ComAct

Community Tailored Actions for Energy Poverty Mitigation

Inventory of energy efficiency technical measures for energy-poor households

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Table of Contents

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1. Introduction

The availability of energy at affordable prices is among the key factors for achieving sustainable development of the society. On the other hand, the production of energy and its use significantly affect the environment, resulting in local and regional pollution and leading to global warming and climate change. Entire world faces the challenge of sustainable development - development that provides security of energy supply while reducing negative impacts on the environment.

Buildings of all types require large amount of energy to maintain design parameters and normal functioning. On the other side, that also gives opportunity for large energy savings. Therefore, energy efficiency of buildings has become priority in public sector, what led to significant energy and cost savings. Recently, energy efficiency in residential sector, both for individual houses and multi-apartment buildings, also gained significant interest for tenants, utility companies and investors.

Long term benefits of increased energy efficiency of buildings are reduced pollution and global warming. Energy should be used in as efficient manner as possible. However, it is important to emphasize that energy efficiency cannot be limited to energy saving. Saving always involves certain sacrifices, while efficiency means keeping the optimal thermal comfort, indoor climate, and lighting levels by 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,
- Increase the investment needed for energy supply,
- Reduce air pollution and climate change emissions,
- Expand employment in unskilled and skilled labor,
- Reduce demands on national and municipal budgets,
- Improve economic competitiveness.

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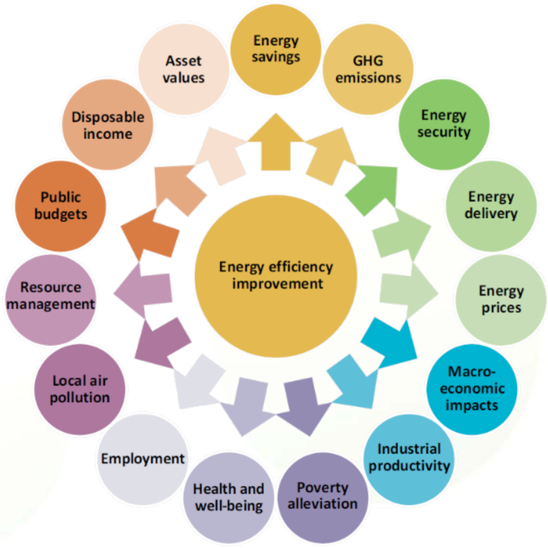
Figure 1 - Multiple benefits of energy efficiency improvements



Interventions in residential energy efficiency can lead to significant improvements in the 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 this can vary significantly), what makes general classification of measures and their analysis relatively harder. However, for multi-apartment buildings there is typology that can be applied, making analysis of energy efficiency measures generally easier.

1.1. Typology of multi-family apartment buildings

The construction of buildings has been subjected to a perpetual development in the course of time. Changes occurred due to the introduction of new materials and new construction techniques, to shifts of costs of natural resources and labor. Furthermore, there were architectonical improvements or innovations, alterations of flavor, changes of wealth, reaction on structural damages, health care and (recently) energy saving. The driving forces have often been economical aspects (minimizing of costs or competitiveness), administrative or juristic/legal reasons (requirements by building code etc.) but recently it is energy consumption reduction and energy efficiency.

The focus lies on the evolution of energy-related properties of buildings, as regards the energy performance of the building elements as well as the possibilities of improvement. 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, i.e. roof, top ceiling, wall, windows and floor of a given building, depends considerably on its age and its size. In addition, the thermal transmittance of these construction elements differ from each other and are also related to the construction time. There are also certain time periods which impose characteristic restrictions to the improvement of the thermal envelope, e.g. historical appearances which are worth saving or neighbor-type situations impeding the outside insulation of walls.

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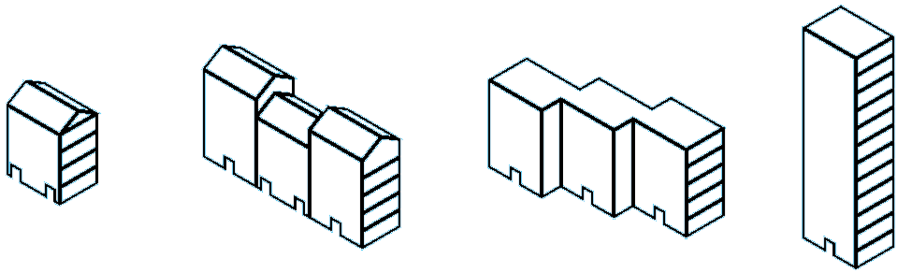
Figure 2 – Schematic representation of building typology and classification: from left to right: multi-family houses, attached apartment buildings in urban blocks, apartment blocks and high-rise buildings



Various approaches for typological assessment of the energy performance are existing in the 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 allow simplifications of 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) typical (common) values are used, representing typical cases. All buildings are in most cases classified according to two basic criteria: built year (e.g. 1961-1970 or 1980-1989) and type (e.g. apartment block or high-rise building).

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

When developing typology, a survey is usually conducted, covering number of various buildings, and measuring all parameters necessary to quantify and fully describe building's envelope, what makes ground for heat loss calculation and energy efficiency estimation. 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 other it is only possible to find core data required for heat loss calculations. This document does not contain detailed information regarding building typology for countries comprehended withing this project, since it is more related to following task (D4.2).

1.2. Energy efficiency measures

Generally, different energy efficiency measures can be proposed, depending on type of building and its year of built, as well as its considered condition and number of tenants. Measures range from simple low-cost to complex and (often) expensive deep-renovation. They target several principal categories:

- Legal and behavioral measures,

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- Building envelope,
- Heating system,
- Preparation of domestic hot water,
- Electric energy consumption.

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 requires significant investment and detailed analysis (e.g. introduction of heat pumps for heating, cooling and preparation of domestic hot water). Finding optimal set of measures to be proposed for certain building can be complex and tedious task, often involving not only engineering aspects, but legal and behavioral as well.

Figure 3 – Schematic representation of insulation of building envelope

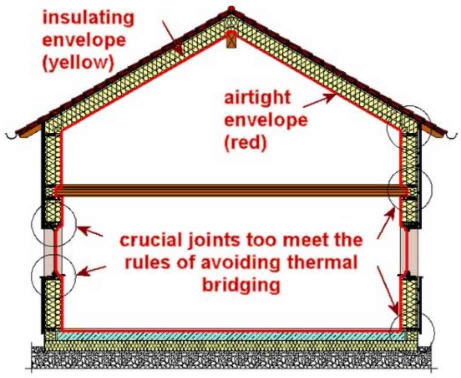
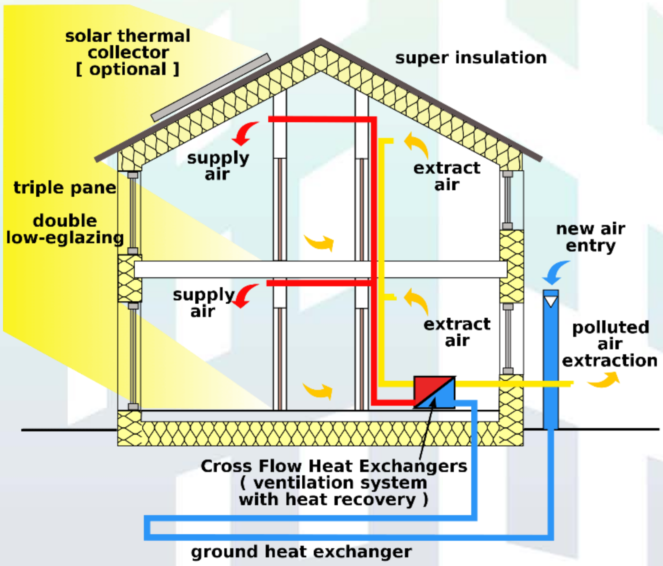


Figure 4 – Schematic representation of insulation and advanced heat source and distribution system



In some cases, by proper combination of measures, energy consumption can be remarkably lowered, and even such low amount of energy required for building could be covered to a very significant extent from

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renewable sources, including sources produced on-site or nearby. That would make that building "nearly zero-energy building", meaning a building that has an exceedingly high energy performance.

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 subjected 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).

Table 1 – Energy efficiency measures proposed for multi-apartment buildings

Group of measures	Complexity	Main effects and benefits
Behavioral and legal	Simple	Financial and energy savings
Building envelope	Simple to moderately complex	Increased thermal comfort, financial and energy savings, increased quality of living and comfort, higher real estate value
Domestic hot water	Moderately complex	Increased living comfort, financial and energy savings
Heating system	Moderately complex to complex	Increased thermal comfort and quality of living, decreased pollution, higher real estate value
Electrical systems	Simple to complex	Financial and energy savings, increased level of energy consumption control

For buildings connected to district heat systems, transition from billing per area to billing per actual consumption is the one of the most specific (and desirable) measures. This measure does not necessarily require changes in buildings yet cause change in tenant’s behavior. It will increase energy efficiency since user will be responsible for reasonable energy consumption.

While this document covers wide range of measures possible to propose for various buildings, it does not give detailed information regarding optimal technical scenarios. That require significantly more details about certain building and is covered and elaborated in task D4.2.

2. Behavioral and legal measures

Aside of technical (engineering) measures, which greatly improve energy efficiency of apartments and building in its entire, there are some measures that can be proposed, and for which tenants/building users are responsible. These measures do not require investment. Just change in behavior can generate energy savings and improve energy efficiency. Such measures are:

- Short and intensive exchanges of air instead of long periods of slightly opened widows,
- Turning off lights when they are not required,

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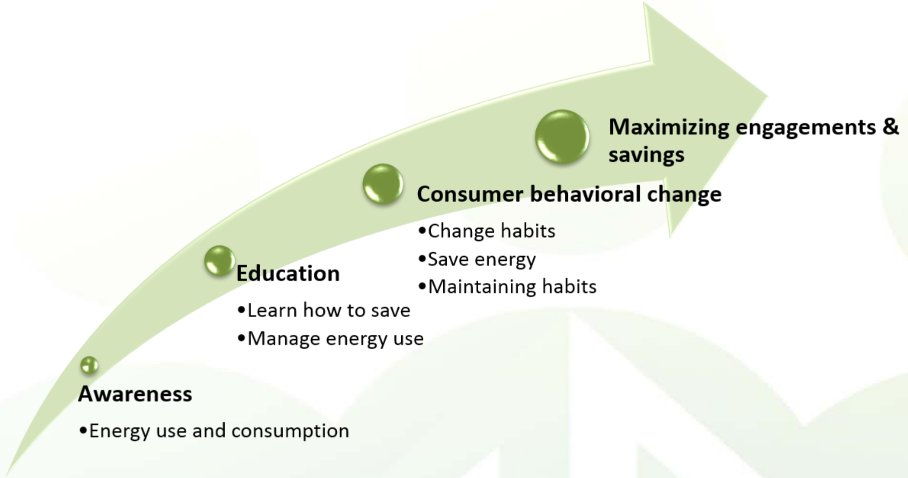
- Turning off electrical equipment when not in use, or installation of automatic switch,
- Using home appliances at their full capacity (e.g. dishwasher and washing machine).

The very first step in behavioral change of users is aware them 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's behavior leads to permanent savings.

Figure 5 – Steps toward maximal engagement of users/tenants in increase of energy efficiency



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

Example of 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-proof 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 apartment warm.

Figure 6 – Draught proofing windows and floors

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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 colors. 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 temporary solution to minimize heat loss. It is cheap solution with short payback time and can be done without special technical knowledge.

Figure 7 – Installing secondary-glazing film

Figure 8 – Small energy consumption measuring devices

As a part of simple behavioral measures that can lead to increase of energy efficiency, much attention should be paid tenant's awareness to energy consumption. To facilitate this, small energy consumption devices can be used. There is no special knowledge required for installing or using them, and they can demonstrate importance of measuring energy consumption at critical points in apartment.

Another simple, cheap, and cost-effective measure is installing radiator reflectors (radiator foils) on the walls behind heating bodies. Such foil consists of foam with aluminum foil at its surface, with thickness of about 4 mm. It eliminates heat flow into wall behind radiator and redirects that heat in inner space.

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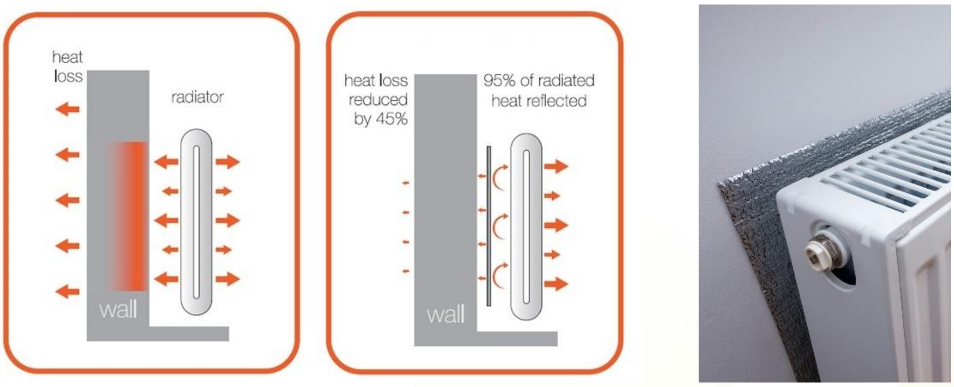
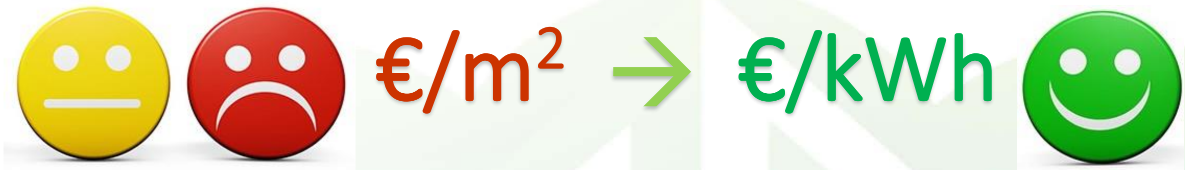
Figure 9 – Schematic representation of radiator reflector (foil) and look as installed



Beside already mentioned measures that can be proposed and suggested to most users (tenants), there is one measure that can significantly affect those connected to district heating systems. That is change of billing system, i.e. transition from billing per area (€/m^2) to billing per actual consumption (€/kWh).

Figure 10 – Transition from billing-per-area to billing-per-consumption would be greatly stimulative to tenants



This measure is rather complex to implement since many buildings do not have technical possibility to easily install individual calorimeters without significant changes in piping system. That makes this measure expensive as well. The reason for this is the original design of heating system, which was acceptable at the time when many buildings connected to existing district heating systems were erected. Piping system is shared among all apartments, usually having several main vertical pipes passing through all apartments. Hence, there is no technically simple solution to separate energy consumption without significant re-design of piping, what is required in case individual calorimeters are to be installed, measuring only consumption in single apartment.

This measure could be highly stimulative to tenants because all measures increasing energy efficiency would lead to reduced energy costs. In case billing per area remains the only option, tenants would pay the same price regardless of measures implemented in apartments. However, it is necessary to bear in mind that in majority of east-European countries companies managing district heating have strong influence on pricing system, and in most cases they are not willing to change it easily from billing-per-area to to billing-per-consumption. This must be considered as one of the major obstacles toward implementation of energy efficiency measures requiring notable investment.

Alternatively, it would be possible to measure heat consumption at level of entire building and find some financial model that would provide fair and stimulating pricing system for all tenants.

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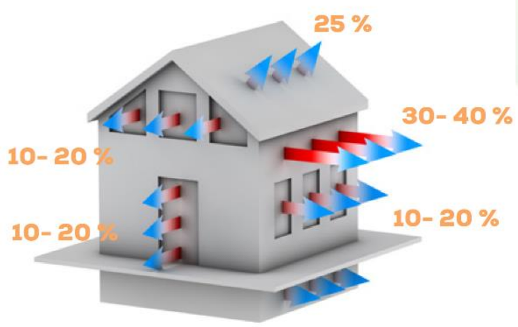
Only small portion of recently erected buildings have individual calorimeters that measure heat consumption for each apartment. In such cases, users (tenants) have strong tendency to take care about all measures, either simple or complex, to maintain high level of energy efficiency.

3. Building envelope

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, siding 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 heating system, will not matter. The reason for this is the building envelope can account for a substantial amount energy loss if not properly attended.

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

Figure 11 – Principal heat loses in residential building



Older buildings were designed in an era where energy was less expensive, hence used components of envelope were less insulating and consequently building in entire was less energy efficient. Nowadays wide range of measures is available to enhance building envelope condition and to reduce heat loses. 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 such common since it requires significant investment and lot of effort to be implemented, while having relatively low return rate. Technical variations in measures are expected due to difference 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 which 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.

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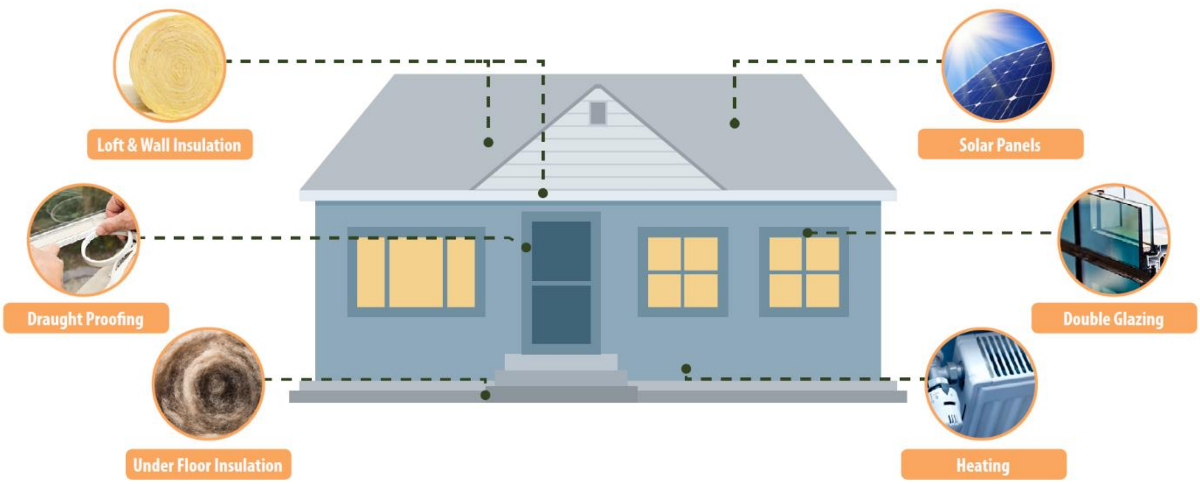
Most common insulation materials work by slowing conductive heat flow and, to a lesser extent, convective heat flow. Radiant barriers, which are not classed as insulation products, and reflective insulation systems work by reducing radiant heat gain. To be effective, the reflective surface must face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

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 12 – Important factors for energy efficient home



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.

The insulating capacity of a material is determined by its thermal conductivity, 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).

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3.1. Thermal insulation of walls

Regardless the building geometry, outside walls represent significant area of building envelope, therefore having high impact on its energy performance. In a typical building, walls account for 30 to 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 the current traditional insulation materials in ever increasing thicknesses of the building envelopes. However, very thick building envelopes are not desirable due to several reasons, e.g. considering space issues with respect to both economy, floor area, transport volumes, architectural restrictions and other limitations.

There are two major groups of insulating materials, traditional (widely used) and state-of-the-art (used when there is no other option or possibility). The third group, future materials, is still under development and therefore not in active use. Here, a short description of different insulating materials is given, with principal properties, pros, and cons of using it. As possible to see, some of them are organic, and some inorganic.

Figure 13 – Materials for building envelope insulation: fiberglass, mineral wool, cellulose and cotton

Fiberglass is the most commonly used insulation material of recent times. Fiberglass is a nonflammable insulation material. Moreover, it is a cheap form of insulation and is therefore the recommended option.

Mineral wool refers to several different types of insulation. It may refer to glass wool (manufactured from recycled glass), rock wool (made from basalt) or slag wool (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, but it is not combustible.

Cellulose insulation 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.

Cotton insulation consists of 85% recycled cotton, and 15% plastic fiber treated with borate: the same flame retardant and insect/rodent repellent used in cellulose insulation. One type of product, for example, are recycles waste trimmings from the manufacture of blue 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. It costs about 15% to 20% more than fiberglass batt insulation.

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Figure 14 – Materials for building envelope insulation: sheep wool, straw bale, polystyrene and polyurethane

Sheep wool is treated with borate for pest, fire, and mold 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. Using sheep wool as insulation can offer benefits in terms of wellbeing, and healthy indoor climate.

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

Polystyrene is commonly used to make foam or bead board insulation, concrete block insulation, and a type of loose fill insulation consisting of small beads of polystyrene. Molded expanded polystyrene (MEPS), commonly used in foam board insulation, is also available as small foam beads. Other polystyrene insulation materials similar to MEPS are expanded polystyrene (EPS), graphite polystyrene (GPS) and extruded polystyrene (XPS).

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.

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.

As possible to conclude, insulation commonly works through a combination of two main characteristics:

- The insulating material's natural capacity to inhibit the transmission of heat, and
- 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.

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Depending on type, insulation materials can be used in form of batts, blankets, boards or in bulk form, while some are applied in spray which later solidifies. 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, labor costs as well as insulation manufacturer and country of origin. It is noteworthy to mention that price also depends on the height of the building due to costs of scaffolding. Usually, insulation price is expressed per m^2 of façade surface, including costs of insulation and additional materials, labor, scaffolding and cleaning. Hence, it is hard to give general estimation of payback period since it depends on both investment and cost savings.

Figure 15 – Various forms of envelope insulation materials: batts, blankets, boards, and bulk

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

There is tendency to decrease usage of polystyrene insulation, and increase using of mineral wool. While more expensive and slightly more complex to be used, it provides fire protection and allows breathing of building. Such factors can be decisive and must be considered for each particular building when proposing energy efficiency measures.

Aside of 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 outer or inner (less common) side of the wall that is part of building envelope, there are various insulated façade systems. They are usually developed by companies specialized 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).

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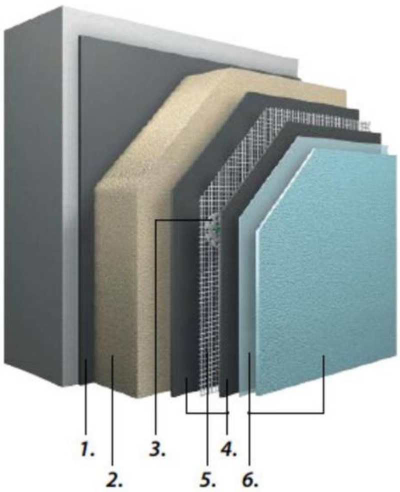
A comprehensive range of these systems is available on the market to meet the various demands of building structure and architecture.

Façade systems are commonly a kit, consisting of certain (specified) prefabricated components being applied directly to the façade onsite. Configuration of system components required for specific building and purpose depends on requirements set by user, investor or by national regulation. In most cases it includes adhesive applied to masonry (1), thermal insulation material (2), anchors (3), base coat (4), reinforcement (5, usually glass fiber mesh) and finishing layer (6). Finishing may include decorations, what make such systems applicable to buildings of aesthetic value or even historical buildings under protection. Such systems include also accessories, e.g. fabricated corner beads, connection and edge profiles, expansion joint profiles, base profiles, what enables full avoidance of thermal bridges.

Figure 16 – Typical components of ETICS façade insulation system



3.2. Thermal insulation of roofs and ceilings

A roof is the top covering of a building, including all materials and constructions necessary to support it on the walls of the building or on uprights, providing protection against rain, snow, sunlight, extremes of temperature, and wind. A roof is important part of the building envelope because uninsulated roof accounts for 15% to 25% of heat losses, depending on type, shape, form, size, and its condition. There are two principal types of roofs on multi-apartment buildings: flat roofs (commonly not accessible) and sloped roofs (used for lofts or attics).

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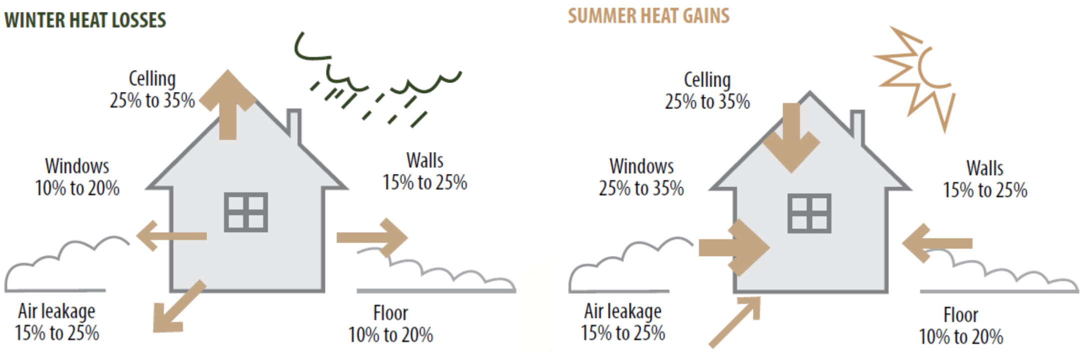
Figure 17 – Thermal heat loses and gains without thermal insulation



Materials used for insulation of roofs are mostly the same as for walls, but they are installed in slightly different manner. Main influencing factor is whether roof is intended to be used for living and using it or not. If it will be used for living (e.g. as loft, terrace, or heated attic), it is necessary to provide adequate finishing layer (e.g. ceramic tiles, or drywall). Installation of thermal insulation in case roof will not be used for living (e.g. gravel terrace, or unheated attic) is simpler and more cost-effective.

Thermal insulation of roofs and ceilings can be considered as cost-effective, usually with short payback periods. This, naturally, depends on building age and configuration, but in most cases is under 10 years.

3.3. Thermal insulation of floors

Floor is usually considered to be bottom of the building. It consists of several layers of different materials to fulfill all required functions. Floors account for 5% to 7% of heat losses, depending on building configuration. There are two principal types of floors on multi-apartment buildings: floor above unheated space (e.g. garage, basement or air) and floor on the ground.

Thermal insulation of floors above unheated space is done similarly to those for walls and roofs. It can be made using same insulating materials, with finishing according to needs. Insulating floor on the ground, however, represents complex and expensive measure to increase energy efficiency, usually with long payback period (50 years or more). The complexity depends on configuration of existing floor, and this measure is commonly combined with changes in heating system (e.g. introduction of floor heating or changes in heat distribution system).

3.4. Replacement of windows and doors

Original windows and outside doors in old buildings are mostly made of wood, with single or double glazing. Their thermal insulation properties are not satisfactory enough for current standards and regulations. Windows and outside doors are also important part of the building envelope because they account for 10% to 20% of heat losses, depending on size, orientation and their condition. Regardless of this, they have significant impact on aesthetical value of building, and therefore are often changed by tenants, even though they have relatively long payback period.

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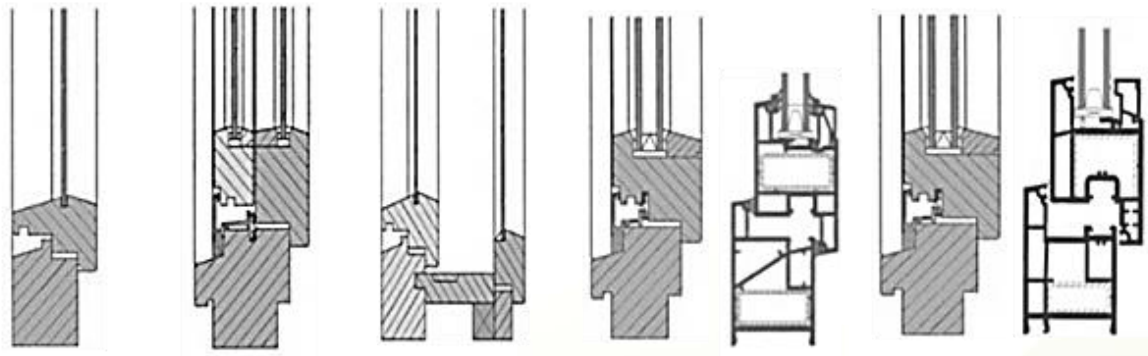
Figure 18 – Examples of window profiles and glazing currently installed in buildings



Nowadays, a wide range of window materials and glazing types are available at the market. They are all developed to fulfill requirements of currently valid standards and regulations regarding energy efficiency and heat losses.

Modern window and door frames are made of 5 or 7 chamber profiles, made of PVC, aluminum, or their combination, with high humidity and dust sealing, as well as good thermal and acoustic protection. Windows glazing is made with 2, 3 or even 4 glasses, with one or two low-E coatings, while space between glasses is filled with inert gasses (most commonly argon). There are also wooden frames available for historical buildings and buildings under protection, that fulfill all requirements set by applicable standards and regulations, yet not influencing overall look. A wide range of window shaders is developed as well to further enhance energy efficiency of modern windows.

Figure 19 – Modern windows are made of PVC profiles with glazing made with two or three glasses

As possible to conclude, investment in new windows and outside doors can be significant. It varies depending on used materials, size, shape, place of assembly and manufacturer.

4. Heating system

Since buildings are erected in different periods, their tenants use various ways to heat living space. In older, usually smaller, buildings, each apartment is individually heated with stove, electric heater or central heating system based on solid fuel, natural gas, or electric energy. Newer, usually larger, buildings are often

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connected to district heating system that uses natural gas or fuel oil. Recently, more and more district heating systems are based on biomass or biogas.

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

One of the key problems with manually operated individual stoves (furnaces) is intermittent heating (and consequently cooling) of living space. This causes a lot of problems, including condensation and developing mold, particularly where thermal bridges are present. Solution in these cases is introduction of either automatic, yet individual, furnaces using pellets or natural gas as fuel, or central heating system using same fuels. The first option is significantly cheaper, while latter requires installation of piping system and radiators or similar heating bodies. Nevertheless, it can also be combined with floor heating.

Figure 20 – Modern condensing gas boiler and boiler for wooden pellets, both to be used in central heating systems in apartments

In apartments using central heating system, regardless the fuel, it is possible to replace common flow control valves with thermostatic valves (valves controlling flow with thermostatic head). This is relatively cheap and simple measure to implement, any yet it can reduce heat consumption by 5% without loss of thermal comfort.

In apartments heated by boilers using natural gas, it is possible to keep entire heating system (piping and radiators), but instead of old type gas boiler install condensing gas boiler. In this way, efficiency of heat generator is increased from approximately 94% to 109%, without loss of thermal comfort.

In apartments using central heating based on solid fuel (boilers using firewood and coal), it is possible to propose introduction of new boilers that will use biomass (e.g. wood pellets). Such boilers are fully automatic, what drastically increase energy efficiency (even up to 30%), with increase of heat comfort and reduction in CO_2 emission. This measure is relatively cheap and simple to implement. The rest of heating system (piping and radiators) can be further enhanced with thermostatic valves in case it is necessary. Space used for stocking firewood and coal can be used (with or without renovation) for stocking pellets.

Apartment blocks and high-rise buildings are relatively newly built, and, in most cases, they are connected to district heating system with dedicated boiler rooms using natural gas and, less common, fuel oil. Changes

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in these systems are not often since that includes much more than engineering. It is possible, however, to propose building dedicated small district heating system that will serve few smaller apartment buildings of residential block. Such system can be based on natural gas, biomass, or biogas.

Entire infrastructure of piping and radiators already existing in apartments can be used and connected to newly built boiler room. In that way, energy efficiency can be even more increased. Further possibilities include combination with domestic hot water preparation and solar systems (for hot water or photovoltaic). Of course, this is expensive measure as it requires significant investment, and has relatively long payback period.

Beside changes in heat source (e.g. changes of boilers or building new district heating system), there are several relatively simple and cost-effective measures that can be applied to heat distribution system. One of the simplest has been already mentioned, that is installation of thermostatic 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, what will increase their efficiency by 1% to 5%, depending on their condition. Balancing heating system with valves (manually or automatically) can increase efficiency of heating system by 1% to 3%, depending on system complexity and condition.

Figure 21 – Thermostatic and balancing valves

One measure possible to propose is installation of electronic circulation pumps instead conventional ones. Such pumps do not directly increase efficiency of heating system but increase efficiency of electric power consumption. They can be programmed to work in different regimes, depending on needs, and can save 25% to 50% of electric energy, depending on working regime and system complexity. These pumps are significantly expensive in comparison with conventional ones, but their installation is relatively simple and does not require major system changes.

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Figure 22 – Electronic circulation pumps

Beside measures described above, it is important to adjust behavior and living habits to 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 in heating system in building has been made, but it was not followed with behavioral change, making situation even worse than it was be before. In case of switching to biomass or wooden pellets as fuel, special attention has to be paid to stocking condition of fuel, since moisture can decrease its properties.

As possible to conclude, replacement of heating system and/or changes in heat distribution system can be relatively complex and expensive. It is more cost-effective to invest in thermal insulation of building than to changes in heating system. 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 building. Those are effects that are relatively hard to be quantified and expressed as benefits.

5. Preparation of 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 (latter often combined with heating system). Heating domestic hot water means at least 50 to 55 °C in the tank, even though there are some heaters that heat up at only 40 °C. There are conventional and unconventional (innovative) heating systems. Conventional systems can be either on-demand (using electricity or gas) or with tanks (using only electricity), while unconventional are generally with tanks.

Conventional on-demand systems activate resistance process (in case electricity is used) or the combustion (in gas heaters) each time hot water is needed. While only suited to supplying small quantities at a single point of use, they limit heat loss, since the water is consumed straight away.

In systems with independent tanks (usually with a capacity of 30 to 100 liters), water is heated and stored in an insulated container, which, over time, leads to heat losses. Energy supply can be regulated to heat the water as soon as it falls below the desired temperature, or to take advantage of off-peak electricity prices.

The efficiency of these water heaters varies greatly according to the model used, sometimes falling below 30% for electric water heaters with independent tanks. The efficiency of gas-fired condensing water heaters is greater than 60%, with the most sophisticated models reaching 90%. It is also significantly affected by position of heater and distance hot water needs to overcome to be used, as well as required temperature

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of water. It is assumed that efficiency of conventional hot water heaters is at its peak, and this is particularly truth for electric heaters. Few things can be introduced to further enhance it, including increase in insulation thickness, what leads to other problems.

Figure 23 – Conventional domestic hot water heaters for electricity and gas

That is reason why innovative and unconventional heaters have been introduced. The most innovative water heaters use heat pumps or solar thermal panels – or both. They heat up water, which is stored in tanks and used according to needs. Clearly, having a tank again causes heat loses, but in this case heating is done by far more efficient system and, consequently, heating water using it gives cheaper hot water.

Buildings with low energy intensity are characterized by increased demand of energy for domestic hot water preparation in relation to the total energy demand, compared to existing buildings. 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 through the warmer or as a source of electrical energy for the heat pump to prepare domestic hot water.

Figure 24 – Unconventional solar domestic hot water heaters

Combining in one building, installations using these two types of renewable energy sources will provide benefits of mutual complementarity, when the energy generation in one of these installations will disappear or will be reduced. In the autumn and winter period, when the possibilities of solar energy are significantly reduced, wind turbines will produce much more energy than photovoltaic cells due to usually occurring windy weather in this time. This situation is changing in the summer period, when the photovoltaic cells produce more energy, due to the longer day and much greater intensity of solar radiation. In the summer

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months, while the air masses are not moving too quickly, in result, it is observed lower wind speeds and therefore wind turbines produce limited amounts of power.

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

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

6. Electric energy consumption

Electric energy is used in residential buildings for various purposes. Beside already mentioned domestic hot water preparation, principal uses are lighting, home appliances, personal computing and other electronic devices, and cooling (or air conditioning).

Lighting in many residential buildings is still based on conventional incandescent lightbulbs, particularly in common spaces. These lightbulbs are cheap, but have energy efficiency of about 10%, meaning that only 10% of energy is used for lighting, while the other is transferred into heat. More energy efficient are compact fluorescent lamps (CFLs), which are simply curly versions of the long tube fluorescent lights. Because they use less electricity than traditional incandescent lightbulbs, typical CFLs can pay for themselves in less than nine months. CFL bulbs are available in a range of light colors, including warm (white to yellow) tones that were not as 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 25 – Different types of available LED lightbulbs

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Light emitting diodes (LED) lightbulbs are a type of solid-state lighting device, and they are semiconductors that convert electricity into light. LED lightbulbs use only 20% of the energy and last 15 to 25 times longer than the traditional incandescent bulbs and use 25% of the energy and last 8 to 25 times longer than halogen incandescent lightbulbs.

Figure 26 – Different types of LED lamps

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 colors and connectors, 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.

Excellent addition to usage of LED lightning are motion sensors. While not of great use in apartments, they can greatly improve energy efficiency of lightning system in common spaces (e.g. hallways, and elevators).

Home appliances are widely used in all apartments, e.g. for cooking and maintenance. Tenants do not have almost any influence on its design since they use them as end-users in accordance with user's manual. However, they should choose appliances with higher energy classes, due to their increased energy efficiency. Education about importance of labeling appliances can be proposed as one of measures.

Personal computing and other electronic devices are 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. Tenants, as end-users of electronic devices, should switch off devices when they are not necessary and/or buy those with automatic switching off.

Cooling (or *air conditioning*) 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 warm (or hot) periods. Some studies have shown that energy consumption due to cooling during summer is higher than one required 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 inner unit is installed. This is low-cost and simple solution. However, it does not solve problem of cooling entire apartment or building, what is required to fully achieve thermal comfort. Installing central climatization system, which comprises one central cooling unit and duct system for air distribution, can treat

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entire building. However, this solution is expensive and complex to be retrofitted. As possible to conclude, proper technical solution can be chosen for particular building and using regime, and must consider building geometry and age, number of tenants and available space for installing all required equipment.

Figure 27 – Split-system air conditioner: indoor (with energy consumption measuring device) and outdoor unit

Nevertheless, in case tenants would like to install air condition 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. As mentioned above, that in part of educational measures.

7. Overview of measures

As elaborated on previous pages, many measures can be proposed to be implemented in multi-apartment buildings, ranging from simple to complex deep-renovation. Every measure increases energy efficiency in 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 different payback period. Table 2 contains 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 of measures depend on actual investment and energy price(s), as well as combination with other measures, and can be determined only in case of certain technical scenario (combination of measures). Some measures, like change in billing system, do not have payback period since they do not have cost.

Table 2 – Overview of proposed energy efficiency measures

Short description of measure	Simple payback period (years)
Behavioral and legal measures	
Changes in behavior and engagement	n/a
Draught proofing	<1
Glazing films for widows	<1
Using small energy consumption measuring devices	1-2
Installation of radiator reflectors	1-2

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Short description of measure	Simple payback period (years)
Change in billing system	n/a
Insulation of building envelope	
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	
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	
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

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Short description of measure	Simple payback period (years)
Electric energy consumption	
Replacement of existing lightbulbs with LED ones	1-3
Using most efficient home appliances (category A+ to A+++)	3-15
Using efficient home computing and electronic devices	5-12
Using highly efficient inverter air-conditioning instead of conventional ones	3-8

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

It is, as well, important to point out that data presented in the table above include only benefits that are possible to be quantified and easily expressed in money. 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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