ComAct
Community Tailored Actions for Energy Poverty Mitigation

Educational materials for energy advisors

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Author(s)	Marin Petrovic (ENOVA)
Reviewed by	Senta Schmatzberger (BPIE) Inga Rovbutas (IWO), Johann Strese (IWO)
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Preface

This document provides a basis for training energy advisors. Intended participants are frontline staff in local municipalities and energy efficiency advisors engaged with the pilot cases of multi-apartment buildings in the ComAct project. It is assumed that not all participants will be (mechanical) engineers, so only basic knowledge about energy and energy efficiency is required. The estimated duration of training is 18 to 20 hours, but it can be modified according to actual needs.

The training is separated into several parts. At the beginning, legal and engineering background is given, and energy pricing explained. The following chapters are divided by measures: simple measures, measures for the building envelope, heating system, preparation of domestic hot water, and for electric energy. For each group, we give the basics, including the current state and possible improvements of energy efficiency, accompanied by more details where necessary. The level of detail aims to enable participants to fully understand the mentioned advantages and drawbacks of each measure, but without confusing or oversaturating them with data.

No investment values or payback periods have been calculated and expressed in numbers, since they depend on local circumstances and market prices, and vary from building to building.

This training material is not intended for energy auditors, who require a deeper level of knowledge, and should already be familiar with the information presented in this document.

1 Introdution

The availability of energy at affordable prices is a key factor for achieving socio-economic development. On the other hand, the production and use of energy significantly affect the environment, resulting in local and regional pollution and leading to global warming and climate change. Sustainable development that provides security of energy supply while reducing negative impacts on the environment is a global challenge.

Buildings of all types require large amount of energy – but this also offers opportunities for large energy savings. The energy efficiency of buildings has therefore become a priority in the public sector, which has led to significant energy and cost savings. Recently, energy efficiency in the residential sector, for both individual houses and multi-apartment buildings, has also gained significant interest for homeowners, tenants, utility companies and investors.

On top of the energy savings, investments in energy efficiency upgrades can have multiple positive impacts for society which directly or indirectly translate into a monetary value. These multiple benefits on a societal and macroeconomic level, as well as on an individual building level, are well documented. Nevertheless, building owners and inhabitants are often not aware of them, so do not take them into consideration when considering and planning renovation activities. A structured consideration of multiple benefits in cost-benefit analyses of local renovation projects would therefore be beneficial – as it would illustrate these benefits and additional cost savings.

> High renovation rates in residential buildings reduce energy bills and exposure to fluctuating energy prices, which can alleviate energy poverty. Additionally, an upgraded building envelope reduces problems with mould, drafts and noise and adds to the health and wellbeing of occupants. Renovated buildings also offer a higher level of thermal comfort, as it is easier to control influences like relative humidity, air temperature, mean radiant temperature and air velocity.

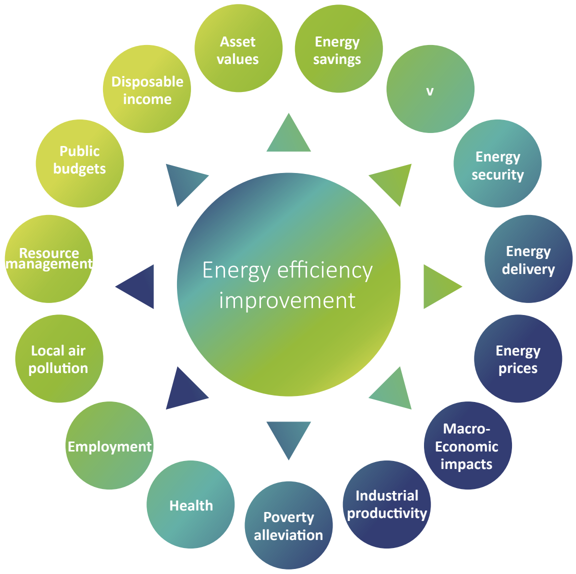


Figure 1 - Multiple benefits of energy efficiency improvements

Long-term benefits of increased energy efficiency of buildings include reduced pollution and global warming. While energy should be used in as efficient manner as possible, energy efficiency should not be confused with energy cost-cutting. Energy-cost-cutting always involves sacrifices, while efficiency means keeping the optimal thermal comfort, indoor climate and lighting levels while using less energy.

Improved energy efficiency has many benefits, depending on the type of intervention. It can:

- Reduce the burden on households as energy prices rise
- Increase energy security
- Decrease the investment needed for energy supply
- Reduce air pollution and climate change emissions
- Expand employment in unskilled and skilled labour
- Reduce demand on national and municipal budgets
- Improve economic competitiveness

> Homeowners who are aware of the full range of multiple benefits for themselves and society are more likely to support deep renovation measures. Energy advisors have a key role to play in this context, by providing measurable information on the additional benefits of different renovation measures and how to achieve the greatest value.

Comprehensive (before/after) monitoring of air quality, moisture and airtightness can illustrate the positive effects of renovation activities. A visual representation of the improved thermal performance – and, if possible, the health effects – helps to make the benefits of renovation more tangible. Creating an emotional connection between energy-efficient renovation and an improved quality of life can lead to an increase in renovation measures[1].

Interventions in residential energy efficiency can lead to significant improvements in living conditions through reduction in energy costs and carbon dioxide emissions. Such interventions for individual houses are strongly dependent on building size and shape, envelope material, construction technique, location and tenant habits, all of which can vary significantly. This makes a general classification of measures and their analysis challenging. However, a typology can be applied for multi-apartment buildings, making analysis of energy efficiency measures generally easier.

[1] BPIE. 2020. Health and wellbeing benefits in owner-occupied buildings.

2

Legal background

Buildings account for more than one-third of all final energy consumption and half of global electricity use. And they are responsible for approximately one-third of global carbon emissions. According to the International Energy Agency, energy consumption in buildings needs to be reduced by 80% by 2050 if we want to limit the world's temperature rise to under 2°C.

Achieving such an ambitious goal cannot be done without a well-developed legal framework, at both national and international level. This is necessary to ensure all involved in energy and energy efficiency use the same approach and methods to calculate heat losses and gains, energy classes and classification for buildings. This is increasingly important in the case of renewables, where several energy sources are combined to meet the demand.

Some documents have been created to facilitate decisions regarding buying or installing equipment, e.g. boilers or home appliances. This significantly helps non-professional end-users to buy what they want and need. International standards also alleviate differences among countries that ratify them, making trade and exchange easier.

There are several groups of legal documents dealing with energy efficiency:

- Standards, international and national
- EU directives
- National laws
- National regulations and ordinances
- National strategic documents and studies

Among standards, series ISO 52000 is the most important. Before this group has been published, a number of other standards covered calculation of heat losses and gains, ventilation and air conditioning, and certification of buildings. With "ISO 52000-1, Energy performance of buildings [EPB] – Overarching EPB assessment – Part 1: General framework and procedures" as its leading document, the ISO 52000 family accelerates energy efficiency in the global building market. From heating, cooling, ventilation and smart controls to energy-using or-producing appliances, the series helps architects, engineers and regulators assess the energy performance of new and existing buildings. The ISO 52000 series of standards enables the assessment of the overall energy performance of a building. This means that any combination of technologies can be used to reach the intended energy performance level, at the lowest cost.

The ISO 52000 series contains a comprehensive method of assessing energy performance as the total primary energy used for heating, cooling, lighting, ventilation and domestic hot water in buildings. It helps to accelerate progress in building energy efficiency and utilising new materials, technologies, and approaches to building design, construction and management. Buildings can be made energy efficient by using high-quality building fabric materials and products, combined with high-quality technical building systems and renewable energy technologies. The key is the systemic approach that assesses the energy performance, considering the dynamic interactions between systems, users and variable outdoor climate conditions. The overarching EPB standard – ISO 52000-1 – is complemented by a set of standards comprising calculation methods for heating and cooling and performance of building elements, as well as aspects regarding energy performance indicators, ratings and certificates.

To boost energy performance of buildings, the EU has established a legislative framework that includes the Energy Performance of Buildings Directive 2010/31/EU (EPBD) and the Energy Efficiency Directive 2012/27/EU. Together, they promote policies that will help achieve a highly energy efficient and decarbonised building stock by 2050, create a stable environment for investment decisions and enable consumers and businesses to make more informed choices to save energy and money.

Following the introduction of energy performance rules in national building codes, buildings today consume only half as much as typical buildings from the 1980s.

Both directives were amended, as part of the Clean energy for all Europeans package, in 2018 and 2019. In particular, the Directive amending the EPBD (2018/844/EU) introduces new elements and sends a strong political signal on the EU's commitment to modernise the buildings sector in light of technological improvements and increase building renovations.

In October 2020, the Commission presented its Renovation Wave strategy, as part of the European Green Deal. The strategy contains an action plan with concrete regulatory, financing and enabling measures to boost building renovation. Its objective is to at least double the annual energy renovation rate of buildings by 2030 and to foster deep renovation.

A revision of the EPBD is therefore an essential part of the Renovation Wave strategy, as it focuses on the central aims while also contributing to the decarbonisation of buildings, in line with the enhanced climate ambition of the European Green Deal. The EPBD covers a broad range of policies and supportive measures that will help national EU governments boost energy performance of buildings and improve the existing building stock.

The Commission has also published a series of recommendations on the building renovation ((EU)2019/786) and building modernisation ((EU)2019/1019) aspects of the new rules. Also, a set of standards and accompanying technical reports has been published to support the EPBD, called the energy performance of buildings standards (known as EPB standards). These are managed by the European Committee for Standardization (CEN).

Another important EU directive is the Energy Labelling Directive 2017/1369, adopted in July 2017, replacing the former Energy Labelling Directive 2010/30/EU. The new labelling regulation will reintroduce the original A-G scale for future labels and establish a common product registry database to support market surveillance. The rescaling of the old labelling will apply to a total of 15 product groups, including some of the most energy-consuming home appliances (e.g., refrigerators, washing machines). As of 1 January 2019, suppliers (manufacturers, importers or authorised representatives) need to register their appliances that require an energy label in the European Product Database for Energy Labelling (EPREL) before selling them on the European market.

National laws, regulations and ordinances in almost all cases follow international standards and EU directives. However, national standards can contain specific appendixes, e.g. including local climate or insolation data used to calculate heat losses and gains.

This legal framework helps make the entire process transparent, from design, development and manufacturing through to installing energy equipment. In this way, manufacturers know what the market needs, while end-users are installing equipment and devices that can bring the desired benefits.

3 Engineering background

Algorithms used for calculating heat losses and gains are given in the ISO 52000 series. This series also covers all other calculations and recommendations regarding heat recovery, ventilation and air conditioning, lighting, and domestic hot water supply. Calculations are based on:

- Data acquired during a building audit (e.g., building dimensions and shading due to surroundings)
- Data on materials used in the building (e.g., thermal conductivity and density)
- Data on climate conditions (e.g., temperatures and insolation)

Data on climate conditions is usually given in documents at national level (e.g., as appendixes to ordinances), since it varies from country to country. If necessary, one country can be divided into several climate zones, to further enhance calculation precision and reliability.

Calculating heat losses and gains, as well as reporting on the energy performance of a building, is a complex task requiring far more detail and knowledge than is provided in this document. While energy auditors and engineers use such information, it is not essential for energy advisors. Here, we present just the information energy advisors need to understand the key measures and concepts, in as simple form as possible.

3.1 Typology of multi-family apartment buildings

The construction of buildings has developed continuously over time. Changes occur as new materials and construction techniques are introduced, and as the costs of natural resources and labour shift. Architectural improvements and innovations, changes in taste and wealth, and corrections due to structural damage or health and safety concerns have all had an effect on building design and construction. The driving forces have often been economic (e.g. minimising costs, increasing competitiveness), administrative or legal (e.g. building code requirements). Recently, reducing energy consumption and improving energy efficiency has become a key priority.

Many factors affect a building's energy performance. One of the determining factors is the geometry, since the related envelope area is responsible for heat transmission losses. The fraction of the thermal envelope elements (roof, ceiling, walls, windows, floor) of a given building depends considerably on its age and its size. In addition, the thermal transmittance differs between these construction elements and according to their construction time. There are also certain time periods which impose restrictions on the improvement of the thermal envelope, e.g., preserving historical facades may impede the outside insulation of walls.

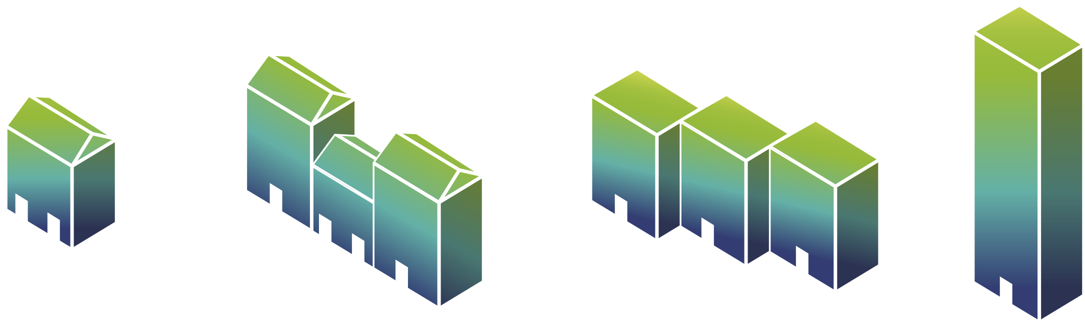


Figure 2 - Schematic representation of building typology and classification. From left to right: multi-family houses, attached apartment buildings in urban blocks, apartment blocks and high-rise buildings

Various approaches for typological assessment of energy performance exist in European countries. Most of these concepts have been applied in the field of energy efficiency analysis. Some of them are also used for building stock modelling. Also, the design of energy performance certificate procedures can be improved by typological aspects which simplify data acquisition. Instead of the investigation of a large number of building details (e.g. thicknesses and materials of construction layers, lengths and insulation of heat pipes), these approaches use typical (common) values, representing typical cases. Most buildings are classified according to two basic criteria: built year (e.g. 1961-1970, 1980-1989) and type (e.g. apartment block, high-rise building).

Usually, building typology (of both public and residential buildings) accompanies national energy or energy efficiency strategies or similar strategic documents. Different countries therefore have different typologies and classifications of public and residential buildings. Differences may vary from small to significant, and they are a consequence of history and geography on one side and available building materials and techniques on the other.

When developing a typology, a survey is usually conducted covering a number of buildings of various types, and measuring all parameters necessary to quantify and fully describe the building envelope, as a basis for calculating heat loss and estimating energy efficiency. It is necessary, however, to bear in mind that typology, regardless how meticulous it is, can hardly cover all buildings and each building type. There are always those which are exceptions, e.g. buildings of particular historical and/or architectural value. Detailed building typologies of some countries are publicly available in electronic form for download, while for others it is only possible to find core data required for heat-loss calculations.

3.2 Building envelope

The building envelope is commonly described as the separator of the interior and exterior of a building. It helps facilitate climate control and protect the indoor environment. It includes doors, windows, roof, floor, walls and all the components such as structural masonry and insulation. If the building envelope is not in good condition all the updates to other systems, such as the heating system, will not matter. The reason for this is the building envelope can account for a substantial amount of energy loss if not properly addressed.

Unfortunately, the building envelope is not just one component, but a variety of independent parts that make up the system. Replacing only one part of the system will increase building energy efficiency to only a minimal degree. Only if all parts of the system are replaced will energy efficiency be as high as it should be with all components operating efficiently.

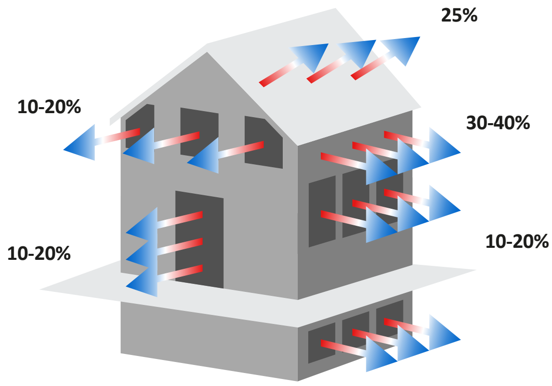


Figure 3 - Principal heat loses in a residential building

Older buildings were designed in an era where energy was less valued, hence the envelope components used were less insulating and consequently the entire building was less energy efficient. Nowadays a wide range of measures is available to enhance building envelope condition and to reduce heat losses. Applicable measures are dependent on building age and type, and commonly include thermal insulation of walls, roofs and floors over unheated spaces, as well as replacing old doors and windows with new ones. Thermal insulation of floors on the ground is not so common since it requires significant investment and a lot of effort to implement, while having a relatively low return rate. Technical variations in measures are expected due to differences among buildings (e.g. thermal insulation of walls from inner or outer side).

To understand how insulation works, it helps to have some knowledge of heat flow. This involves three basic mechanisms: conduction, convection and radiation. Conduction is the mechanism seen when heat passes through materials, such as when a spoon placed in a hot cup of coffee conducts heat through its handle to our hand. Convection is in evidence when heat circulates through liquids and gases, and is why lighter, warmer air rises, and cooler, denser air sinks in our houses. Radiant heat travels in a straight line and heats anything solid in its path that absorbs its energy.

Most common insulation materials work by slowing conductive heat flow and, to a lesser extent, convective heat flow. Radiant barriers, which are not classed as insulation products, and reflective insulation systems work by reducing radiant heat gain. To be effective, the reflective surface must face an air space.

Regardless of the mechanism, heat flows from warmer to cooler areas until there is no longer a temperature difference. In buildings this means that, in winter, heat flows directly from all heated living spaces to adjacent unheated attics, garages and basements, and to the outdoors. Heat flows can also occur indirectly through interior ceilings, walls and floors, wherever there is a difference in temperature. Similarly, during the seasons when cooling is needed, heat flows from the outdoors to the interior of a building.

3.3 Energy efficiency measures

Different energy efficiency measures can be proposed, depending on the type and age of the building, as well as its condition and number of tenants. Measures range from simple low-cost to complex and (often) expensive deep renovation.

They target several principal categories:

- Building envelope
- Heating system
- Preparation of domestic hot water
- Electric energy consumption
- Behavioural measures

Some of these measures can be relatively easily proposed and implemented for most of buildings (e.g. heat insulation of walls or replacement of windows), while other require significant investment and detailed analysis (e.g. introduction of heat pumps for heating, cooling and preparation of domestic hot water). Finding the optimal set of measures to be proposed for certain buildings can be a complex and tedious task, often involving not only engineering but legal and behavioural aspects as well.

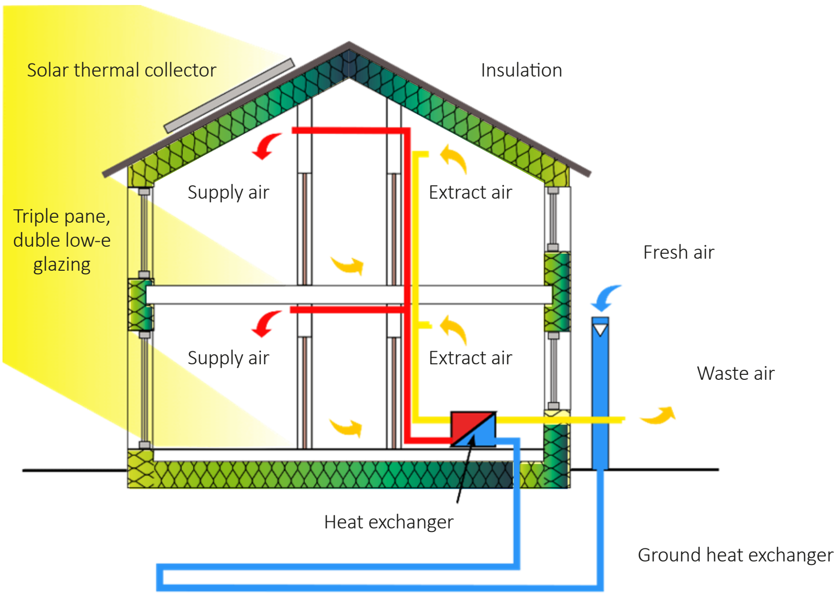


Figure 4 - Schematic representation of possible measures to be applied to a building

In some cases, the right combination of measures can reduce energy consumption remarkably, and the remaining low amount of energy can be largely or wholly covered by renewable sources, including those produced on-site or nearby. This would classify as a "nearly zero-energy building", meaning a building that has an exceedingly high energy performance.

GROUP OF MEASURES	COMPLEXITY	MAIN EFFECTS AND BENEFITS
Building envelope	Simple to moderately complex	Increased thermal comfort, financial and energy savings, increased quality of living, higher real estate value
Heating system	Moderately complex to complex	Increased thermal comfort and quality of living, decreased pollution, higher real estate value
Domestic hot water	Moderately complex	Increased living comfort, financial and energy savings
Electrical systems	Simple to complex	Financial and energy savings, increased level of energy consumption control
Behavioural	Simple	Financial and energy savings

Table 1 - Overview of energy efficiency measures applicable in multi-apartment buildings

It is important to bear in mind that energy performance also depends on the type of heat generator and distribution system. These technical installations are subject to shorter renovation cycles or complete changes. Therefore, only a poor correlation of the supply system type with the construction period of the building can be expected. This is particularly true for buildings where several possible heat sources can be used in different apartments (e.g. district heating system, electric energy and natural gas).

3.4 Energy pricing

Energy price is one of key inputs for calculating the rate of return for investments in energy renovation. It varies from country to country, depending on local conditions regarding fuel availability, taxes, policy and transportation/distribution costs. The two major groups of fuels used are fossil fuels and renewables. While EU and national climate policies aim to accelerate the phase-out of fossil fuels, in many countries they remain a cheaper source of energy, particularly for space heating, although the price of renewable energy sources continues to fall.

The price district heating energy (for heating) and electric energy (for heating and electric devices) depends on the source used for its production as well as other factors. Both can be based on fossil fuels, renewables, or a combination.

FUEL	ENERGY (calorific) VALUE
Coal, anthracite	6.60-9.05 kWh/kg
Coal, lignite	3.90-4.90 kWh/kg
Fuel oil, heavy	11.60-11.80 kWh/kg
Fuel oil, light	12.20-12.50 kWh/kg
Liquefied petroleum gas (LPG)	12.75-15.35 kWh/kg
Natural gas	11.65-15.30 kWh/Sm^3
Pellets and woodchips	4.30-5.00 kWh/kg
Wood, briquette	4.50-5.50 kWh/kg
Wood, dry firewood	3.60-4.45 kWh/kg

Table 2 - Overview of energy (calorific) values of various fuels

Table 2 gives common fuels used in buildings and their energy (calorific) values. Given values can vary depending on source, purity and processing techniques. Values for wood and coal vary due to water content, and values for briquettes and pellets vary depending on composition. Value for wood also varies depending on the kind of wood (soft or hard wood).

Considering the energy values given in Table 2 and local prices for the listed fuels, it is easy to calculate the energy price for each building in every county. Generally, coal and firewood are cheapest, while natural gas and fuel oils are expensive. The price of electricity and heat from district heating systems is defined in a different manner, and varies due to number of factors, including possible subsidies.

In many cases, in buildings connected to district heating systems, billing is done per apartment area. Only a small portion of recently erected buildings have individual calorimeters that measure actual heat consumption for each apartment. In such cases, users (tenants) have a strong tendency to take care of all measures, either simple or complex, to maintain a high level of energy efficiency.

If, however, heating is billed per area (usually heated area of apartment), tenants/users/owners are not stimulated to invest in energy efficiency, nor to maintain the envelope and heating system in optimal condition. This is easy to understand, because the price for heating will remain the same regardless of whether they install the simplest or most complex measures. Tenants in such cases usually show no intention to use less energy for heating; rather, they simply open windows.

Changing the billing system from billing per area (€/m^2) to billing per actual consumption (€/kWh) can significantly affect the behaviour of those connected to district heating systems. Tenants would be stimulated to reduce energy consumption and their investment in energy efficiency measures would be justified. This could lead to a decrease in overall energy consumption and significantly reduce greenhouse gas emissions.

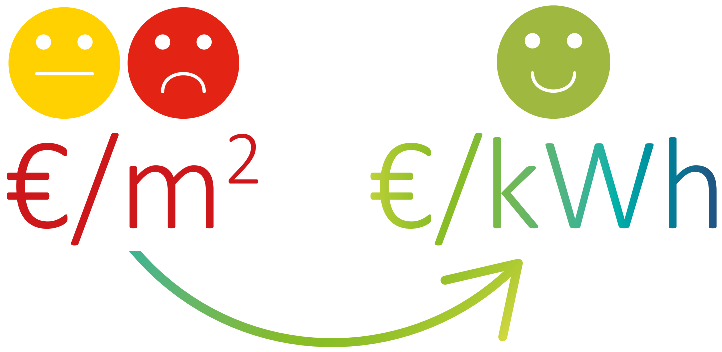


Figure 5 - Transition from billing-per-area to billing-per-consumption stimulates tenants to reduce energy use

This change is rather complex to implement, however, from both a legal and technical point of view, and could be extremely expensive. Because of the way they were originally designed, many buildings do not have the technical possibility to easily install individual calorimeters for each apartment. The piping system is shared by the whole building, usually having several main vertical pipes passing through all apartments. There is no technically simple solution to separate and measure energy consumption in individual apartments without significantly re-designing the whole piping system.

If billing per area remains the only option (see Figure 6), tenants would pay the same price regardless of measures implemented in apartments, as implemented measures do not change the area of the apartment. Also, in most Eastern European countries, companies managing district heating have a strong influence on the pricing system, and may be unwilling to change it easily from billing-per-area to billing-per-consumption. This must be considered as one of the major obstacles toward implementation of energy efficiency measures requiring notable investment.

It would be possible to measure heat consumption at the level of the entire building and establish a calculation model that would provide a fair pricing system for all tenants that incentivises energy saving. Such a model is shown in Figure 7, for single-pipe and two-pipe heating systems. In the case of a single-pipe system it would be necessary to install bypasses for hot water, located near heating bodies, so hot water can flow to the next consumer in case the flow is reduced or closed by a thermostatic valve in that heating body. By measuring heat consumption at building level, all tenants would be responsible for efficient use of energy. This, in return, incentivises tenants to invest in energy efficiency measures and maintain the building in good condition, increasing thermal comfort and reducing heat energy costs and pollution, leading to long-term changes in behaviour.

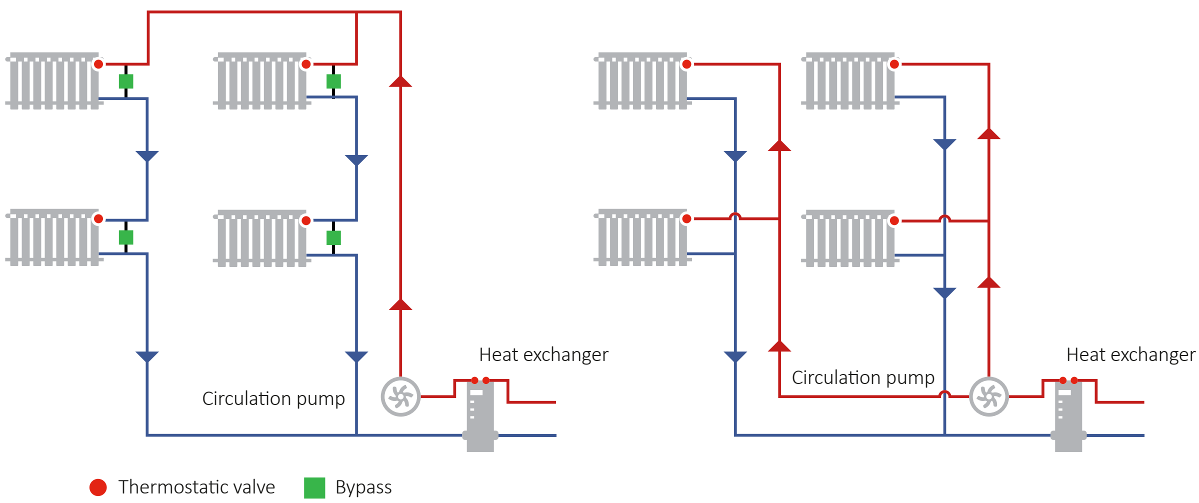


Figure 6 - Single-pipe (left) and two-pipe (right) heating system without heat meter

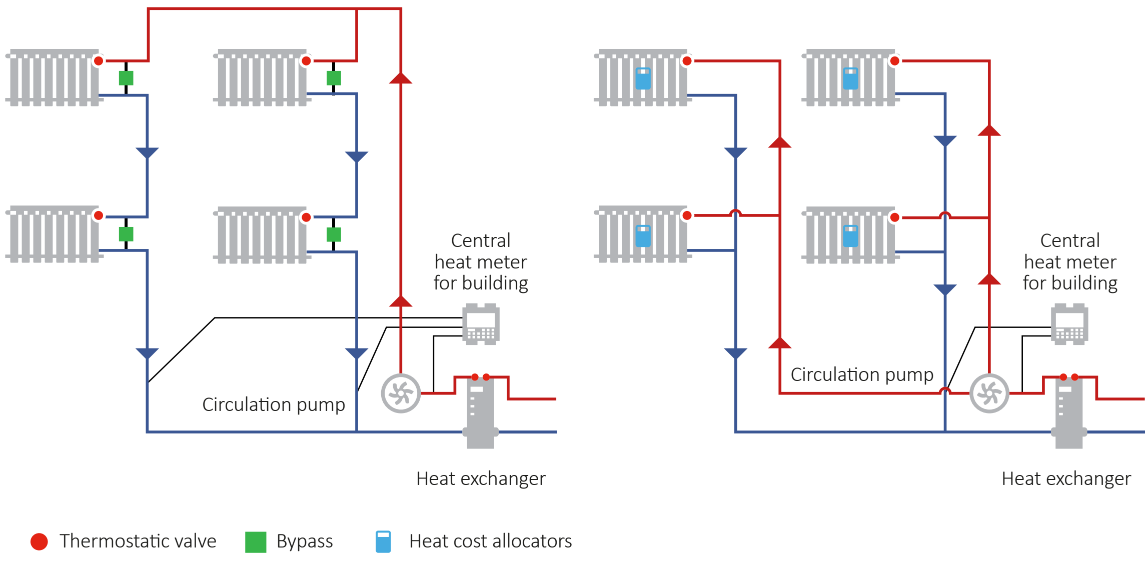


Figure 7 - Single-pipe (left) and two-pipe (right) heating system with heat meter for building level

However, it is still possible that some tenants would act irresponsibly, which in the end affects the consumption and heating costs of the entire building. In such cases, it would be possible to use heat cost allocators installed on radiators (heating bodies) to control heat consumption at the level of individual heating bodies.

Figure 8 - Heat cost allocators

Data about consumption nowadays can be transferred wirelessly to a central control unit, and irresponsible users can be easily identified. This system could also be used in cases of heat leakage and malfunctioning equipment.

The best possible solution would be to measure heat consumption individually, at apartment level, as shown in Figure 9. This system is used mainly in newly erected buildings.

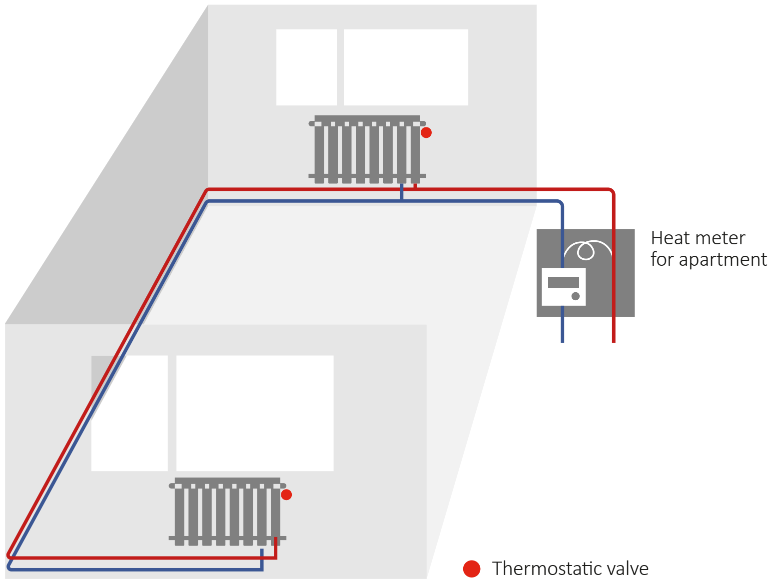


Figure 9 - Two-pipe heating system with heat meter for apartment level

3.5 Benefits

Implementation of energy efficiency measures, regardless of their complexity, yields energy and financial benefits (i.e. savings). Energy benefits are commonly calculated and elaborated in detailed energy audits of buildings, while financial benefits can be calculated based on known energy savings and energy prices. Since for each building a number of measures can be proposed, corresponding benefits can be shown in a table, as in Table 3.

Measure	Investment	Heat energy saving	Electrical energy saving	Heat energy saving	Electrical energy saving	Specific savings	Return period	Benefits
	€	kWh/yr	kWh/yr	€/yr	€/yr	kWh/€	yr	
Measure 1								
Measure 2								
Measure 3								
SUM								

Table 3 - Overview of energy and financial benefits for proposed measures

As can be seen, some measures give heat savings, others electrical energy savings, and some measures give both. Data organised as shown in Table 3 gives a clear overview of all principal energy and financial indicators. Moreover, it is possible to easily combine measures in scenarios and calculate the return rate for any scenario, i.e. combination of measures. While numbers in this table should be filled in only by energy auditors, they can be easily understood by tenants. Based on these numbers, they can make informed decisions about investing in energy efficiency measures.

4 Simple measures

Simple measures are available to almost all users/tenants, and require low levels of technical knowledge, as well as low investment or no investment at all.

One such measure is draught-proofing, which is one of the cheapest and most effective ways to save energy and money in any type of residential building. Controlled ventilation helps reduce condensation and damp, by letting fresh air in when needed. However, draughts are uncontrolled: they let in too much cold air and waste too much heat. Draught-proofing an apartment means blocking unwanted gaps that let cold air in and warm air out. Saving warm air means using less energy to heat inner space, therefore reducing heating costs, as well as making the apartment warmer.

Figure 10 - Draught-proofing windows and floors

Draught-proofing is usually done by using self-adhesive tapes made of EPDM rubber, which is an exceptionally durable elastomer that keeps shape for years. Tape is produced in various profiles (e.g. E and C) and dimensions, and therefore is suitable for many window frames and doors. There are also tapes made of polyurethane and other polymers, but they cannot maintain properties as long as EPDM tapes. However, tapes are prone to come unstuck, usually due to inadequate preparation of surfaces, so draught-proofing usually does not represent a reliable long-term solution for increasing energy efficiency.

Sash windows, especially old single-glazed ones, are notorious for being draughty. If it is not possible to install double glazing, draughts still can be cut by using window foam seal. This is like a thick tape and comes in rolls in various colours. It is easy to install, cheap and available at larger stores. However, it does not work well for sliding windows.

Secondary-glazing film is a transparent tape that fixes to windows to create a double-glazing effect. However, the film may need to be re-stretched periodically (with a hairdryer), which can be inconvenient, and it can easily tear. However, this measure can be used as a temporary solution to minimise heat loss. It is a cheap solution with a short payback time and can be done without special technical knowledge.

Figure 11 - Installing secondary-glazing film

These measures are acceptable as temporary solutions until better, more reliable, long-term solutions are found, e.g. replacement of windows or doors, in whole or partially, which is not always possible (e.g. in winter or in case insufficient funds are available).

In most cases tenants and users are not aware of their electrical energy consumption, and very few are aware of the electrical power of devices and appliances they use. As efficiency is considered to mean wise, rather than decreased, energy consumption, users should be able to track how energy is consumed. The common way is observing electrical energy bills. This, however, does not give consumption for individual devices, nor give consumption distribution during the month. To facilitate a better understanding, small energy consumption devices can be used.

Figure 12 - Small energy consumption measuring devices

Such devices can be found in specialised stores. There is no special knowledge required for installing or using them. They are plugged into a wall socket, and devices are plugged into the measuring device. All of them can track energy consumption, some can record it in time, and some can show actual values of voltage and frequency. More advanced versions allow simple programming of consumption via a timer, so energy can be spent overnight or at a specific time of day. These devices can demonstrate the importance of measuring energy consumption at critical points in an apartment, possibly in time. Consequently, tenants and users can be self-trained to use energy in a more efficient way.

Another simple, cheap and cost-effective measure is installing radiator reflectors (radiator foils) on the walls behind heating bodies. These consist of foam with aluminium foil on its surface, with a thickness of about 4 mm. They eliminate most of the heat flow into the wall behind the radiator and redirect that heat back into the room.

Figure 13 - Radiator reflector foil

In conclusion, simple measures are cheap and easy to implement. They require no specific technical knowledge to be effectively used, and the payback period is usually one year or less. However, draughting should be considered only as temporary solution for short-term increase of thermal comfort and energy efficiency.

5 Measures for the building envelope

To maintain comfort, the heat lost in the winter must be replaced by the heating system, and the heat gained in the summer must be removed by the cooling system. Properly insulating a building will reduce these losses and gains by providing effective resistance to the heat flows.

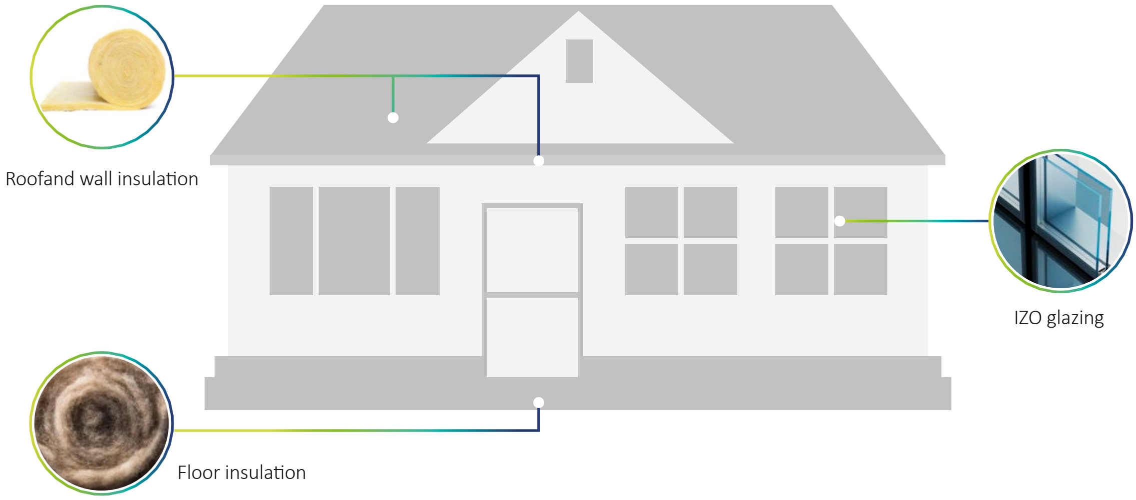


Figure 14 - Principal measures applied to the building envelope

Thermal insulation involves the reduction of heat transfer (the transfer of thermal energy between objects at different temperatures), between objects in thermal contact, or between objects within range of radiating influence. Thermal insulation can be achieved through specially engineered methods or processes, as well as by selecting suitable object shapes and materials. Heat transfer is an inevitable consequence when objects of different temperatures come into contact with each other.

Thermal insulation provides an insulating area in which thermal conduction is reduced, or thermal radiation is reflected, rather than being absorbed by the lower-temperature body.

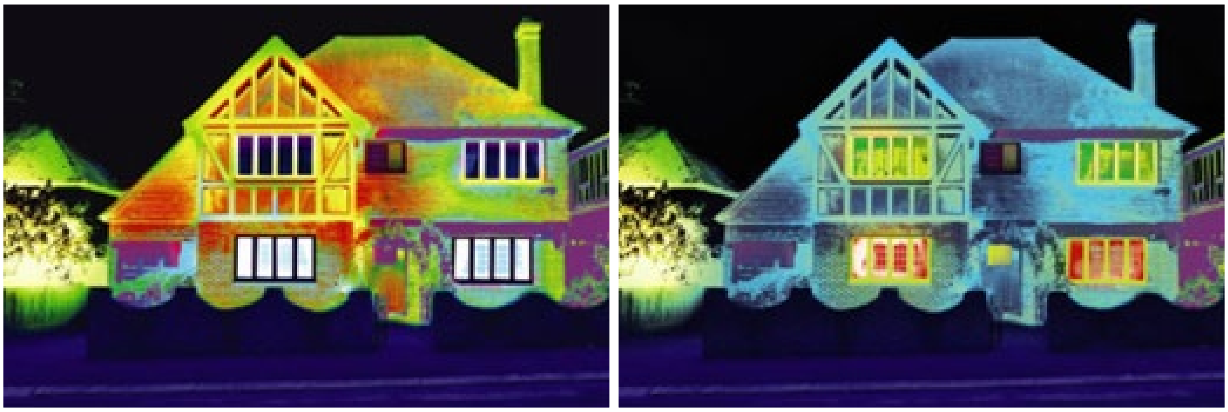


Figure 15 - House before (left) and after (right) thermal insulation

The insulating capacity of a material is determined by its thermal conductivity (λ), where low thermal conductivity is equivalent to a high insulating capacity (R-value). In thermal engineering, other important properties of insulating materials are density (ρ) and specific heat capacity (c).

5.1 Thermal insulation of walls

Regardless of the building geometry, outside walls represent a significant area of the building envelope so have a high impact on its energy performance. In a typical building, walls account for 30-40% of heat losses, depending on geometry. To achieve the highest possible thermal insulation, new materials and solutions with low thermal conductivity values have been and are being developed, in addition to using traditional insulation materials in ever increasing thicknesses. However, very thick building envelopes are not desirable for several reasons, e.g. considering space issues with respect to economy, floor area, transport volumes, architectural restrictions and other limitations.

Figure 16 - Schematic representation of insulation layers and real look of insulation without finish render.

There are two major groups of insulating materials: traditional (widely used) and novel (usually more expensive, often state-of-the-art and less commonly used). A third group of future materials is still under development and not in active use.

Here, a short description of different insulating materials is given, with principal properties, pros and cons. These include both organic and inorganic materials.

Figure 17 - Materials for building envelope insulation: fibreglass, mineral wool, cellulose and cotton

Fiberglass is the most commonly used insulation material of recent times. As a result of the way it is produced, by weaving fine strands of glass into an insulating material, fibreglass is able to minimise heat transfer. It is commonly used to produce two different types of insulation – blankets (batts and rolls) and loose fill – and can also be found in the form of rigid boards and duct insulation. Manufacturers now produce medium and high-density fibreglass batt insulation products that have slightly higher R-values than the standard batts. The denser products are intended for insulating areas with limited cavity space. Fibreglass is a non-flammable insulation material. Moreover, it is a cheap form of insulation and is therefore the recommended option. However, installing it requires safety precautions. It is important to use eye protection, masks and gloves when handling fibreglass.

Mineral wool refers to several different types of insulation. First, it may refer to glass wool, which is fibreglass that has been manufactured from recycled glass. Second, it may mean rock wool, which is a type of insulation made from basalt. Finally, it may also refer to slag wool which is produced from the slag generated by steel mills. Mineral wool can be purchased in batts or as a loose material. Most forms of mineral wool do not have additives that make them fire resistant, which means they are a poor choice for use in applications where extremes of heat may be present. However, mineral wool is not combustible. Therefore, when used in conjunction with other, more fire-resistant forms of insulation, mineral wool can be an effective choice of material to insulate large areas.

Cellulose is arguably one of the most eco-friendly forms of insulation. It is produced from recycled cardboard, paper and other similar materials, and is supplied in a loose form. Some recent studies on cellulose have shown that it may be an excellent product to prevent fire damage. As a result of its dense nature, cellulose contains virtually no oxygen. This lack of oxygen retards combustion, and therefore helps to minimise the amount of damage that a fire could cause. Manufacturers tend to add the mineral borate, sometimes blended with less costly ammonium sulphate, to cellulose insulation to ensure fire and insect resistance. Cellulose insulation typically requires no moisture barrier and, when installed at the appropriate densities, does not settle in building cavities.

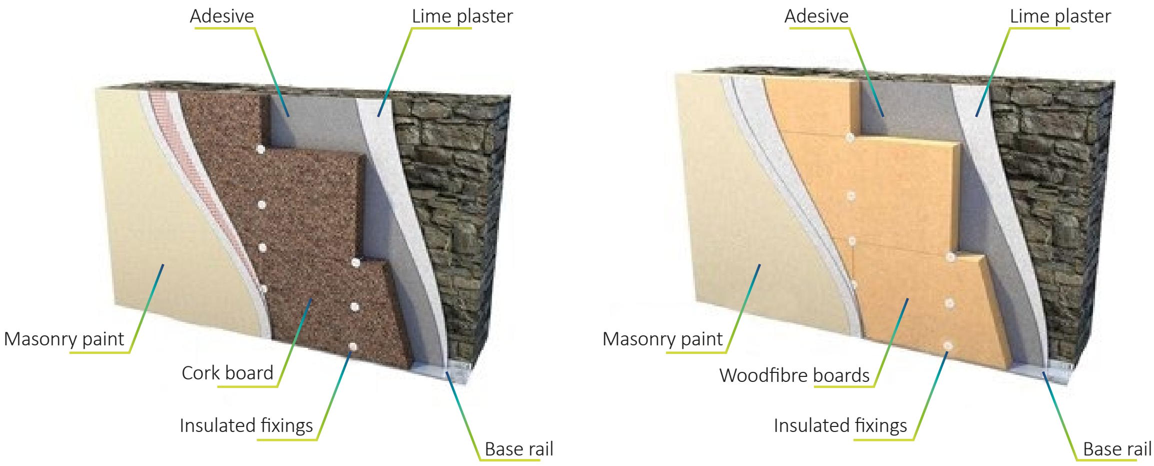


Figure 18 - Examples of insulation by using cellulose-based boards (cork and wood)

Cotton insulation consists of 85% recycled cotton, and 15% plastic fibre treated with borate: the same flame retardant and insect/rodent repellent used in cellulose insulation. One type of cotton insultation product, for example, uses recycled waste trimmings from the manufacture of denim jeans. As a result of its recycled content, cotton insulation requires minimal energy to manufacture. It is available in batts. Cotton insulation is also nontoxic and can be installed without the use of respiratory or skin-exposure protection. However, cotton insulation costs about 15% to 20% more than fibreglass batt insulation.

Figure 19 - Materials for building envelope insulation: sheep wool, straw bale, polystyrene and polyurethane

Sheep wool is also treated with borate for pest, fire and mould resistance. It can hold large quantities of water, which may be an advantage in some walls, but repeated wetting and drying can result in borate being leached from the material. The R-value of sheep wool batts is similar to other fibrous types of insulation. Using sheep wool as insulation can offer benefits in terms of wellbeing and healthy indoor climate. Sheep wool is a proven material when it comes to absorbing and neutralising harmful substances. It is a natural protein made up of 18 different types of amino acid chain, 60% of which have a reactive side chain. These reactive areas allow the wool to absorb harmful and odorous substances including nitrogen dioxide, sulphur dioxide and formaldehydes, which are then neutralised through a process known as chemisorption.

Straw bale construction, which was popular some 150 years ago, has received renewed interest in recent times. When stacked together, typical straw bale contains numerous gaps. A process for fusing straw into boards, without adhesives, was developed in the 1930s. Panels are usually 5-100 mm thick and faced with heavyweight kraft paper on each side.

Polystyrene, a colourless, transparent thermoplastic is commonly used to make foam or bead board insulation, concrete block insulation, and a type of loose fill insulation consisting of small beads. Moulded expanded polystyrene (MEPS), commonly used in foam board insulation, is also available as small foam beads. These beads can be used as a pouring insulation for concrete blocks or other hollow wall cavities, but, because they are extremely lightweight and hold a static electric charge very easily, they are notoriously difficult to control. Other polystyrene insulation materials similar to MEPS are expanded polystyrene (EPS), graphite polystyrene (GPS) and extruded polystyrene (XPS). The R-value of polystyrene foam board depends on its density. Polystyrene loose fill or bead insulation typically has a lower R-value compared with the equivalent foam board.

Polyurethane is a foam insulation material that contains a low-conductivity gas in its cells. Polyurethane foam insulation is available in closed-cell and open-cell forms. In closed-cell foam, the high-density cells are closed and filled with a gas that helps the foam expand to fill the spaces around it. Open-cell foam cells are not as dense and are filled with air, giving this form of insulation a spongy texture and a lower R-value. Foil and plastic facings on rigid polyurethane foam panels can help stabilise the R-value, slowing down thermal drift. Reflective foil, if installed correctly and facing an open-air space, can also act as a barrier to radiated heat transfer. Polyurethane insulation is available in liquid sprayed foam and rigid foam board forms.

Polyisocyanurate, also known simply as polyiso, is a thermosetting type of plastic, closed-cell foam that contains a low-conductivity, hydrochlorofluorocarbon-free gas in its cells. Polyisocyanurate insulation is available as a liquid, as a sprayed foam, and as a rigid foam board. It can also be produced as laminated insulation panels with a variety of facings. Over time, the R-value of polyisocyanurate insulation may fall as the low-conductivity gas in its voids escapes and is replaced by air, a phenomenon known as thermal drift. Foil and plastic facings on rigid polyisocyanurate foam panels can help stabilise the R-value. Some manufacturers use polyisocyanurate as the insulating material in structural insulated panels (SIPs), which can be manufactured from both foam board and liquid foam.

Figure 20 gives an overview of the thermal conductivity of some insulating materials commonly used today, as well as classes of these materials.

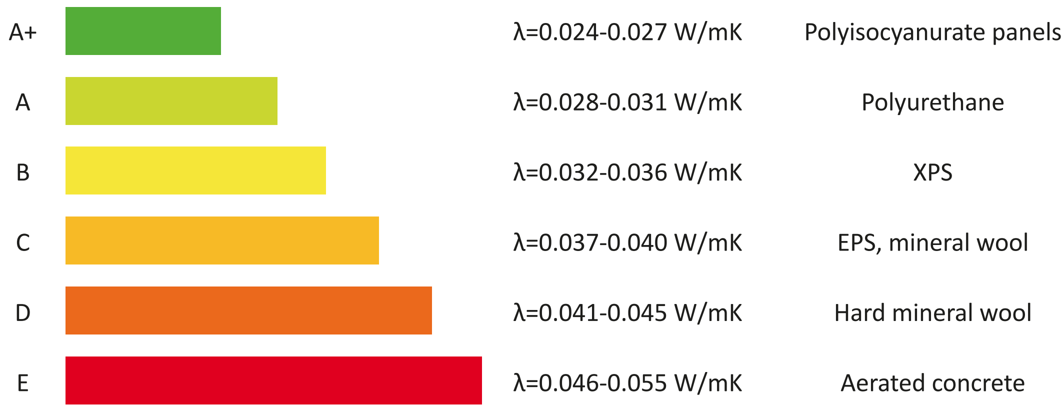


Figure 20 - Overview of thermal conductivity of various insulating material

To better understand importance of adding thermal insulation to existing walls, Figure 21 illustrates thickness of walls made of different materials required to achieve same thermal conductivity of just 1 cm of EPS panel. This can be used for convincing users/tenants/owners to invest in energy efficiency measures.

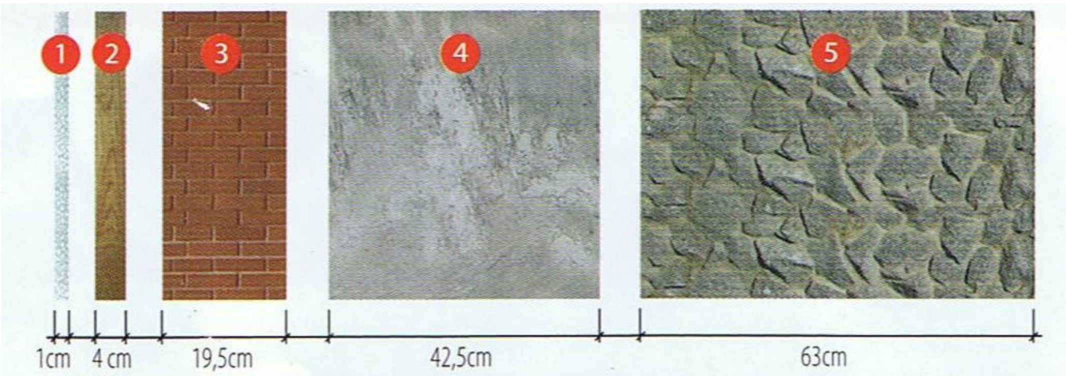


Figure 21 - Thickness of different materials required to achieve same thermal conductivity as 1 cm of EPS, 1: EPS, 2: wood, 3: brick, 4: ferroconcrete, 5: stone wall

Insulation commonly works through a combination of two main characteristics:

- The insulating material's natural capacity to inhibit the transmission of heat
- The use of pockets of trapped gas which act as natural insulators

Gases possess poor thermal conduction properties, compared with liquids and solids; therefore, if they can be trapped, they make good insulation materials. Dispersing the gas into small cells, that cannot transfer heat effectively by natural convection, will further enhance a gas's insulating effectiveness. Convection involves larger, bulk flows of gas, driven by buoyancy and temperature differences. It does not take place effectively in small cells where there is little density difference to drive it. In foam materials, small gas cells or bubbles are present in the structure. In fabric insulation, such as wool, small variable pockets of air occur naturally.

Depending on type, insulation materials can be used in the form of batts, blankets, boards or in bulk form, while some are applied as sprays which later solidify. There are insulating panels available as well.

The price of wall insulation may differ, depending on various factors, such as type and thickness of insulation, façade details and finishing, labour costs as well as insulation manufacturer and country of origin. Price also depends on the height of the building due to scaffolding costs. Usually, insulation price is expressed per m^2 of façade surface, including costs of insulation and additional materials, labour, scaffolding and cleaning. This makes it hard to give a general estimation of the payback period, since it depends on both investment and cost savings.

Figure 22 - Various forms of envelope insulation materials: batts, blankets, boards, and bulk

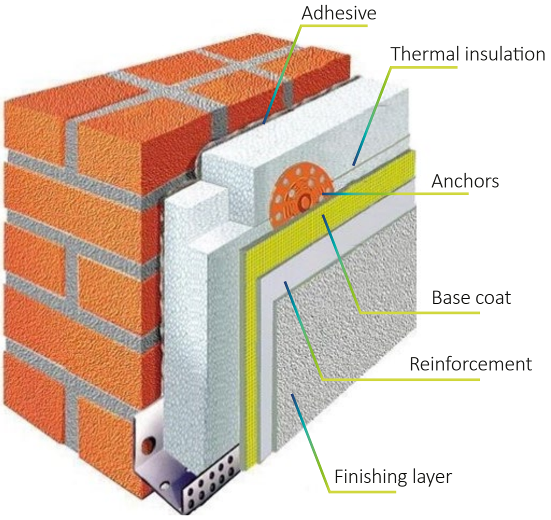
It is, however, worth mentioning that there is a small difference in price between insulation panels (e.g. EPS or GPS) of 8 cm and 10 cm, while they provide big difference in the energy savings. This is important information for homeowners or potential investors.

There is a tendency to decrease usage of polystyrene insulation, and increase use of mineral wool. While more expensive and slightly more complex to use (it can require frames), mineral wool provides fire protection and allows the building to breathe. Such factors can be decisive and must be considered for each particular building when proposing energy efficiency measures.

Aside from the insulating materials listed above, there are some which are currently under development, and are yet to be proven as successful replacement for conventional insulation materials and technologies. Examples are vacuum insulation panels, gas-filled panels and aerogels.

Beside wall insulation that is applied to the outer or (less common) inner side of the wall that is part of building envelope, there are various insulated façade systems. They are usually developed by companies that specialise in insulation and known under acronyms like ETICS (exterior thermal insulation composite system), EIFS (exterior insulation finishing system), ICF (insulated concrete formwork) or TIR (thermal insulation render). A comprehensive range of these systems is available on the market to meet the various demands of building structure and architecture.

Façade systems are commonly a kit, consisting of certain (specified) prefabricated components being applied directly to the façade on-site. The configuration of system components required for specific buildings and purposes depends on requirements set by the user or investor, or by national regulation. In most cases it includes an adhesive applied to masonry, thermal insulation material, anchors, base coat, reinforcement (usually glass fibre mesh) and finishing layer. Finishing may include decorative elements, which makes such systems applicable to buildings of aesthetic value or even protected historical buildings. Façade systems include also accessories, e.g. fabricated corner beads, connection and edge profiles, expansion joint profiles and base profiles, which enables full avoidance of thermal bridges.



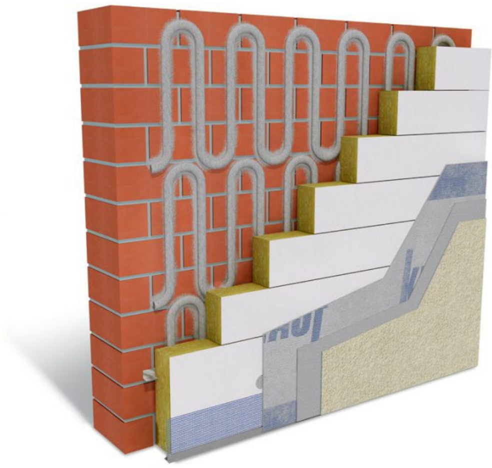


Figure 23 - Typical components of ETICS façade insulation system based on EPS (left) and mineral wool (right)

There are also ventilated façade systems, or ventilated façades. Ventilated façades are an outdoor cladding building solution that can be applied to both newly built and existing buildings. They are of special interest to architects for a number of reasons, such as improved thermal insulation and the façade's continuous appearance. Such a façade is generally faster to install and easier to clean. Ventilated façades allow the circulation of air between the supporting wall and the cladding material. Cladding can be made of marble, ceramic tiling, metallic panels or other materials. In this manner, the supporting wall is protected from both the cold and heat, resulting in energy savings. Ventilated façades usually have an in-built system of components made by a single manufacturer.

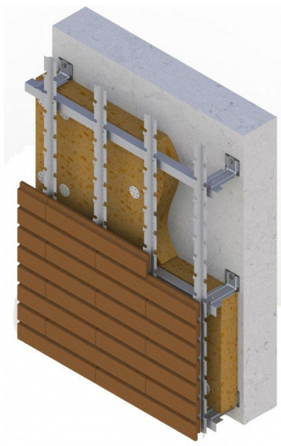


Figure 24 - Schematic representation of ventilated façade system with bricks (left) and stone tiles (right)

Any type of masonry may be used as a support to attach the ventilated façade, e.g., concrete or brick wall. Thermal insulation used in a system is the material that provides thermal and, additionally, acoustic insulation. It must have a continuous finish to avoid thermal bridges. Insulation is attached to masonry by either attachment points with a resin anchor and threaded rod, or by special profiles, comprising a series of mounts attached to the supporting wall and anchor points that maintain insulation fixed to the profiles. Space between the supporting wall and the cladding material protects the supporting wall in summer by allowing ventilation and preventing heat conductivity, while in winter it prevents humidity being transferred to the supporting wall. Cladding installation is the last part in the ventilated façade system, and is only visible from outside.

One of the best materials to use in ventilated façades are 3 cm thick natural stone slabs, which can be easily attached. There is no specific slab size required for this type of façade since the system is adjustable.

Ventilated façades have a different type of performance depending on the outdoor temperature, varying greatly between seasons. During the summer, the air chambers work like a chimney: sunlight hits the façade, heating up the cladding and the chamber. This hot air then rises, making room for cooler air to cool down the chamber and maintaining comfort inside the building, as shown in Figure 25.

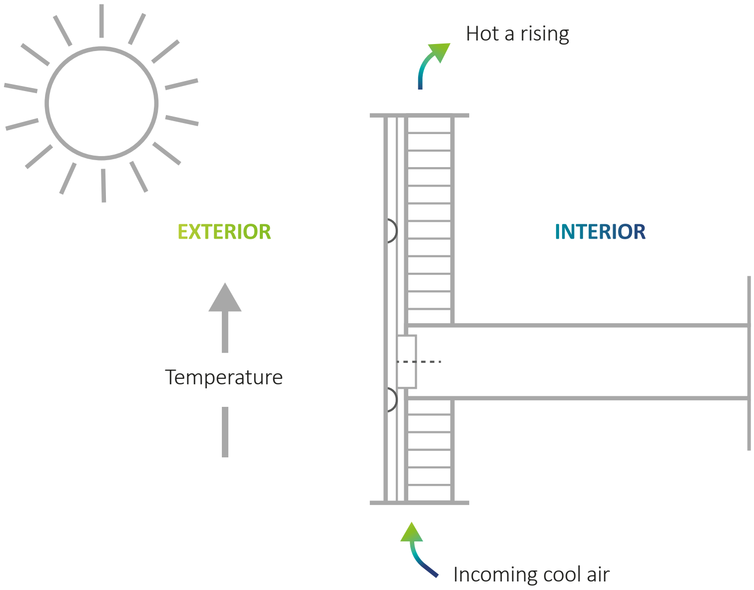


Figure 25 - Operation of a ventilated façade in summer

In the winter, solar radiation is not strong enough to produce this chimney effect. However, the air inside the chamber remains warmer than the outdoor air, producing the effects of a heat accumulator that maintains the system's thermal stability along with the thermal insulation that is attached to the supporting wall, as shown in Figure 26.

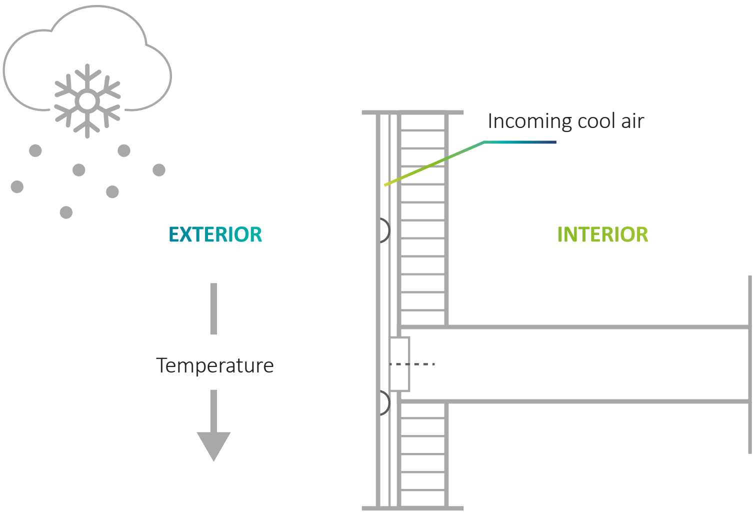


Figure 26 - Operation of a ventilated façade in winter

Application of thermal insulation of walls represents a large-scale change in building appearance and functionality. Doing it properly is not an easy task. It includes not only preparation of existing walls (e.g. cleaning and filling eventual holes), but also requires removing of all auxiliary devices and parts from walls (e.g. outer units of air conditioners, lighting rods, gutters). After insulation is set in place, it will be necessary to carefully put these all back and avoid any damages to the insulation or façade system.

In most cases, insulation of building walls includes balconies and terraces and their walls (if any), as well as other surfaces that can be considered part of the building's walls. In this way the building gets compact and uninterrupted wall insulation, which is important not only from an engineering point of view (i.e. avoiding or minimising of thermal bridges), but from an aesthetic point of view as well.

5.2 Thermal insulation of roofs

A roof is the top covering of a building, including all materials and constructions necessary to support it on the building walls or on uprights, providing protection against rain, snow, sunlight and wind. The roof is an important part of the building envelope because uninsulated roofs account for 25% to 35% of heat losses, depending on type, shape, form, size and condition.

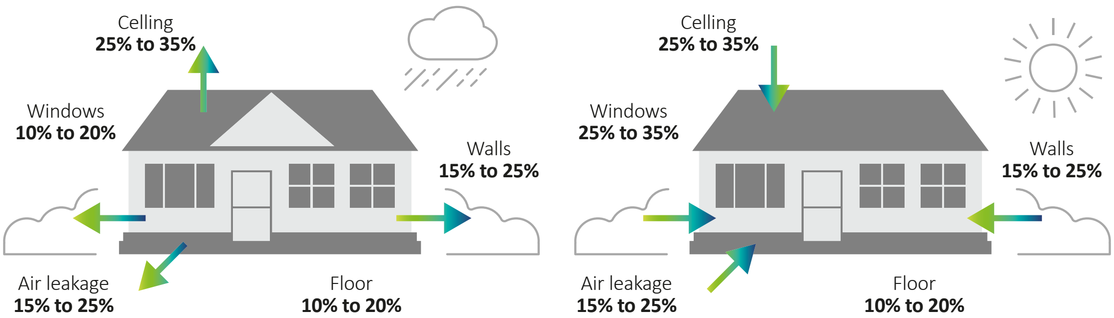


Figure 27 - Thermal heat losses (left) and gains (right) without thermal insulation

There are two principal types of roofs on multi-apartment buildings: sloped roofs (used for lofts or attics) and flat roofs (commonly not accessible, sometimes used as a terrace). Sloped roofs are relatively common among multi-apartment houses and attached apartment buildings in urban blocks; space under the roof is used as living or storage space.

Figure 28 - Different uses of sloped roofs: unheated attic (left) and apartments (right)

Flat roofs are common among apartment blocks and high-rise buildings, and may include communal terraced areas.

Figure 29 - Different uses of flat roofs

Materials used for insulation of roofs are mostly the same as for walls, but they are installed in a different manner. XPS boards are commonly used for flat roofs, while mineral wool in batts, blankets and boards is commonly used for heated and unheated attics. If a flat roof will be used as e.g. a terrace or communal outdoor space, it is necessary to provide an adequate finishing layer made of e.g. ceramic tiles or concrete pads, while the insulating material must have the necessary compression strength (hence XPS as a material of choice). If an attic will be used for living, the interior finishing layer is usually painted drywall. Installation of thermal insulation where a flat roof or attic will not be used for living is simpler and more cost-effective, as with a gravel terrace, unheated attic or storage space.

A schematic representation of insulation of a flat roof is shown in Figure 30, while Figure 31 shows different variants of insulation profile. Through appropriate shapes and profiles, it is possible to achieve slopes and specific geometries that could help with e.g. drainage.

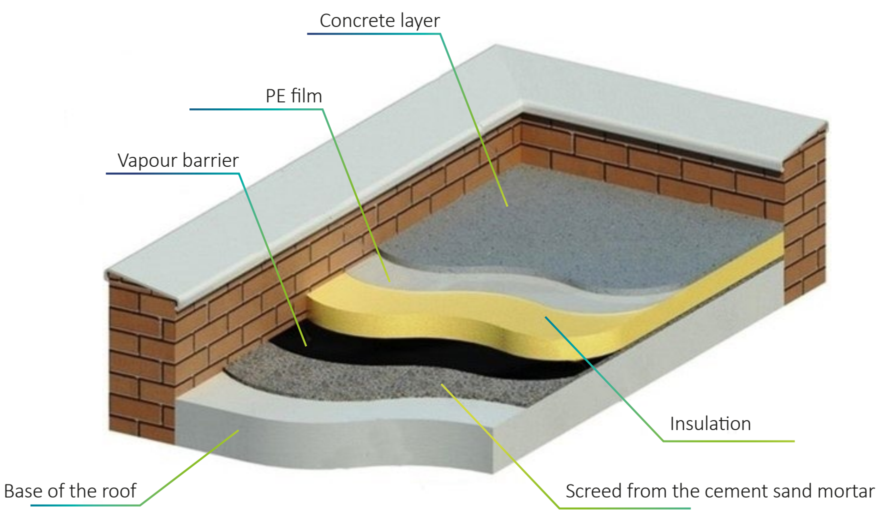


Figure 30 - The construction of the flat roof with insulation and waterproofing layer

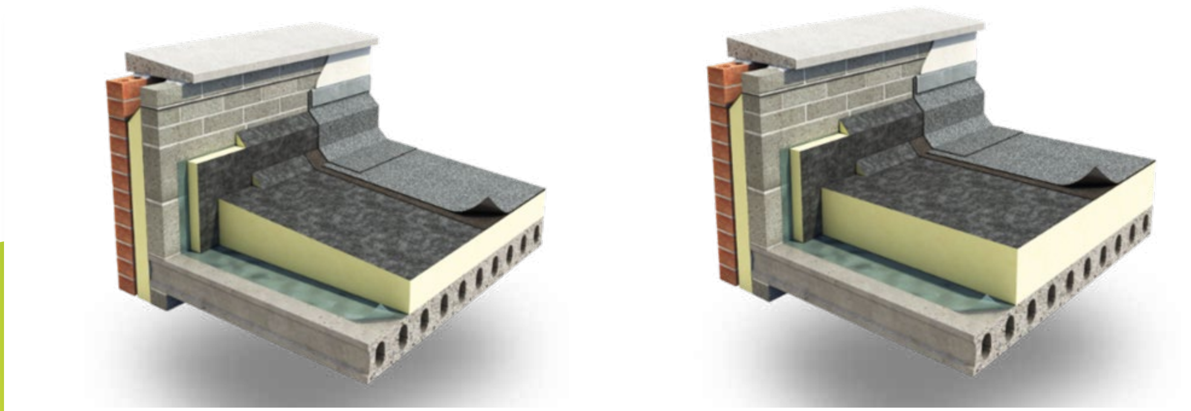


Figure 31 - The construction of a flat roof with or without sloping parts

In case of attics, insulation can be installed in the roof or on the attic's floor, depending on how the attic space is used. Both variants are similar and shown in Figure 32.

Figure 32 - Different ways to install insulation in attic, in roof (left) and floor (right)

If possible, during renovation a vented (unheated) attic should be transformed into an unvented (still unheated) attic. This somewhat increases the necessary investment, but significantly raises thermal comfort and space usability, and reduces heat losses.

Like thermal insulation of walls, insulating roofs often includes large-scale work and changes the building's appearance and functionality. Insulating attics requires moving everything out of the space, since it is done from inside. All piping, wiring, lighting and other devices and equipment need to be carefully disassembled prior to work and reassembled afterwards.

In general, thermal insulation of roofs and ceilings can be considered as cost-effective, usually with short payback periods. In most cases it is between 5 and 10 years. However, the payback period for each individual building depends on roof type, roof shape and dimensions, insulation type and thickness, building height and accessibility of roof, and of course on insulation and workforce price (the latter also affected by the volume of work).

5.3 Thermal insulation of floors

Floors consist of several layers of different materials to fulfil all required functions. Floors account for 5% to 15% of heat losses, depending on building configuration. There are two principal types of floors on multi-apartment buildings: floors above unheated space (e.g., garage, basement, or air) and floors on the ground (e.g., placed on soil or gravel).

Thermal insulation of floors above unheated space is similar to insultation of walls. It uses the same insulating materials, with a finish layer as needed. In many cases it is done together with wall insulation, so that properties and appearance of all exterior surfaces can be matched.

Insulating floors on the ground in multi-apartment buildings, however, usually represents a complex and expensive measure to increase energy efficiency, having a long payback period (50 years or more). The complexity depends on the configuration of the existing floor. This measure is commonly combined with changes in the heating system (e.g., introduction of floor heating or changes in the heat distribution system). The fact that everything must be taken out of the area where insulation is to be installed increases both complexity and cost.

In certain cases, it is possible to apply insulation directly over the existing floor, without removing any of its layers. This radically simplifies insulating but takes out 10 cm or more of room height, so it is not always a good choice, and is more appropriate in either buildings with high ceilings or public buildings.

Figure 33 - Examples of installation of thermal insulation of floors

Sometimes it is possible to apply a relatively thin insulating layer of modern, high-tech insulation. Such insulations are usually branded (e.g., Gerfloor®), and while providing improved thermal properties, in most cases they still are not fulfilling values required by regulations. They do, however, increase thermal comfort.

5.4 Replacement of windows and doors

Windows and outside doors in old apartment buildings are mostly made of wood, with single or double glazing. Those in communal spaces (e.g., staircases, hallways, basements) may be made of steel or aluminium profiles, with thermal breaks. Frames and glazing are often in poor condition, allowing significant heat losses and infiltration of cold air into heated space. Due to their age, the connection between windows and surrounding walls is often loose, allowing even higher heat losses. Windows and outside doors are an important part of the building envelope, accounting for 10% to 25% of heat losses, depending on size, orientation and condition. Heat losses through windows and doors can be lowered by applying adhesive draughting tape, but this can be considered only as a temporary solution.

Windows also have a significant impact on the aesthetic value of a building, and therefore are often changed by tenants, even though this has relatively long payback period. Newly installed windows and doors are made of PVC or wood (rarely aluminium), with double or triple glazing. They are often replaced individually by tenants or owners, which leads to installation of different windows.

A wide range of window materials and glazing types are available to retrofit older buildings. Most are developed to have insulating properties even higher than required by current standards and regulations regarding energy efficiency and heat losses.

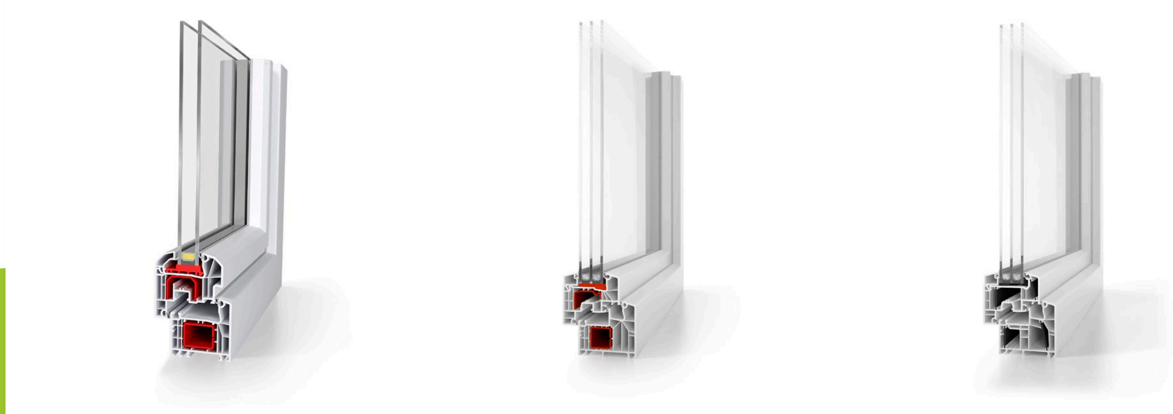


Figure 34 - Examples of different PVC windows with U_w value of 0.99, 0.83 and 0.81 W/m²K

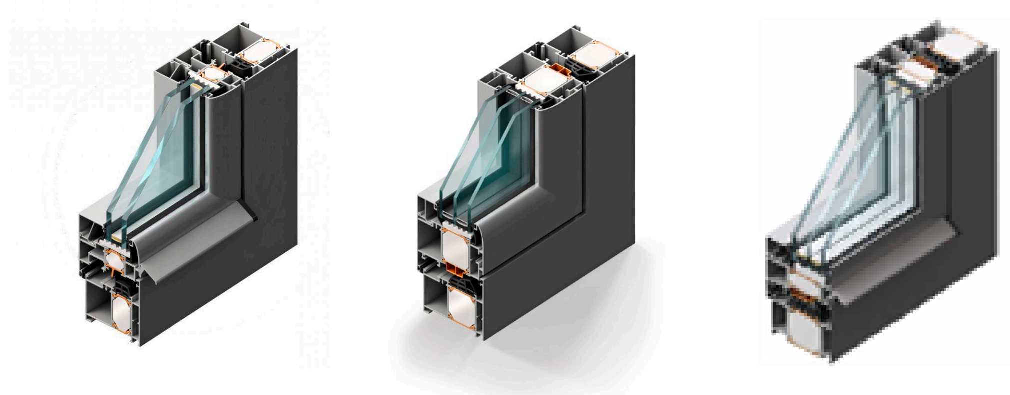


Figure 35 - Examples of different aluminium windows with U_w value of 1.30, 1.10 and 0.80 W/m²K

Modern window and door frames are made of five or seven chamber profiles, made of PVC (Figure 34), aluminium (Figure 35), wood (Figure 36), or a combination (Figure 37), with high humidity and dust sealing, as well as good thermal and acoustic protection. It is possible to combine new windows with anti-burglar systems and safety glazing.

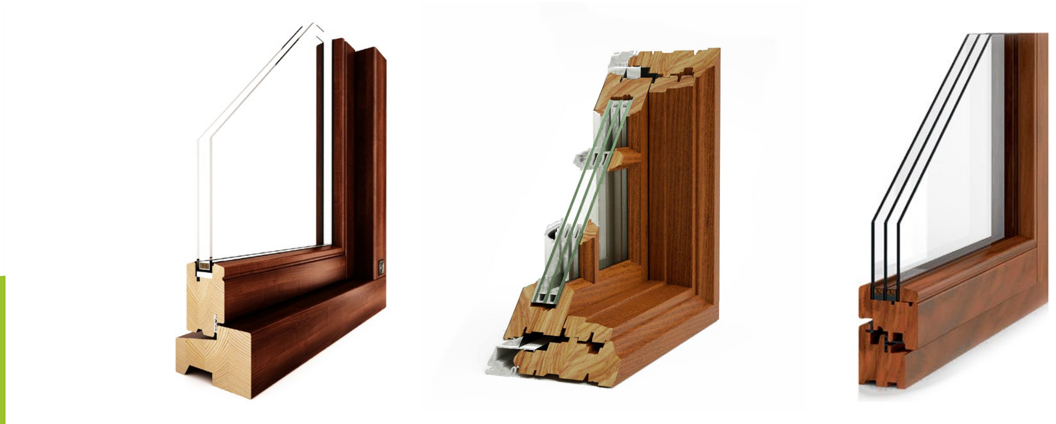


Figure 36 - Examples of wooden windows

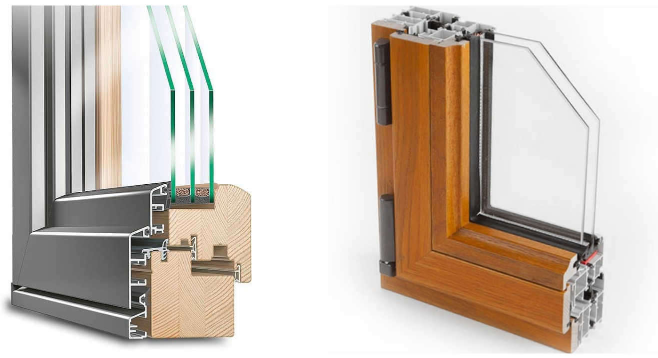


Figure 37 - Examples of windows with combined wood-aluminium frames

Window glazing is made with two or three, sometimes even four sheets of glass, with one or more low-E coating, while the space between glasses is filled with inert gases (e.g., argon). In this way, the U-value is usually from 1.10 to 1.20 W/m^{2}K. Low-e glass is transparent float glass coated with metal oxides by the method of cathode vapour disposition in vacuum conditions. This vapoured layer blocks long-wave heat radiation and is known as a low-emission layer (Figure 38).

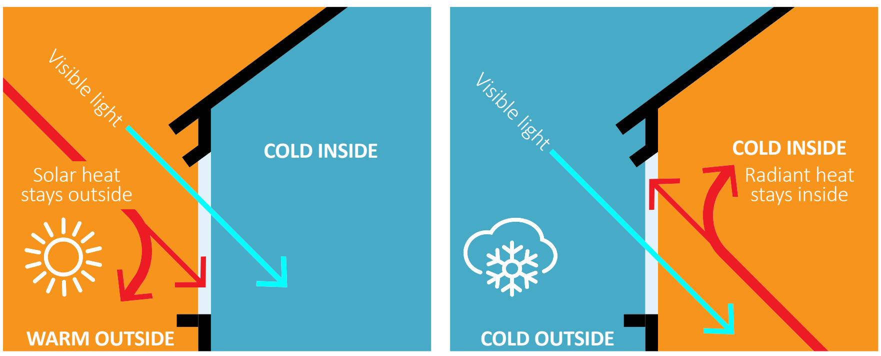


Figure 38 - Basic principle of how low-e layer improves insulation

Windows can be without a low-e coating, but adding it to each glass improves the insulating properties of glass itself, contributing to the insulating properties of the entire window (Figure 39).

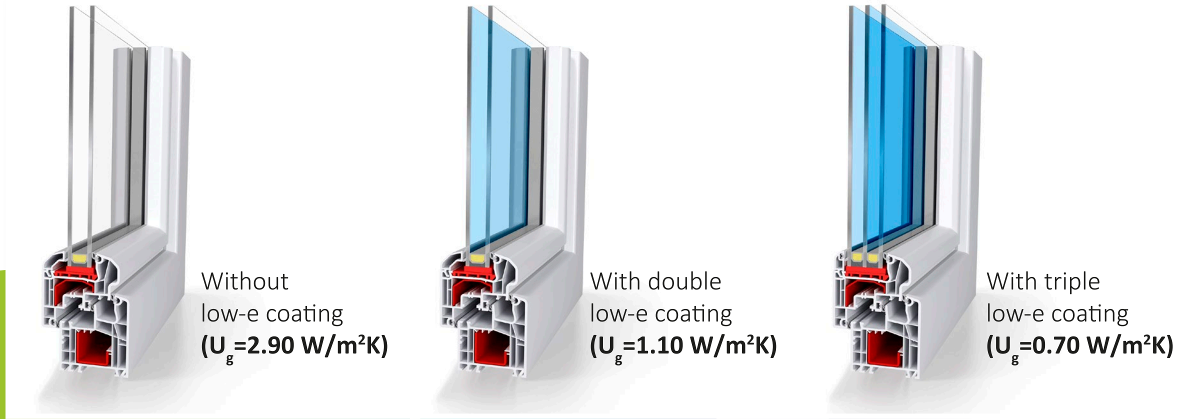


Figure 39 - Comparison of insulating properties of glass

There are also wooden and wood-imitating PVC frames available for historic buildings and buildings under protection, that fulfil all requirements set by applicable standards and regulations without influencing the overall look. Nowadays, windows can be made in any required shape and dimensions, regardless of the material of the frame or glazing. It is also possible to produce sliding windows of any size, but in this case, sealing can be an issue.

Investment in new windows and outside doors can be significant. It primarily depends on material(s) used for the frame and the type of glazing. Other influencing factors are place of assembly and manufacturer. Like other envelope measures, replacing old windows and doors is a major task, requiring skilled labour and careful installation. Even though windows themselves have low U values and represent an insulated part of the building envelope, poorly executed installation can annul all expected benefits. This is the case when, for instance, an expensive triple low-e wood-aluminium window is installed without proper insulation around it by PU and/or mort. Heat is going to be lost not through the window itself, but rather through the poorly insulated part of the wall around it.

Unlike wall or roof insulation, when generally only a small amount of material is removed, replacing windows generates significant amounts of waste, consisting of wood, glass, bricks, concrete and mortar. This needs to be considered and taken into account when estimating replacement costs.

Besides windows, there is the possibility to install shutters or blinds. They are of great help in cases of extremely low temperatures, winds and intensive insolation. They can be easily installed on existing windows, and more advanced versions (e.g., with motors and sensors) can be installed during renovation.

Shutters provide an excellent way to protect windows and doors from the sun and rain (external influence) and can reduce heating costs and air-conditioning costs throughout the year. They are made from PVC material that is easy to maintain and have metal reinforcements contributing to their strength and resistance to burglary. Shutters with fixed lamellas are set at an angle and thus allow air flow, but cannot completely darken the room. Shutters with adjustable lamellas enable residents to choose the quantity of air and light in the room using a mechanism for rotating the lamellas (Figure 40).

Figure 40 - PVC (left) and aluminium (right) shutters

Roller shutters are a great choice because they offer protection against external influences, protect privacy and contribute to heat and sound insulation. They can be easily installed on new constructions or existing structures and require minimal maintenance (only occasional cleaning). With roller shutters, it is possible to completely darken the space and provide excellent heat and sound insulation at the same time. Anti-theft roller shutters offer additional security, and roller shutters with integrated insect screens prevent unwanted insects from invading inner space. These types of shutters can be paired with sensors and motors, enabling automatic opening and closing and enhancing protection from cold, heat or insolation (Figure 41).

Figure 41 - Roller shutters installed in small residential building

Venetian blinds are the second most used type of blinds after roller shutters. They provide excellent protection against sunlight and unwanted views, thus contributing to the feel of comfort and privacy, and are an aesthetically pleasing addition. They can be installed both internally and externally. By adjusting the angle of the slats, internal venetian blinds protect from direct sunlight and block unwanted views, while also serving as a decorative element. External venetian blinds provide both thermal insulation and protection from the weather. They are installed in front of the window from the outside, which prevents direct heat from entering the space. Together with the façade, they further enhance the exterior of the building. Usually, it is possible to choose from a wide range of colour combinations of slats, masks, guide rails and finishing bars, as well as between manual crank handle and electric control (Figure 41 and Figure 42).

Figure 42 - External venetian blinds with exposed (left) and built-in (right) mechanism

6 Measures for heating system

The heating system is the most complex system in multi-apartment buildings. It consists of many mutually connected and dependent components, and every single piece has its own influence on the overall system efficiency. Recently, in some residential buildings, heating systems are complemented by air conditioning supported by or based on renewables. In such cases, air in apartments is not only heated, but cooled, ventilated or (de)humidified.

Changes in the heating system almost always represent major change, particularly if several or all apartments are involved. Such changes should always be recommended, planned and supervised by highly trained personnel. Even seemingly insignificant changes in a system can have undesired effects on system efficiency. Here, we give some basics and guidelines for possible changes in heating systems and general recommendations towards increasing their energy efficiency. Energy auditors or heating system designers will require more detailed information.

6.1 Heat source

Since buildings were erected in different periods, their tenants use various ways to heat living space. In older, usually smaller, buildings, each apartment is individually heated with a stove, electric heater or central heating system based on solid fuel, natural gas or electric energy. Newer, usually larger, buildings are often connected to district heating systems that use natural gas or fuel oil. Recently, more and more district heating systems are based on biomass or biogas.

Proposed changes in heating systems that aim to increase energy efficiency are strongly dependent on building age and configuration, available fuel(s) and fuel prices. There are many possibilities and combinations, some of which are applicable for each building type. Some of them are relatively simple, while others represent and/or require major changes.

A significant problem in apartments and buildings is intermittent heating and, consequently, cooling of living space. This is even more problematic in apartments where only certain rooms are used and heated during winter, while the rest remain unheated. Heating in such cases is often provided by manually operated individual stoves (furnaces) located in heated spaces, usually using solid fuel (firewood and coal) or less often fuel oil. Sometimes tenants use various types of electric heaters to heat space when necessary (e.g. convectors or infrared heaters located in bathrooms). Intermittent and selective heating of spaces causes a lot of problems, including condensation and developing mould, particularly where thermal bridges are present. The number of thermal bridges (cold points) in selectively heated apartments is significantly larger than in evenly heated apartments.

One solution in such cases is the introduction of individual but automatic furnaces using pellets or natural gas, with a control system that adjusts the dosing and burning of these fuels. Fuels like firewood and coal are not suitable for small individual automatic furnaces, because they must be dosed manually. Installing automatic furnaces is a relatively cheap solution, and it solves the problem of intermittent heating and cooling of space, therefore reducing the possibility of developing mould.

Another option is installation of a central heating system. This can use pellets or natural gas, but it can also be based on renewables such as geothermal energy. This is a more expensive solution, requiring installation of not only a heat source but a piping system and radiators (or similar heating bodies) as well. It can also be combined with floor heating. Installation of a central heating system also solves the problem of intermittent heating and cooling, but additionally provides even heating of the entire apartment. Therefore, implementation of such a system eliminates temperature variations and reduces the number of thermal bridges, which eliminates mould formation and significantly increases indoor air quality. An additional advantage of a central heating system is the possibility to combine it with a system for preparation of domestic hot water.

In apartments heated by boilers using natural gas, it is possible to keep the entire heating system (piping and radiators), but to replace the existing boiler with a condensing gas boiler. This improves the efficiency of heat generation from approximately 94% to 108%, without loss of thermal comfort.

Figure 43 - Modern condensing gas boiler (efficiency 108%) and individual gas furnace (efficiency 96%)

In apartments using central heating based on solid fuel (boilers using firewood and coal), it is possible to propose introduction of new boilers that use biomass (e.g. wood pellets). Such boilers are fully automatic, which dramatically increases energy efficiency (up to 30%), while increasing thermal comfort and reducing CO_2 emissions. This measure is relatively cheap and simple to implement. The rest of the heating system (piping and radiators) can be further enhanced with thermostatic valves where necessary. Space used for stocking firewood and coal can be used (with or without renovation) for stocking pellets.

Figure 44 - Modern boiler for wooden pellets and individual pellet furnace (both efficiency 92%)

Apartment blocks and high-rise buildings are relatively newly built, and, in most cases, they are connected to a district heating system with dedicated boiler rooms using natural gas and, less commonly, fuel oil. Changes in these systems are rare since they require not only engineering solutions, but political and strategic changes. It is possible, however, to propose building dedicated small district heating systems that will serve a few smaller apartment buildings of a residential block. Such systems can be based on natural gas, biomass or biogas. The entire infrastructure of piping and radiators already existing in apartments can be used and connected to a newly built boiler room. In this way, energy efficiency can be increased. Further possibilities include combination with domestic hot water preparation and solar systems (for hot water). Of course, this is an expensive measure as it requires significant investment and has a relatively long payback period.

6.2 Heat distribution system

Beside changes in heat source (e.g. changes of boilers or building new district heating systems), there are several relatively simple and cost-effective measures that can be applied to the heat distribution system.

In apartments using central heating, regardless of the fuel, it is possible to replace common flow control valves with thermostatic valves (valves controlling flow with a thermostatic head). This is a relatively cheap and simple measure to implement, yet it can reduce heat consumption by 5% without loss of thermal comfort. Balancing the heating system with valves (manually or automatically) can increase the efficiency of the heating system by 1% to 3%, depending on system complexity and condition.

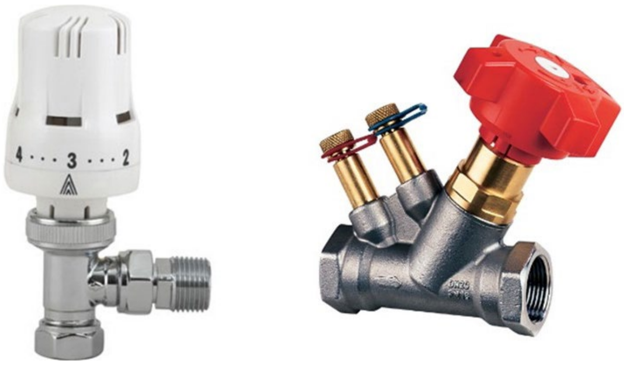


Figure 45 - Thermostatic and balancing valves

Radiators, as principal heating bodies in apartments using central or district heating systems, can lose their efficiency due to deposits of impurities in water and pieces of corroded metal. Such radiators can be dismounted and rinsed, which will increase their efficiency by 1% to 5%, depending on their condition.

One measure that can be proposed is installation of electronic circulation pumps instead of conventional ones. Such pumps do not directly increase the efficiency of the heating system but increase efficiency of electric power consumption. They can be programmed to work in different ways depending on needs, and can save 25% to 50% of electric energy, depending on working regime and system complexity. These pumps are significantly more expensive than conventional ones. However, payback period is short since electricity is expensive. Installation is relatively simple and does not require major system changes.

Figure 46- Electronic circulation pumps

Beside measures described above, it is important to adjust behaviour and living habits to the new heating system. This includes introduction of zones in apartments, changes in space usage and habits of ventilation. There are some cases where a significant change is made to a building's heating system, but is not followed with behavioural change, making the situation even worse than it was before. In case of switching to biomass or wooden pellets as fuel, special attention must be paid to stocking condition of fuel, since moisture can decrease its properties.

Since replacement of the heating system and/or changes in the heat distribution system are complex and expensive, it is more cost-effective to invest in thermal insulation of the building. As explained above, changes in the heating system are generally justified only after the entire envelope is in excellent condition. However, it is necessary to bear in mind that changes in heat source and heat distribution system not only increase energy efficiency, but also reduce pollution and increase thermal comfort inside the building. These are effects that are relatively hard to quantify and express as benefits.

6.3 Cooling

Cooling (or air conditioning) has recently gained a lot of attention in terms of energy efficiency. Nowadays, with increased requirements for thermal comfort, it is not only necessary to provide heating during cold periods, but also to provide cooling during hot periods. Some studies have shown that energy consumption due to cooling during summer is higher than for heating during winter. Unfortunately, there is no simple and cost-effective solution to this issue.

Installing split air-conditioning systems, either single-split or multi-split, can provide cooling in spaces where the inner unit is installed. This is a low-cost and simple solution. However, it does not solve problems of cooling entire apartments or buildings, which is required to fully achieve thermal comfort. Installing a central air-conditioning system, which comprises one central cooling unit and duct system for air distribution, can treat an entire building. However, this solution is expensive and complex to retrofit. A proper technical solution needs to chosen to suit the particular building and usage regime, and must consider building geometry and age, number of tenants and available space for installing all required equipment.

Figure 47 - Split-system air conditioner: indoor and outdoor unit

Nevertheless, in cases where tenants want to install an air-conditioning system for themselves, they should consider only those with high energy efficiency. Nowadays, such systems are inverter air conditioners, which can be used for heating as well.

6.4 Heat recovery

Heat recovery ventilation (HRV), also known as mechanical ventilation heat recovery (MVHR), is an energy recovery ventilation system which works between two sources at different temperatures. Heat recovery is a method which is increasingly used to reduce the heating and cooling demands (and thus energy costs) of buildings. By recovering the residual heat in the exhaust gas, fresh air temperature is increased (or reduced) before it enters the room. A typical heat recovery system in buildings consists of a core unit, channels for fresh air and exhaust air, and blower fans. Exhaust air is used as either a heat source or heat sink, depending on the climate conditions, season and requirements of the building. Heat recovery systems typically recover about 60-95% of the heat in exhaust air and have significantly improved the energy efficiency of buildings.

A heat recovery system is designed to supply conditioned air to the occupied space to maintain the desired level of comfort. The heat recovery system keeps the inner space fully ventilated by recovering the heat which is coming from the inside environment. Heat recovery systems work by transferring the thermal energy from an outgoing stream of air to incoming air, while maintaining no contact between streams.

Large-scale heat recovery systems need a lot of space. The best possible solution is to consider their installation right at the beginning, during the design and planning phase. Generally, retrofitting such systems is problematic, due to the dimensions of ventilation conduits and space required for them, which is subtracted from usable inner volume. Exchangers can also have large dimensions. In residential buildings, communal space could be used for heat exchangers.

There are several types of heat exchangers, as illustrated in Figure 48.

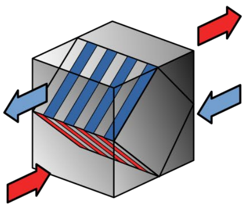
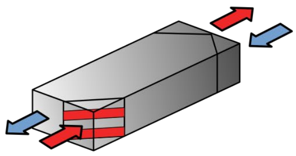
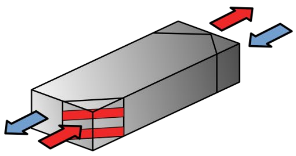
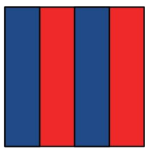
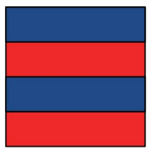
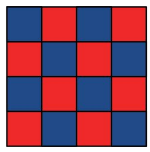
Principle			
Profile			
Counter current heat exchanger	Vertical flat panel	Horizontal flat panel	Cellular
Efficiency	50-70 %	70-80 %	85-99 %

Figure 48 - Types of heat exchangers

Figure 49 - Heat recovery units

Besides these large-scale heat recovery units with a capacity of 5,000 m^3/h and more, there are smaller, more affordable units. Usually described as "wall units", their capacity goes up to 50 m^3/h. They are intended to be used individually and not connected to a central system. They are well suited to kitchens and bathrooms. As well as heat recovery, they can prevent excessive condensation and problems with mould. An example unit is shown in Figure 50.

Figure 50- Small heat recovery units

In most industrialised countries, heating, ventilation and air conditioning (HVAC) is responsible for one-third of the total energy consumption. Cooling and dehumidifying fresh ventilation air comprises up to 40% of the total energy load for HVAC in hot and humid climatic regions. However, that percentage can be higher if 100% fresh air ventilation is required. This means more energy is needed to meet the fresh air requirements of the occupants. Heat recovery is becoming a necessity due to the increasing energy cost for treatment of fresh air. The main purpose of heat recovery systems is to mitigate the energy consumption of buildings for HVAC by recovering the waste heat. In this regard, standalone or combined heat recovery systems can be incorporated into residential or commercial buildings to reduce energy consumption and greenhouse gas emissions.

6.5 Heat pumps

A heat pump is a device used to warm and, sometimes, also cool buildings by transferring thermal energy from a cooler space to a warmer space using the refrigeration cycle, being the opposite direction in which heat transfer would take place without the application of external power. Common device types include air-source heat pumps, ground-source heat pumps, and water-source heat pumps. Heat pumps are used for heating, cooling and preparation of domestic hot water.

The efficiency of a heat pump is expressed through coefficient of performance (COP), or seasonal coefficient of performance (SCOP). The higher the number, the more efficient a heat pump is and the less energy it consumes. For example, COP of 3.6 means that for every kWh of electricity taken from the grid, 3.6 kWh of heat is given into space. When used for heating, these devices are typically much more energy efficient than simple electrical resistance heaters, which give approximately 1 kWh of heat for every kWh taken from the grid. It is possible to combine heat pumps with other systems to increase reliability or efficiency, e.g. with solar panels and/or wind turbines.

Figure 51 - Heat pumps

Air-source heat pumps are used to move heat between two heat exchangers. One is outside the building, and is fitted with fins through which air is forced using a fan. The other either heats the air inside the building directly or heats water which is then circulated around the building through heat emitters that release the heat to the building. These devices can also operate in a cooling mode where they extract heat via the internal heat exchanger and eject it into the ambient air using the external heat exchanger.

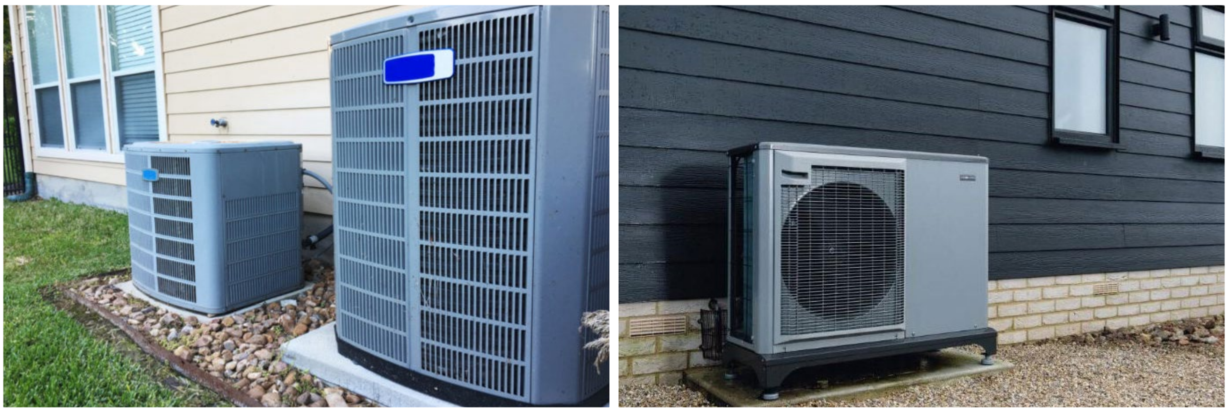


Figure 52 - Air source heat pumps

They are normally also used to prepare domestic hot water, which is stored in a domestic hot water tank. Air source heat pumps are relatively easy and inexpensive to install and are the most widely used heat pump type. In mild weather, COP may be around 4.0, while at temperatures below around 0 °C an air-source heat pump may still achieve a COP of 2.5. The average COP over seasonal variation is typically 2.5-2.8, with exceptional models able to exceed this in mild climates.

Ground-source heat pumps (or geothermal heat pumps) draw heat from the ground or groundwater, which is at a relatively constant temperature all year round below a depth of about 9 metres. Well-maintained ground-source heat pumps typically have COPs of 4.0 at the beginning of the heating season, with lower seasonal COPs of around 3.0 as heat is drawn from the ground. Ground-source heat pumps are more expensive to install due to the need to drill boreholes for vertical placement of heat exchanger piping or dig trenches for horizontal placement of the piping that carries the heat exchange fluid (water with a little antifreeze). A ground-source heat pump can also be used to cool buildings during hot days, thereby transferring heat from the dwelling back into the soil via the ground loop. Solar thermal collectors or piping placed within the tarmac of a parking lot can also be used to replenish the heat underground.

A water-source heat pump works in a similar manner to a ground-source heat pump, except that it takes heat from a body of water rather than the ground. The body of water needs to be large enough to be able to withstand the cooling effect of the unit without freezing or creating an adverse effect for wildlife. Usually, the water-source is a pond, lake or sometimes river.

Heat pumps are expensive and sensitive pieces of equipment, coupled with electronics and many sensors that control operation, which is fully automated. Decisions about installation and use of heat pumps, particularly for multi-apartment residential buildings, should be made by energy auditors and engineering professionals. Many factors must be considered, envelope condition being one of the most important. All these factors influence investment value, as well as possible savings. Installation of any type of heat pump makes sense only in buildings with envelope in excellent condition. Using a heat pump can also require changes in behaviour of tenants/users.

7

Measures for domestic hot water

Domestic hot water is heated tap water used in bathrooms, showers and kitchens. In apartments, conventional independent water heaters are powered by electricity or gas (the latter often combined with the heating system). Heating domestic hot water means reaching at least 50 to 55 °C in the tank, even though there are some heaters that heat up to only 40 °C. There are conventional and unconventional (or innovative) heating systems. Conventional systems can be either on-demand (using electricity or gas) or with storage (using electricity), while unconventional are generally with storage.

Conventional on-demand systems activate a resistance process (where electricity is used) or combustion (in gas heaters) each time hot water is needed. While only suited for supplying small quantities at a single point in an apartment, they limit heat loss since the water is consumed straight away. The downside is electrical energy consumption, since such heaters can have 3 to 5 kW of installed power. Despite this, they are increasingly popular, due to their relatively low price and easy installation.

In systems with independent storage tanks (usually with a capacity of 30 to 80 litres, and sometimes 100 litres), water is heated and stored in an insulated container, which, over time, leads to heat losses. The heater can be set to heat the water as soon as its temperature falls below the desired value, or to heat water only during periods with lower electricity prices (e.g. overnight) to reduce energy costs by using off-peak electricity prices. Turning the heater on overnight can be done using a timer, or manually.

Figure 53 - Conventional domestic hot water heaters for electricity (left) and gas (right)

The efficiency of these water heaters varies greatly according to the model, sometimes falling below 30% for electric water heaters with independent tanks. The efficiency of gas-fired condensing water heaters is approximately 60%, with the most sophisticated models reaching 90%. It is also significantly affected by the position of the heater and the distance hot water needs to travel, as well as the required temperature of the water. It is assumed that efficiency of conventional hot water heaters is at its peak, particularly for electric heaters, though a few things can be introduced to further enhance it. These include change of insulating material (therefore reducing insulation thickness) and using two-part storage, where one part is used for fast heating of a smaller amount of water and the other is used as the principal storage unit.

Innovative and unconventional domestic hot water systems may use heat pumps, solar thermal panels or a combination of both for water heating. They heat up water which is stored in large-capacity tanks and used according to needs. Such tanks have a capacity of 300 to 500 litres, with thick insulation. Clearly, having a tank causes heat losses, but in this case, heating is done by a more efficient system and, consequently, gives cheaper hot water, so certain heat losses should be considered acceptable. Further improvements are possible by introducing pumps for circulation of hot water in the system. For these pumps, and generally for all auxiliary equipment in such systems, electrical energy is used.

Solar hot water systems are more complex than conventional systems. Figure 54 shows one possible arrangement.

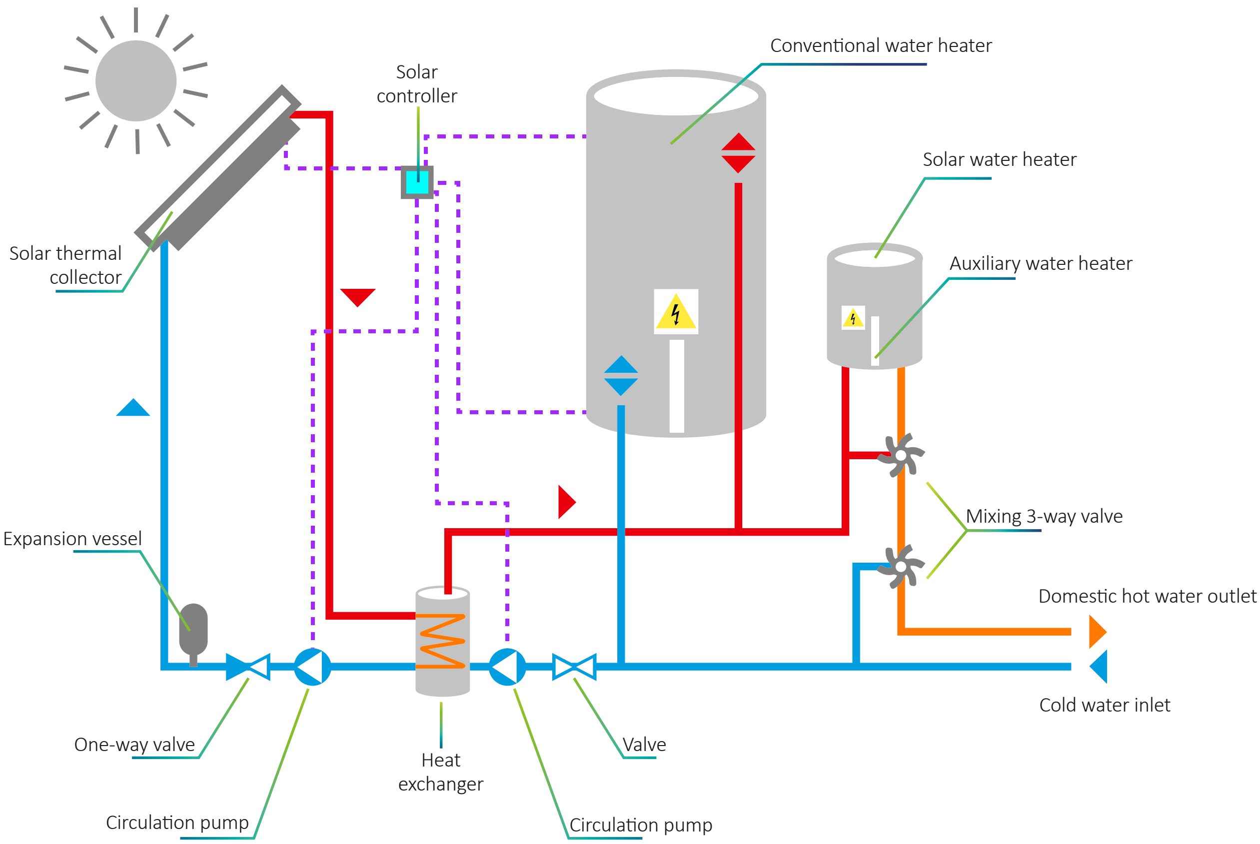


Figure 54 - System with auxiliary electrical heater as backup

Generally, solar systems for preparation of domestic hot water cannot rely solely on solar energy and must be equipped with a backup heating system/device. Hot water tanks are therefore sometimes equipped with an additional conventional electric heater, while others have an additional heat exchanger (coil) connected with a gas boiler. Sometimes backup is an auxiliary electric boiler or gas heater, which is used when the temperature of water from the solar system is too low. Figure 55 shows solar collectors, and Figure 56 solar storage tanks.

Figure 55 - Solar collectors (panels)

Figure 56- Solar storage tanks

It is also possible to use heat pumps for preparation of domestic hot water, as shown in Figure 57. Such systems are usually combined with heating. In this case a backup heating device is not necessary, as heat pumps can work during all seasons. However, for practical reasons, a large storage tank is still required.

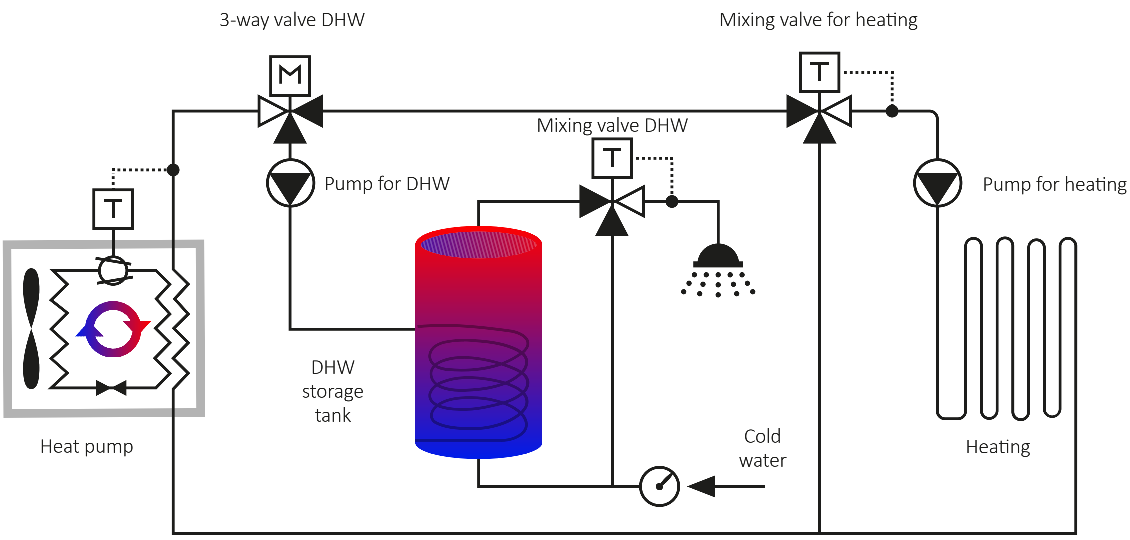


Figure 57 - Schematic representation of using heat pump for preparation of domestic hot water

Use of renewable sources such as wind and solar energy significantly reduces the primary energy demand in the building. Electricity generated by wind turbines with vertical axis of rotation and photovoltaic cells can be used to heat the hot water in the tank using a heater or as a source of electrical energy for the heat pump to prepare domestic hot water.

Installations combining these two types of renewable energy sources in one building can provide balance when one or other source is generating less energy. In the autumn and winter, when the possibilities of solar energy are significantly reduced, wind turbines will produce much more energy than photovoltaic cells. This situation changes in summer, when the photovoltaic cells produce more energy due to the longer day and much greater intensity of solar radiation, compensating for the lower wind speeds.

Renewable energy installations like these can cover the significant demand for electricity that is required to power heat pumps for domestic hot water. In case of excess electricity and a lack of heating needs, this energy can be used to maintain the temperature of hot water in the tank. Such systems will reduce the energy demand for primary fuels used to generate electricity. However, installing them requires significant investment and is a complex operation. In most cases it does not have a short payback period, but this depends on system complexity, number of tenants (i.e. users) and usage intensity. It could be feasible to install such a system in larger buildings with more tenants.

However, it is relatively hard to estimate investment needs for the above-mentioned measures based on renewables. Implementation of a solar system and/or heat pump includes major changes in the piping system and adjustments of masonry. This could be an issue, particularly in larger multi-apartment buildings. Solar panels take up a considerable area of roof and must be installed on a supporting structure, increasing loads on ceiling and roof structures. Another possible issue is insolation, and this must be considered when planning the system, since with insufficient insolation the system will not perform at the desired level. In almost every case, a backup solution for heating is recommended, which increases investment. Calculation of required heating capacity and storage volume depends on tenants' habits and building size. Distances between tank and tap could easily reach 30 metres, causing heat losses. All these can be challenging tasks to overcome.

In case of disadvantageous solar conditions, the installation of renewable energy sources may be uneconomical. Then the preparation of domestic hot water from a district heating system should be analysed, where heat from such systems is used in special boilers installed locally in apartments. This is a cheaper and simpler solution to implement, but it is not always possible to do it, and it is not as cost-effective in the long run, since heat from district heating systems is far more expensive, compared with on-site renewables.

The investment needed for switching to a more efficient local source of hot water (e.g. new electric or gas boiler) is simpler to estimate. This replacement requires no significant work on piping or walls, and is easily done.

8

Measures for electric energy consumption

Electric energy is used in residential buildings for various purposes. Besides domestic hot water preparation, principal uses are lighting, home appliances, personal computing and other electronic devices, and air conditioning.

A significant part of lighting in many residential buildings is still based on conventional incandescent lightbulbs, particularly in communal spaces (e.g. staircases and hallways). These lightbulbs are cheap, but have energy efficiency of only about 10%, meaning that only 10% of energy is used for lighting, while the rest is transferred into heat. Even though they have been withdrawn, it is still possible to find them on the market. Halogen incandescent lightbulbs are still used in reflectors and some specific lamps, mostly decorative. However, they have been gradually replaced over time by compact fluorescent (CFLs) or, more recently, LED lightbulbs.

Figure 58 - Different types of incandescent lightbulbs

Compact fluorescent lamps are simply curly versions of the long tube fluorescent lights. Because they use less electricity than traditional incandescent lightbulbs, typically CFLs can pay for themselves in less than a year. CFLs are nowadays available in a range of colours, including warm tones that were not available when first introduced. Some are encased in a cover to further diffuse the light. However, fluorescent bulbs contain a small amount of mercury, and they should always be recycled at the end of their lifespan.

Figure 59 - Different types of available CFL lightbulbs

Light emitting diodes (LEDs) are a type of solid-state lighting device. They are semiconductors that convert electricity into light.

Figure 60- Different types of available LED lightbulbs

LED lightbulbs use only 20% of the energy and last 15 to 25 times longer than traditional incandescent bulbs and use 25% of the energy and last 8 to 25 times longer than halogen incandescent lightbulbs. LED lightbulbs are currently available in many products such as replacements for 40 W, 60 W, and 75 W incandescent lightbulbs, reflector bulbs often used in recessed fixtures, and small track lights, desk lamps, kitchen undercabinet lighting, and outdoor area lights. They come in a variety of colours and connections, and some are dimmable or offer convenient features such as daylight and motion sensors. LED lighting systems work well indoors and outdoors because of their durability and performance in cold environments. While LED lightbulbs are more expensive, they still save money because they last a long time and have exceptionally low energy use.

Besides replacing lightbulbs with LEDs, it is possible to install new types of LED lamps. Many are based on LED strips, having unusual shapes and forms (Figure 61). They not only increase energy efficiency but also increase indoor comfort.

Figure 61 - Different types of LED lamps

An excellent addition to LED lighting usage are motion sensors. While not of great use in apartments, they can greatly improve energy efficiency of lighting system in communal spaces (e.g. hallways and elevators). Today many LED lamps intended to be used in communal spaces are already equipped with sensors, so light switches and timers are redundant.

Replacing lightbulbs or lamps with LED ones can lead to significant savings in energy, money and maintenance costs. Replacement is easy and requires no special knowledge. Even installing new lamps and lighting devices requires no special skills and can be easily done by an electrician. Payback period is usually less than one year, depending on usage. Installing sensors is slightly more complicated, as it requires professional expertise, but it is possible to install LED lamps with integrated motion sensors. Such lamps are slightly more expensive but can contribute to reduced electricity bills.

Personal computing and other IT and electronic devices are an inevitable part of everyday life. Even though they have relatively low electric power compared with conventional home appliances, the fact they are switched on 24/7 (in many cases) causes significant energy consumption. Consumption of PCs, Wi-Fi routers, TVs and audio devices can be as high as one third of total electrical energy consumption. Tenants, as end-users of electronic devices, should switch off devices when they are not necessary and/or buy those with automatic switching off. This is quite a simple measure yet gives excellent results. In case tenants/ users need to be convinced about the energy consumption of these “small devices” and educated about possible savings, small energy measuring devices (described above) can be used to measure consumption of, for instance, a single PC or Wi-Fi router.

Home appliances are widely used in all apartments, e.g. for cooking and maintenance. Tenants should be encouraged to choose energy-efficient appliances with higher energy classes. For this, it is important to learn to read energy certificates that are issued for every home appliance. The form of this certificate and the information within are defined by EU directive 2017/1369 (July 2017), replacing the former Energy Labelling Directive 2010/30/EU. Since March 2021, the energy label rating system uses A to G rankings only, instead of A+++ to D ratings as before. This new rating system applies to refrigerators, dishwashers, washing machines, televisions, and lightbulbs and lamps. The first four product groups must feature the rescaled labels from 1 March 2021. Lightbulbs and lamps must feature the rescaled label from 1 September 2021.

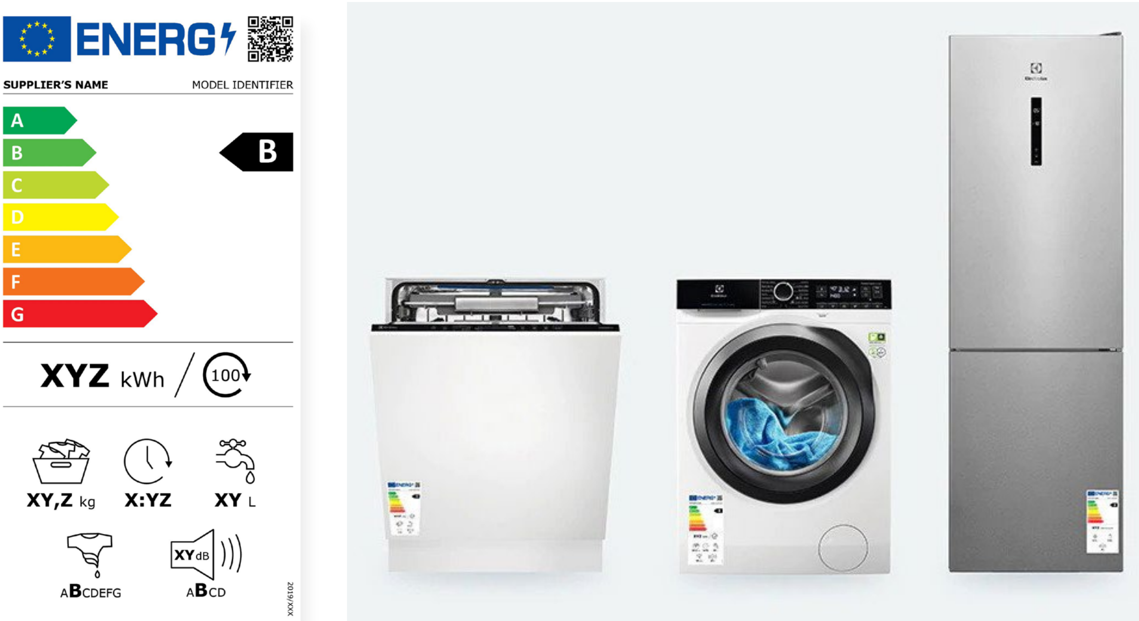


Figure 62 - Label and examples of labelling

More efficient devices are more expensive, often double the price of a cheap one, but that price is justified as they use fewer resources for the same job. This is particularly important for e.g. dishwashers and washing machines, as they use both water and electrical energy.

9 Behavioural measures and energy management

Aside from engineering measures, which greatly improve energy efficiency of apartments and building in their entirety, there are some measures that can be proposed for which tenants/building users are responsible. These measures do not require investment: simple changes in behaviour can generate energy savings and improve energy efficiency. Such measures include:

- Short and intensive exchanges of air instead of long periods of slightly opened windows
- Turning off lights when they are not required
- Turning off electrical equipment when not in use, or installation of automatic switches
- Using home appliances at their full capacity (e.g., dishwasher and washing machine)

The very first step in behavioural change of users is making them aware that energy is commodity like any other, and that they pay for it. Afterwards comes education, leading to change in habits. Through education users/tenants can learn how to maintain energy efficiency using simple measures. Only long-term change in user behaviour leads to permanent savings.

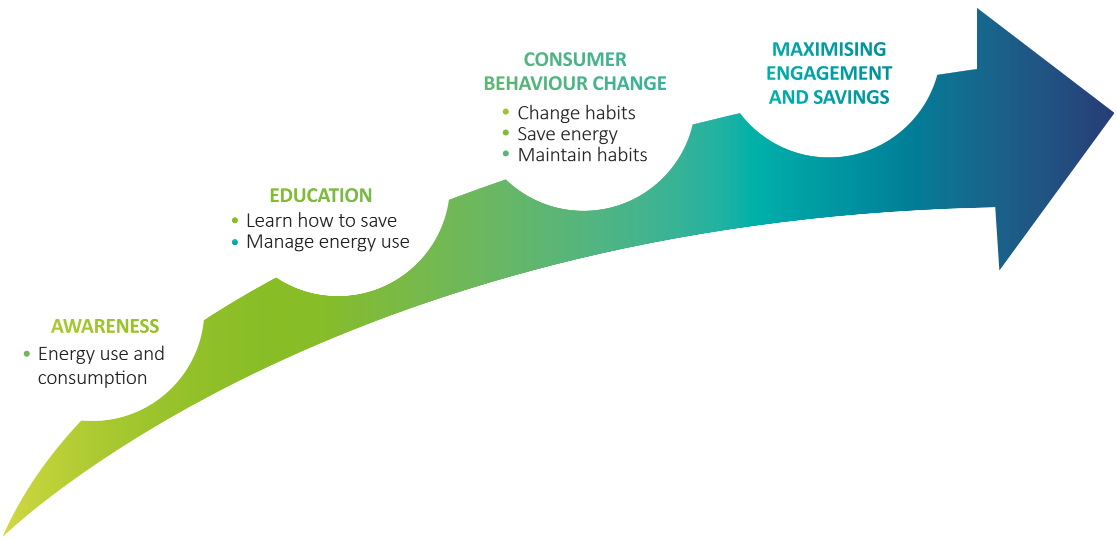


Figure 63 - Steps toward maximal engagement of users/tenants in increasing energy efficiency

The importance of behavioural change is as high as correctly implementing measures for improving energy efficiency. Just insulating walls and replacing windows will not yield expected long-term benefits if tenants/users do not change their habits.

Generally, by implementing energy efficiency measures, the energy consumption will be reduced to the level calculated during the detailed energy audit and remain at that level for some time. However, experience from many implemented projects has shown that after some years, the energy consumption starts to increase again. Three-to-five years later the energy consumption has sometimes returned to the same level as before the energy efficiency measures were implemented. Similar trends have also been experienced in new buildings. This unexpected phenomenon is illustrated in Figure 64.

To avoid this, energy monitoring was introduced. Energy monitoring is a control tool aimed at keeping the energy consumption at the correct and expected level, on a permanent basis. Energy monitoring is based on periodic registration (weekly) of the energy consumption and measurements of the corresponding mean outdoor temperature. Energy monitoring has proved to be a useful tool not only after implementation of an energy efficiency project, but during the whole lifetime of a building. In addition to discovering and avoiding excess use of energy and water, energy monitoring enables the building owner and the operation and maintenance personnel to:

- Ensure correct operation of technical installations
- Document results from all types of energy saving measures
- Identify buildings with the highest energy efficiency improvement potential
- Receive quick feedback on the consequences of changes in operational routines
- Increase awareness on energy saving possibilities
- Improve budgeting of energy and water costs

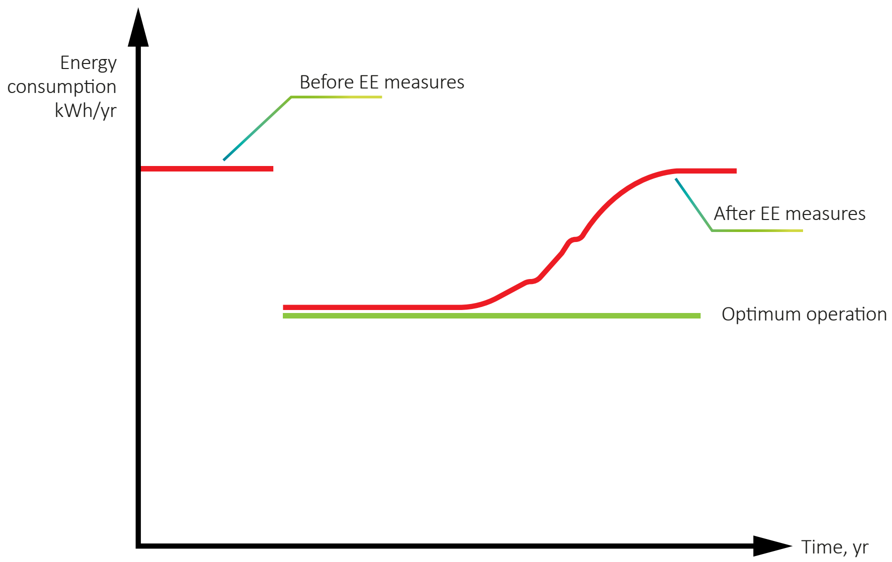


Figure 64 - Energy consumption before and after implementation of measures

International experiences from implementing energy monitoring as a separate measure show that achieved savings of energy and water consumption are between 5% and 15%. This of course requires action immediately after deviations from target values are registered.

The basic tool in an energy monitoring system is the “Energy-Temperature diagram”, or ET-diagram, as shown in Figure 65.

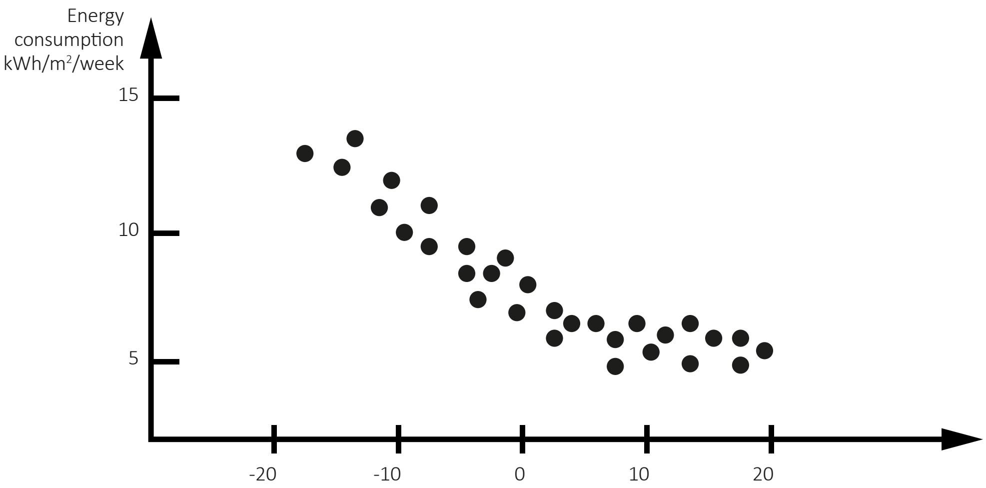


Figure 65 - Energy-Temperature diagram

The horizontal axis shows the mean outdoor temperature per week (°C/week), and the vertical axis shows the energy consumption per heated area for the same week (kWh/m²/week). The ET-diagram shows the measured energy consumption and the corresponding outdoor temperature for a given period. In Figure 65, each dot represents one week. The "trendline" given by these measurements is called the "ET-curve". During the heating season, energy consumption increases with the decreased outdoor temperature. As outdoor temperatures increase energy consumption decreases to its minimal level outside the heating season. This level includes energy consumption for domestic hot water, fans, pumps, lighting, various equipment etc. If the building is air conditioned, the energy consumption will increase again during the hot summer months.

Every building has its own, unique ET-curve (Figure 66). An ET-curve is established based on the results of energy calculations done by suitable software, which can be part of detailed energy audit. An ET-curve shows what the energy consumption should be for different outdoor temperatures, assuming correct operational conditions. This value is called the target value. If the weekly consumption is more than 5% to 10% outside the target value, actions should be taken to identify the cause and make corrections. Normal variations caused by fluctuations in sun, wind and user patterns are within these limits. An ET-curve for an existing building is established based on assumptions about the specific operational conditions and user patterns. If conditions are changed as a result of the energy efficiency measures, construction work or new operational routines, the ET-curve of the building will also change (Figure 66).

The figure shows typical changes in an ET-curve after energy efficiency measures have been implemented.

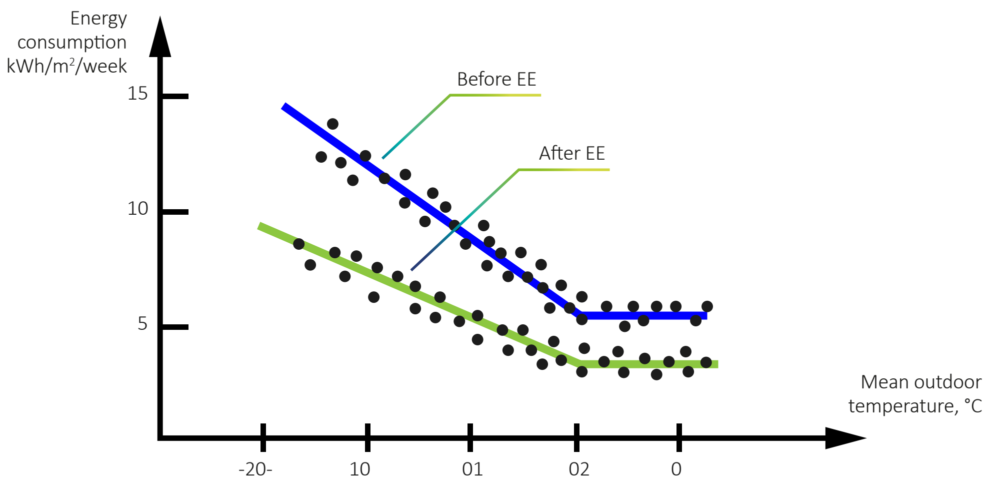


Figure 66 - ET-curve for a building before and after implementation of energy efficiency measures

The procedures for energy monitoring, based on the ET-curve methodology, should be accomplished in the following steps:

- Read the energy meter(s) in the building once a week and calculate the specific energy consumption. Some buildings with very high energy consumption could have more frequent readings, depending on the operation.
- Register the outdoor mean temperature for the corresponding period. Plot these two registrations for the week in an ET-diagram.
- Deviations from the ET-curve indicate some malfunctioning equipment or wrong operation settings. This should be investigated and required repairs or adjustments implemented

Equipment and tools required for the establishment and operation of energy monitoring programmes are mean outdoor temperature meter, energy meters, energy account schemes, ET-curve, and deviation checklists. An example of how an ET-curve should be created and used is given in Figure 67.

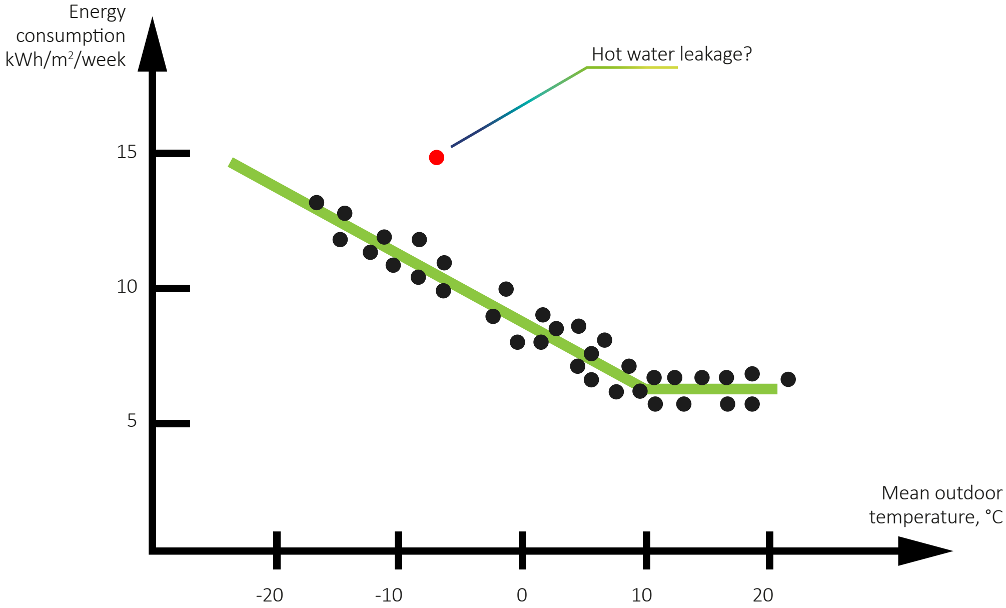


Figure 67 - Example of ET-curve with problem that needs to be identified and solved

Considering the above, it is clear that a building should be operated and maintained by trained personnel. Unskilled personnel and a lack of appropriate operation and maintenance routines can lead to an increased energy consumption in the future, despite the installed energy efficiency measures.

Correct operation and maintenance of a building is important in order to provide suitable conditions for the activities in the building. In each building it is important for the operation and maintenance personnel to ensure the energy consumption is as low as possible, on a permanent basis. In order to minimise the energy consumption in a building, the technical installations must operate correctly. This can only be accomplished by skilled operational personnel, continuous inspection (manually or by computers) and systematic maintenance. This will prevent large and expensive repairs.

A regular maintenance programme can avoid large and expensive repairs and secondary operational costs. The working environment and indoor environment are also improved by continuous maintenance.

Operation and maintenance of a building should be based on some general requirements:

- The personnel must have the skills and motivation required for the job
- The responsibility for operation and maintenance should be distributed, so that everyone knows the responsible person/persons for maintenance, energy and budgets
- The complete documentation for operation and maintenance of the building and the technical systems should be available and well organised
- Suitable work and time organising tools (manual, job cards or computer-based systems) should be used

Energy monitoring devices are important tools for systematic and continuous control of the operational conditions and of the energy consumption.

10

Overview of measures

As elaborated on previous pages, many energy-saving measures can be proposed for multi-apartment buildings, ranging from simple improvements to complex deep renovation. Every measure increases energy efficiency to a certain extent and requires different investment. Every measure also has benefits other than just increasing energy efficiency, e.g. reduced pollution or better control of heat distribution. Consequently, each measure has a different payback period.

Table 4 contains a short description of proposed measures and their simple payback period. However, these periods should be considered as general and based on experience, since they may vary significantly based on particular cases. Real payback periods depend on actual investment, energy prices and technical scenarios, such as their combination with other measures. Some measures, like changes in billing systems, have no payback period since they have no cost.

BEHAVIOURAL AND LEGAL MEASURES	
SHORT DESCRIPTION OF MEASURE	**SIMPLE PAYBACK PERIOD (YEARS)**
Changes in behaviour and engagement	n/a
Draught proofing	<1
Glazing films for windows	<1
Using small energy consumption measuring devices	1-2
Installation of radiator reflectors	1-2
Change in billing system	n/a

INSULATION OF BUILDING ENVELOPE

SHORT DESCRIPTION OF MEASURE	SIMPLE PAYBACK PERIOD (YEARS)
Thermal insulation of outside walls	3-10
Thermal insulation of roofs and ceilings	6-16
Thermal insulation of floors	4-26
Replacement of windows and doors	8-15

HEATING SYSTEM

SHORT DESCRIPTION OF MEASURE	SIMPLE PAYBACK PERIOD (YEARS)
Replacement of individual stoves with furnaces using pellets	n/a*
Replacement of individual stoves with furnaces using natural gas	n/a*
Replacement of individual stoves with central heating system based on boiler using pellets	n/a*
Replacement of individual stoves with central heating system based on boiler using natural gas	n/a*
Replacement of conventional natural gas boilers for central heating systems with condensing boilers	12-20
Replacement of central heating system based on firewood and/or coal with system using pellets	n/a*
Replacement of central heating system based on firewood and/or coal with system using natural gas	n/a*
Replacement of current heating system with inverter air conditioners	12-23
Replacement of current heating system with heat pumps	8-15
Conversion of local district heating system from fossil fuel to pellets	10-16
Installation of thermostatic valves in apartments	13-30
Installation of balancing valves in system	18-40
Replacement of conventional circulating pumps with electronic ones	3-10

PREPARATION OF DOMESTIC HOT WATER

SHORT DESCRIPTION OF MEASURE	SIMPLE PAYBACK PERIOD (YEARS)
Replacement of current system with solar system	12-16
Replacement of current system with heat pump	14-18
Replacement of current system with solar system combined with heat pump	11-14
Replacement of current system with solar system combined with heat pump, supported by wind turbine	8-11

* Denotes cases when switching to more expensive fuels is made, so increase in efficiency of system does not cover increase in energy price. Can be considered in combination with other measures.

ELECTRIC ENERGY CONSUMPTION	
SHORT DESCRIPTION OF MEASURE	SIMPLE PAYBACK PERIOD (YEARS)
Replacement of existing lightbulbs with LEDs	1-3
Using most efficient home appliances	3-15
Using efficient home computing and electronic devices	5-12
Using highly efficient inverter air conditioning instead of conventional ones	3-8

Table 4 - Overview of proposed energy efficiency measures

It is important to point out that data presented in the table above includes only benefits that can be quantified and easily expressed in financial terms. It does not include benefits achieved indirectly through pollution reduction, increase of public health and new jobs generated by green technologies.

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