, safety and control equipment, etc.).

Indicate the degree of solar coverage (the percentage of energy for DHW heating obtained from the solar system).

Describe the manner of additional heating of hot water in periods of inadequate insolation or increased consumption and during the periods when the central heating system is not used.

List the assumptions used to calculate energy needs: the quantity of consumed water, hot water temperature, cold water temperature.

Briefly describe the calculation method and provide main calculated data - required collector surface, tank volume, calculated savings, investment costs, and payback period, as well as economic lifetime.

Provide a scheme of the proposed DHW heating system.

Investment estimate

The cost of the system depends on the type of product, ranging between 400 and 1500 EUR/m2 of a collector area.

The approximate ratio of the total system costs is as follows: collector module 36%, installation 21%, tank with heat exchanger 26%, solar station including the control 8%, and other costs 9%.

Potential saving

60% of the electricity used for DHW heating

Procedure and period of maintenance

Annual servicing is recommended, and it should include: inspection and cleaning limescale off the water tank (after 1-3 years), an inspection of /replacing Mg-anode (replacement after 1-3 years), replenishing glycol, an inspection of expansion vessel pressure (replacement after 10- 15 years), insulation inspection (replacement of external UV-resistant insulation after 10 years), replacing pumps after about 15 years.

Investment payback period

5-10 years

Duration of the measure
25 years

Measure 9: Installing thermostatic valves on existing radiators

If buildings do not have local temperature regulation, they are heated regardless of the actual temperature requirements in separate rooms. Consequently, the rooms get overheated, and because the temperature cannot be simply regulated in any other way than by ventilation, major heat losses are sustained.

One of the simplest solutions is to install thermostatic valves with thermostatic heads that regulate the room temperature by controlling the hot water flow through the radiator.

It is very important to pay attention to what type of thermostatic head is proposed for a particular building.

There are two main types of thermostatic heads: a classic one intended for residential buildings and a protected thermostatic head for public spaces i.e., intended for installation in public buildings.

This division is very important to bear in mind when the measures for non-residential buildings are concerned. If installed in such buildings, the classic thermostatic heads cannot regulate temperature well, being not resistant to vandalism and unprotected against unauthorized operation. Thermostatic heads intended for public (non-residential) buildings can be set to the desired temperature only by special tools that only an authorized person can have.

Please, pay attention to:
For the thermostatic valve to achieve its maximum efficiency, it is necessary to check or ensure the optimum hydraulic balance of the pipe network by installing a hydraulic balancing valve.

Recommended room temperatures:
In literature and designing standards, it is possible to find the recommended indoor temperatures in buildings used for different purposes (hospitals, schools, kindergartens, theatres, cinemas, hotels ...).

Description of the existing state
Describe the indoor temperature conditions in the building.

If the temperature is measured by data loggers at characteristic places in the building, the data should be compared with the recommended temperatures depending on the purpose of the building.

Indicate the subjective impression of the occupants.

Description of the measure
Recommend thermostatic valves to be installed on the existing radiators to regulate the indoor temperature, and reduce heat consumption.

Specify which type of thermostatic head should be used given the purpose of the building, i.e., a classic type or an additionally protected model intended for schools and public spaces.

Recommend to which temperatures to set the thermostats depending on the purpose of spaces.

If necessary, suggest that a hydraulic balancing valve be installed.

Briefly describe the installation process and its step: emptying the heating system (discharging water from the system), replacing/installing thermostatic valves, filling the system, venting, and, if necessary, hydraulic balancing of the heating system.

Investment estimate

15-20 EUR/pc a classic type, 25-40 EUR/pc the so-called anti-vandal type (disassembling and assembling included)

Potential saving

5-15% of consumed fuel

Procedure and period of maintenance

The system does not require special maintenance

Investment payback period

Around 3 years

Duration of the measure

15 years (if the product is of good quality)

Measure 10: Frequency regulation

Frequency regulators are electronic devices that regulate the speed of asynchronous and synchronous motors by converting mains voltage and frequency, which are fixed values, into variable values. Much has changed since the appearance of the first frequency regulators with thyristors to the present-day microprocessor-controlled regulators, but the basic principle has remained the same.

Ventilators, pumps, and compressors are often used without speed control. In that case, the flow is regulated by valves or damping in other ways. When the flow is regulated without speed control, the motor runs at full speed. Heating, ventilation, and air conditioning (HVAC) systems rarely require maximum flow, and the flow depends on different factors, such as outside temperature, etc.

The valves and dampers reduce the flow, and the system unnecessarily consumes energy most of the time.

The frequency regulator has great advantages over the mechanical flow control methods, and it achieves great energy savings, especially in ventilation and pumps plants.

The flow is directly proportional to the velocity, while the pressure is proportional to the square of the velocity. From the point of view of energy saving, the most important is that the consumed power is proportional to the third degree of speed. For example, a drive that runs at half speed consumes only 12.5% of rated power.

In addition to great energy savings, the use of frequency regulators has some other advantages:

- The number of starting and stopping of the machine can be drastically reduced by using the full speed control;
- By gradual acceleration and deceleration, stress and sudden shocks in machine assemblies are avoided;
- Maintenance costs are reduced.

Description of the existing state

Carefully study the available project documentation concerning the building, paying special attention to the mechanical and electrical parts of the installations.

Obtain insight, on the spot, about the heating, cooling, and ventilation systems, and other motor drives if they exist in the building (e.g., pump plants, production plants, etc.).

Precisely determine if the frequency regulation is used in compressors, pumps, ventilators, and generally all asynchronous and synchronous motors in those systems and if it operates well.

Description of the measure

The complete heating, ventilation, and air conditioning system (HVAC system) is sized by the highest required values of process variables (flow, pressure, temperature…), which means that pumps, ventilators, and compressors are oversized during most of the operation time. Figure 41 shows a typical operating cycle of a pump or ventilator. During 90% of the operating time, the required flow is below 70%.

By controlling the speed of the pump or ventilator motor, considerable energy savings can be achieved.

Potential saving

By using a frequency regulator to control the motor speed, up to 70% of the energy can be saved.

Duration of the measure

The duration depends on the life span of frequency regulators, which can be from 5 to 15 or more years, depending on the quality of the device.

Measure 11: Replacing classic light fixtures

Today, 70% of light fixtures are fluorescent tubes. Since they are widely used in commercial buildings, there is great potential for savings that can be achieved by replacing the present light fixtures with new, more energy-efficient ones.

With the development of fluorescent lighting technology, the diameter of the fluorescent tube has been reduced, which contributes to the greater efficiency of the lighting system (the light source is closer to the point source). Today, 26 mm diameter (T8 - 8/8”) tubes are most commonly used, and new generation tubes have a diameter of 16 mm (T5). There are also 38 mm (T12) and 7 mm (T2) tubes.

Fluorescent tubes cannot be directly connected to the mains voltage but need a ballast or ballast and starter in case of older generation tubes (they need more voltage when started than in operation - used only with magnetic ballasts).

Magnetic ballasts are inductors connected in a series to a light source. Modern lighting systems are increasingly using electronic ballasts. The use of modern technologies and methods can bring about significant energy savings.

LED	CFL	Incandescent
Avg Life: 25,000 Hrs	Avg Life: 8,000 Hrs	Avg Life: 1,200 Hrs
No Mercury	Mercury	No Mercury
6-8 Watts	13-15 Watts	60 Watts
Uses 84% less energy	Uses 75% less energy	90% energy lost to heat

Infographic by Jill Fehrenbacher

Therefore, fluorescent tubes have significant potential for energy savings. For example, just by replacing a magnetic ballast with an electronic one, up to 25% energy savings can be achieved, and additionally, the life span of the fluorescent tube is extended, the operation is flicker-free, maintenance costs are lower, and the cos ϕ is improved.

Description of the existing state

Thoroughly inspect all the rooms in the building and ascertain the number and state of all light fixtures, the type of lamps, and the type and power of light bulbs. Determine if the fluorescent lamps use magnetic or electronic ballasts and if the lux sensors and motion sensors are used.

Determine the manner of lighting control and the regime of lighting system use, i.e., the average daily use of light fixtures.

Measure the lighting intensity in several rooms (preferably in all rooms) using a lux meter and compare it with the standard intensity. If the lighting is insufficient or too strong, this should be considered, when proposing measures to improve the lighting system.

Description of the measure – an example

The table below shows the present state of the lighting system in a commercial building.

Present lighting fixtures	Piece	kW/pc	kW	Hours per day (on average)	Days per year	kWh/year
Incandescent (ordinary) light bulbs	42	0,1	4,2	6	248	6249,6

Fluorescent 2x58W (magnetic ballast) bulbs	140	0,144	20,16	6	248	29998,08
						36247,68

Table II-1 – before the measures have been implemented

Fluorescent lamps with an opal cover and two 58W fluorescent tubes, using magnetic ballast..

1. The measure envisages replacing all existing fluorescent lamps with the type T5, 2x55W fluorescent lamps, which have electronic ballasts and daylight sensors to optimize the use while fulfilling the required light intensity. As a result, the expected average daily usage per lamp will be reduced by about 2 h on average. The installed power of the new lamp is 110W. The photometric calculation established that this measure meets the standard, i.e., that it can produce an average illuminance of about 500 lux.

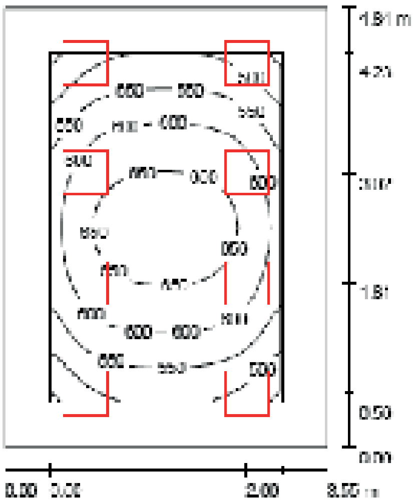


Image II-3 – photometric calculation

2. Lamps with 100W incandescent bulbs are used in sanitary, utility, and shared rooms, and the measure implies replacing them with 23W compact fluorescent lamps, which yield 20% higher illuminance.

The table below shows the situation after the measures have been implemented:

New light fixtures	**Piece**	**kW/pc**	**kW**	**Hours per day (on average)**	**Days per year**	**kWh/year**
Incandescent (ordinary light bulbs)	42	0.023	0.966	6	248	1437.4
Fluorescent 2x55W T5 (electronic ballast) bulbs	140	0,11	15,4	4	248	15276,8
						16714,2

Table II-2 – after the measures have been implemented

Investment payback period

The above example, Tables 1 and 2, shows that an energy saving of 19,533 kWh/year can be achieved. If the price of electricity is 0.1 €/kWh, the annual savings amount to **1953.3 €.**

The cost of investment:

Replacing 42 ordinary light bulbs = 42 * 3 = 126 €

Removing old light bulbs and putting in 140 new fluorescent lamps with sensors

= 140* 75 = 10500 €

Totally: 10526 €

Based on this, the payback period is **5.38** years.

When replacing a lighting system, the payback period varies from a few months (replacing incandescent lamps with fluorescent, compact ones) to 10 and more years for major investment interventions.

Procedure and period of maintenance

It is important to ensure regular maintenance and replacement of damaged tubes and ballasts and regular cleaning in order to maintain the planned lighting level.

Measure 12: Peak energy management

Peak power

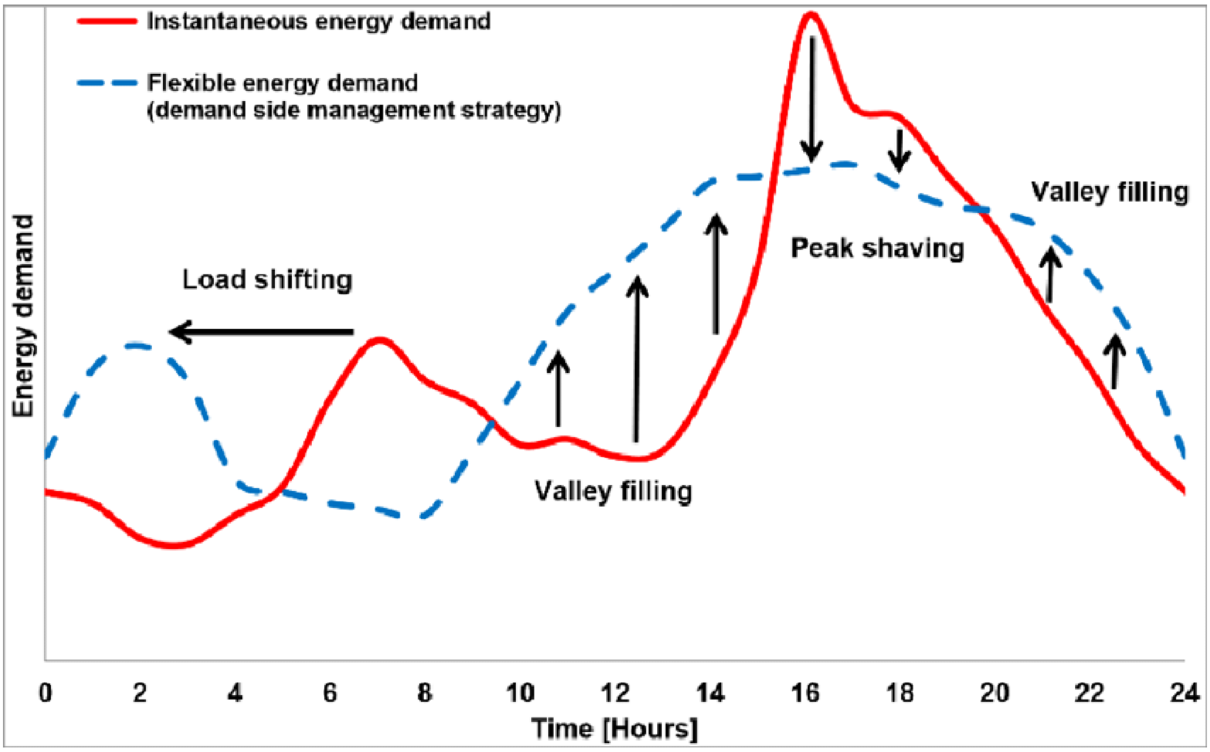
In addition to active and reactive energy, peak power is also measured for large appliances/consumers.
Peak power, i.e., peak energy management, is a very interesting, i.e., cost-effective energy efficiency measure for such consumers.

The power demand or peak power is the maximum mean value of active power measured over 15 minutes during the month using a maximeter.

On average, the peak power costs make between **30% - 50%** of the total bill for the consumed electricity, and the power demand costs may exceed the costs of the consumed active power.
Electricity distribution companies justify such high prices by the need to ensure the system stability and optimal operation of the electrical system, and the main way to do so is to keep the electricity buyers within the agreed consumption. It is clear from the above that it is necessary to analyze the possibility of reducing the power demand costs.

Description of the measure

Peak load is managed by controlling the operating regimes of the largest consumers. The goal is to avoid simultaneous work, i.e., to schedule a full load period of different consumers at different times, so they do not overlap, as shown in Figure III-1.

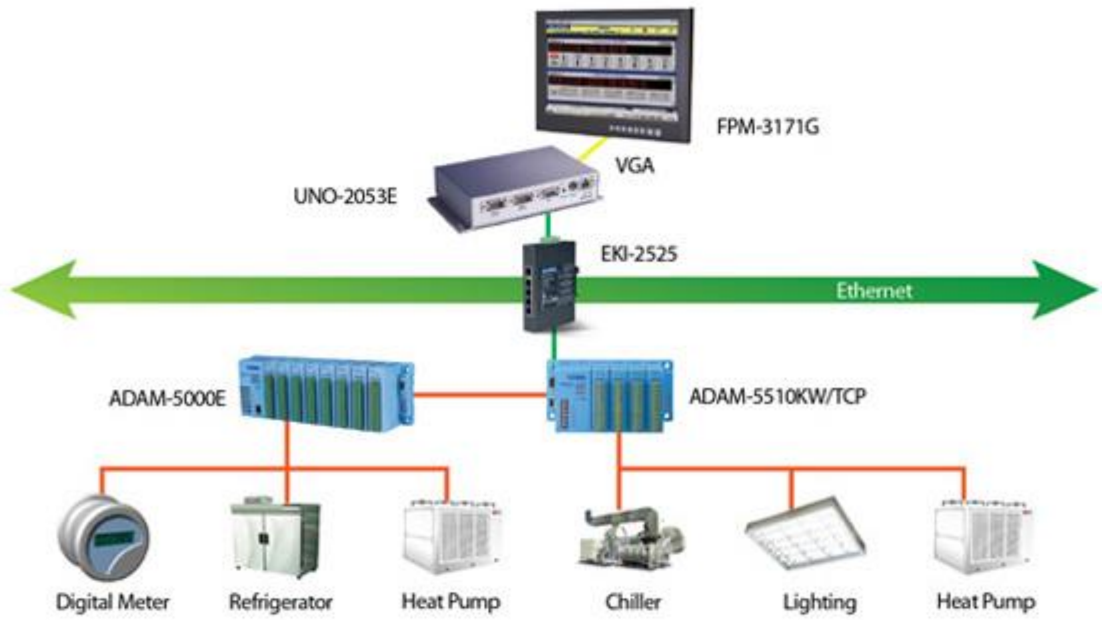


An example of peak energy management

Implementation

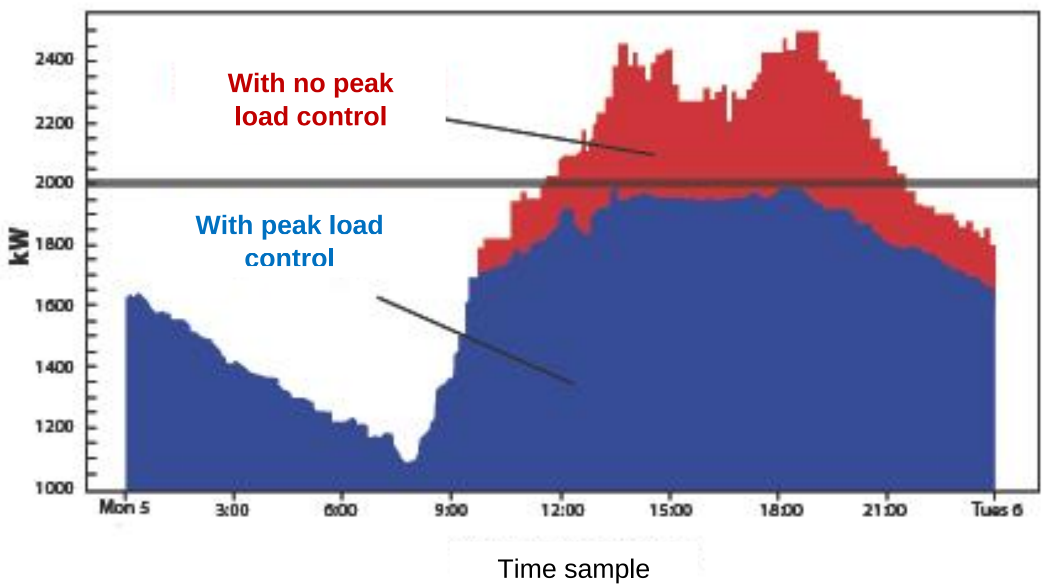
The first phase includes installing network analyzers at the key energy points in the facility (factory, plant, shopping centre, and other major consumers). By the networking of analyzers, all the data are sent to a central computer that monitors and manages the consumption. In that way, all the consumption parameters are instantaneously monitored, including the current power and peak power. Already in this stage, some useful data are obtained, such as electricity consumption by production sectors or product units, overloading of cables and transformers, unbalanced operation, ...

The second phase includes managing individual consumers by switching them on according to a schedule or switching off temporarily, for short periods, those consumers that will not disrupt the production process, e.g., air conditioners.



an example of the peak energy central management scheme

The effect achieved by the implementation of this measure can be seen in image above.



Potential for savings

It has been proved that such systems can reduce the cost of peak load by over 50%.

Investment payback period

In most cases, the payback period of the investment is less than one year, ranging from several months to several years.

Evaluation of the proposed measures from the point of view of energy efficiency and cost-effectiveness

After identifying potential measures for improving the energy performance of the building, it is necessary to indicate, for each measure, energy savings it can achieve, an estimate of investment costs, and a calculation of a payback period. That should be done for each measure, and combinations of individual measures, in order to provide an optimal choice of measures and recommendations for optimal investment.

Investment costs need to be estimated as accurately as possible using the market prices of energy sources on the day when energy savings are calculated. After choosing the optimal combination of measures, environmental savings should be calculated.

Measures	Description	Investment assessment x	Estimated savings y	Payback period x/y
1	Installing efficient lighting	50.000	25.000	2
2	Installing devices for reactive power compensation	20.000	8.000	2.5
3	Installing a system for peak power management	500.000	100.000	5
4	Buying devices of an A energy class	80.000	15.000	5.3

To calculate CO_2 and other anthropogenic greenhouse gas emissions, the IPCC methodology (Intergovernmental Panel on Climate Change) has been developed within the United Nations Framework Convention on Climate Change (UNFCCC). The IPCC methodology determines anthropogenic gas emissions from sources and absorptions by sinks. The dominant source of anthropogenic greenhouse gas emissions is the combustion of fossil energy sources in power plants.

Depending on the place of their origin, emissions can be direct and indirect. Direct emissions occur at the sites of immediate energy consumption (e.g., residential and non-residential buildings) resulting from burning fossil energy sources in stationary power plants (e.g., boilers). On the other hand, when electricity and/or heat are supplied from district heating plants or boiler houses, the emission does not occur at the site of immediate energy consumption, so it is necessary to calculate the indirect emission from electricity or heat production.

List of all lessions:

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2_Audit_Phase 1 Activities before the site visit	>>> link	[18:58]
3_Audit_Phase 2 Activities during the site visit	>>> link	[24:00]
4_Audit_Phase 2_Site visit_images	>>> link	[16:10]
5_Audit_Phase 3 Activities after the site visit - measures-envelope	>>> link	[19:41]
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