Sustainable Buildings for the High North. Existing buildings – technologies and challenges for residential and commercial use

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Depending on the intended use lifecycle of buildings may vary remarkably. Short term constructions such as summer cottages may last only a few decades whereas age of historical buildings may extend over hundreds of years. In Europe, three quarters of building stock is comprised of residential buildings. Approximately 40 % of the stock is built before 1960s, at the time when energy legislations were rather scarce. Consequently the age of buildings that have not undergone renovation is largely associated with the energy consumption level. Nowadays, scheduled renovations are commonly planned to reduce energy use in older section of building stock. Impacts of refurbishments are also associated on mitigation of the climate change as well as on improvement of indoor climate quality.

1 Introduction

Large share of the European residential buildings stock is built before 1960s, at a time when energy regulations were rather scarce [1] (#cite-text-0-0). As also lifespan of buildings may be rather long, up to 200 years (Paloheimo 2004) high 40 % share of the energy end-use is consumed by the sector.

Abundant possibilities exist for energy saving measures in buildings as energy is consumed in several processes; space and water heating, cooling, ventilation, lighting, cooking and other appliances [1] (#cite-text-0-0). Primarily the basic energy level is defined already in the planning and design phases. The made selections induced by municipal legislation, financial issues, trends in the manufacture, usage of building materials and inner technical systems influence on the energy outcome of building. By directing additional inputs toward the design process, the lifespan could be increased by 1.5 fold, along with lowered operation and maintenance costs and need for renovation at later phases [2] (#cite-text-0-2).

Between-country comparisons of commercial buildings are challenging due to lack of higher level decision regarding categorization of building types. In addition, the concept of floor area is versatile between countries and can include either gross outer floor area, inner floor area, heated, or net and treated part of building. The same terms can have different meaning or definitions among countries [1] (#cite-text-0-0).

In this report structures and technologies of current building stock are discussed along the challenges associated in renovation process of buildings. The work is mainly done for the purposes of the Sustainable Buildings for the High North-project, funded by EU Kolarctic.

2 Residential buildings

In Europe largest share, 75 % of the building stock is comprised of residential buildings. These include single and multi-dwelling buildings and holiday resorts [1] (#cite-text-0-0). Two third of the housing stock are single family houses and one third apartment blocks. Of all residences 16 % locate in high-rise buildings constructed mainly in the period 1960-1980 [1] (#cite-text-0-0).

In residential sector the age of the buildings that have not undergone renovation, is largely associated with the energy consumption level. The older the buildings, the higher the energy consumption levels are. The main regions in Europe, North-West, East-Central and South show no strong variation in the studied age groups of buildings (old < 1960, modern 1961-1990, recent 19-2000) except higher proportion of old buildings in North-West.

Forty percent of residential buildings were constructed before 1960 at the time when regulations regarding energy regulations of buildings were rather scarce. Construction boom experienced in the modern period 1961-1990 doubled the housing stock in almost all the countries. Country-level research for a set of European states showed that the most recently constructed housing building stocks are in Ireland, Spain, Poland and Finland [1] (#cite-text-0-0).

Residential buildings-segment consume majority of the energy end-use of buildings. In a year 2009, the share of households was 68 % of the total final energy used by buildings [1] (#cite-text-0-0). According to the various estimations, energy-efficient and cost effective refurbishment of the apartment buildings could result in 28 % energy saving potential in general. The most promising energy saving area locate in Eastern Europe where regionally even up to 39 % energy saving is reachable [3] (#cite-text-0-8).

High performance sustainable buildings are based on energy efficient technical solutions and reduced energy requirements. The less energy resources are consumed in construction phase and during the whole life-cycle, the higher performance levels are gained in building. The usage of recycled materials forms one essential part of the sustainability. From the point of view of owners and users, the economics of solutions provide best incentives for the reduction of the energy-use.

2.1 Requirements

Overview on some main directives regarding building energy efficiency and technology are presented. Technology related requirements are issued in more detailed under subsequent titles and by other work package of the SBHN-project.

()2.1.1 Main directives and national legislations

Kyoto Protocol regarding long-term climate strategy came into force in 2005 and clarified the climate agreement for United Nations. The Protocol, which was ratified by Parties and EU Community in 2002, is first juridical binding agreement to decline emissions internationally. Requirements are set to Parties to restrain the climate change. The first commitment period consisted years 2008-2012. The target was the reduction of GHG emissions on average by five percent from the level of 1990. The commitment covered 37 industrial countries and EU Member States. The second period for 2013-2020 is in progress, and the target is to decrease emissions by 18 % from the level of 1990. Finland, Sweden, Norway and Russia have achieved the set goals for the first period [4] (#cite-text-0-9).

Buildings constitute central role in reaching EU Climate and Energy objectives. The general goals include reduction of greenhouse gas emissions by 20 %, gain energy saving of 20 % and increase energy usage from renewable sources by 20 % until 2020.

EU-member states are committed to follow main energy efficiency directive for buildings called Energy Performance Building Directive 2002/91/EC (EBPD), which was recast in 2010. National level legislations have been set accordingly, and some countries have published additional, more ambitious goals for improvement of energy efficiency.

The aim of the EPBD is to enhance energy performance and reduce carbon dioxide emissions. Directive covers both new buildings and renovation of existing stock. Three main areas are presented: implementation of energy certificate, minimum requirement for energy performance, and periodic inspections of heating boilers and air conditioners.

Finland aims to achieve 38 % of renewable energy use until 2020 [5] (#cite-text-0-10). Several programs and projects are established to discover measures to achieve the goals. For example, one of the targets of ERA 17-programme is to increase knowledge regarding energy performance among various business sectors. Exploitation of the gathered information could be shared with other countries and it could be used to form as one export product.

Energy certificate

Before introduction of the EPBD, only few states had set requirements for inspections, certifications, renovation and training regarding energy-use of buildings. Instead, thermal insulations have been regulated in most of the countries before EPBD [1] (#cite-text-0-0).

Energy certificate (ECP) is based on the characters of the building and the related energy consumption. Certificate allows the easy comparison of buildings without the user influence. Energy efficiency-class is derived as the outcome of the calculated energy use, but also the actual energy consumption is published [6] (#cite-text-0-12). Total energy consumption (E-value) is calculated for new buildings. The purchased energy under standard use of building for the heated net area is multiplied with the coefficient given for each energy form. Coefficients are for electricity 1.7, district heating 0.7, district cooling 0.4, fossil fuels 1.0 and renewable energy fuels 0.5.

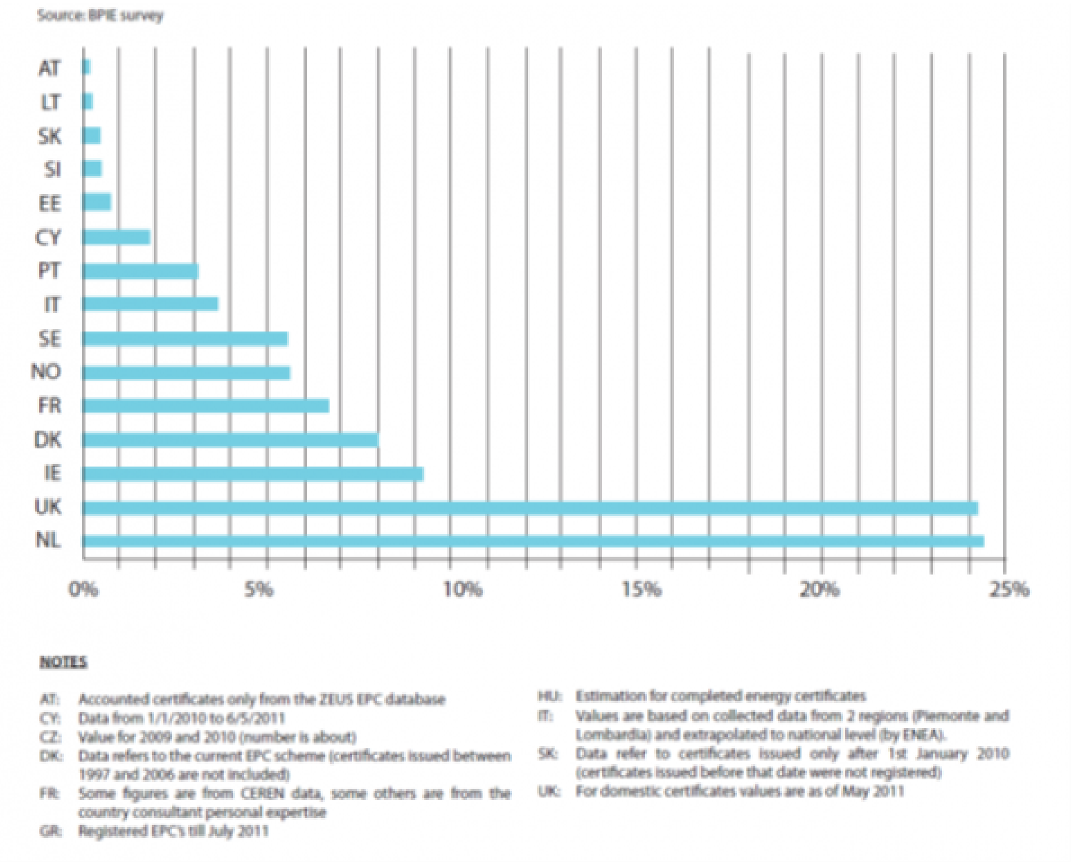


FIGURE 2-1. Proportion of dwellings that are registered with ECP [1] (#cite-text-0-0)

For new buildings values are not allowed to exceed the given limits in the category D3 of Finnish building code (Finnish Building Code). Member states have mostly implemented ECP in stages and mostly to new buildings. It is regarded as easiest measure due to other on-going processes and projects that aim also to develop approval system of new building stock. Larger energy saving can be gained when energy saving measures are identified to current building stock [1] (#cite-text-0-0). In 2011, after a few years of enact, above 90 % of dwelling were not certificated (Figure 2-1). In Netherland national energy certification system has been in operation since 1995 which have produced higher percentage of certified buildings.

2.2 Techniques

Building technology, whether associated to outer envelope or internal systems, is basic element in defining the energy consumption level of buildings. Simulation study, applying Ekorem model, indicated that buildings constructed in the period 1960-1980 and before 1920 have the highest levels of heat losses. Ventilation forms a large share of the heat loss for different building types. For example, in apartment buildings ventilation and windows induce 36 % and 33 % losses [7] (#cite-text-0-14). Slightly different estimates are obtained for detached houses. Windows deliver 33 % and ventilation 23 % of the heat. In attached buildings similar heat losses are accounted with different characteristics of ventilation, door, window, wall, rood and floor [7] (#cite-text-0-14).

Here some main building structures and technologies are discussed in present day building stock in Finland and elsewhere with emphasis on potential energy saving options.

()2.2.1 Envelope

Building envelopes experience all the typical seasons of the countries. Envelope, separator between indoor and outdoor climate, enable generation of desired conditions within buildings. It resembles energy filter that provides resistance for transfer of water, air, heat, noise and light between the two climates [8] (#cite-text-0-16). Especially three basic elements of the envelope; air- , thermal and vapor barrier structures, promote the formation of controlled indoor climate. The location of these elements may vary, for example unheated attic or basement may lack thermal components installed elsewhere in the building [9] (#cite-text-0-17).

Generally, envelope is formed of outer walls, roof, foundation, ceiling, windows, doors and related insulations. Performance of the outer shell is commonly measured by inspecting its durability, energy efficiency, provided physical protection toward weather and climate, and indoor air quality [10] (#cite-text-0-18). The air-tightness value of the building is used as major indicator of the goodness of outer shell. The volume of heated air that is escaping from internal part of building within hour at the pressure of 50 Pa indicates the tightness, or compatibility between outer construction elements at the junction points. The set requirement in Finnish National Building Code is 4 $m^3/(h*m^2)$. The better value must be indicated by the air pressure test. Air tightness below 0.6 $m^3/(h*m^2)$ is achievable which fulfills the criteria of passive houses. If the air tightness is weaker, the enhanced air flow through the leakage point can induce the moisture damages, bad indoor air quality, decay of structures and also lower energy performance levels (National Building Code D3). Therefore good air tightness enables efficient ventilation, sound insulation and fire security. Also heating energy need is reduced as well as risk for damages in the structures [10] (#cite-text-0-18).

In the Section C3 of Building Code of Finland reference and maximum values are given for the coefficients of heat passage for the shell of the building. The values are used for calculations of thermal losses through the shell (see Table 2-1 and 2-2). Along the years, energy performance of building structures have been improved by tightening the allowed U-values for building components.

TABLE 2-1. Reference coefficient values for warm, specially warm or cooled [11] (#cite-text-0-20)

Structure	W/m^2K
Wall	0,17

Logg wall (average minimum thickness 180 mm)	0,40
Roof and base floor contacting the outside air	0,09
Base floor reaching subfloor space (the number of ventilation holes is at most 8 per mill of the surface of subfloor)	0,17
Component of structure contacting the ground	0,16
Window, roof window, door	1,0

Generally, heat losses of the building are formed by the total outcome of the heat losses through the outer shell, leakage air and ventilation. The requirement set in section D3 of National Building Codes is achieved when the total heat loss indicated by the balancing calculation are at most the level of reference values [12] (#cite-text-0-21).

TABLE 2-2. The maximum values for coefficient of heat passage (U-value) [11] (#cite-text-0-20)

Structure	**W/m^2K**
Wall, roof, base floor	0,60
Window (warm space)	1,80

Air bridges

Gaps at the junction points between elements of a building envelope for example in corners, can induce significant energy losses. The most typical is the joint between window frames and surrounding wall. This has consequences on the air tightness level of building. Low air tightness levels indicate high energy consumption levels. On the other hand, really high air tightness value may enhance the risk of unhealthy condition for occupants in terms of poor indoor quality, especially if sufficient ventilation capacity is missing [10] (#cite-text-0-18).

In past construction techniques the level of detailing has often been weak which expose older buildings for higher air leakage levels. Here regional variations occur. In countries where long traditions prevail for energy regulations (e.g. Germany, Sweden) the level of air leakages in old buildings is less than in other countries (e.g. Bulgaria, Latvia). According to studies, in moderate climate the leakage in envelope can increase the yearly heating need 5 to 20 kWh/m^2 even when today´s levels of air leakages are used [1] (#cite-text-0-0).

Insulation

In European building stock more than 40 % of the buildings are built before 1960s. Lack or low level of sufficient thermal insulation characterizes those buildings that have not undergone major renovation or energy retrofit. Older buildings with low performance level and high U-values for exterior walls consume more energy and form significant share of the high energy consumption in building sector [1] (#cite-text-0-0).

Sufficient thermal insulation minimizes thermal transfers, heat losses and gains through the envelope across the year. Although the heating energy need is lower in countries with milder winters located in Southern Europe, the energy use can be relatively high partly due to lack of adequate thermal envelope insulation. These homes are often equipped with air-conditioners, and in Southern Europe cooling is the major contributor to the overall energy consumption [1] (#cite-text-0-0).

Improving the insulation of outer walls declines the energy losses significantly as walls constitute the largest share of the envelope. Additional insulation can be done for outer or inner walls. Outdoor-based insulation is reasonable to perform in liaison with renovation or replacement of outer shell. Formation of condensation point is avoided by the selection of appropriate insulation and weather boarding that has water vapor permeability characters in line with the old structures. The usage of breathable insulation material such as mineral wool and airing behind the outer boarding are one example of optimal solutions [13] (#cite-text-0-27).

Adding insulation from inside building is cost-effective during the replacement of interior lining or when fixing defective vapor or air barrier in the structure. Depending on the thickness of the moisture permeable insulation, new vapor barrier might be required in place of old barrier. Thin layers of insulation do not usually require the steam stop [13] (#cite-text-0-27).

Generally, changing the entire insulation is reasonable if buildings are insulated with sawdust. The thermal conductivity of sawdust is at least 50 % higher than in mineral wool. The replacement of old material with better insulating wool does not increase the thickness of the structure, but only the thermal insulation capacity almost two-fold. New steam stop is installed below the lining plate from the internal direction of outer walls.

In studies, the installation of additional insulation on outer walls brought on average 11.68 % energy saving in the studied 78 buildings [14] (#cite-text-0-29). In the other research, heating energy consumption was reduced in half of the outer wall-insulated apartment buildings, and was increased in the other half [15] (#cite-text-0-30).

Windows and doors

In detached houses windows can deliver 33 % of the heat [7] (#cite-text-0-14). Enhancing the sealing of windows and doors quantities of lost energy and draught are reduced which create positive effects also on living comfort. Sealing is evaluated to be one of the most cost-efficient measures in the improvement of energy efficiency [16] (#cite-text-0-32).

Due to decreased level of uncontrolled escape of heat and wind, room temperature can be lowered 1-3 Celsius degrees without influencing living comfort. Decline of room temperature with one degree reduces heating energy need by five percent. On average, saving of 8 % on heating energy consumption can be gained when windows and doors are sealed properly. Especially in old buildings adjustments on ventilation systems might be required after sealing because air flow through the gaps and via other envelope structures are prevented and can induce low indoor air quality, in case readjustment of ventilation is missing [16] (#cite-text-0-32).

The focus on air tightness of replaced windows and doors during the refurbishment of façade are needed to ensure energy efficiency. As in the case of sealing, the properly operating air ventilation must be taken into account. The heating technological features and permeability for solar radiation (G-value) are central properties of windows which effect room temperature particularly in summer time.

Research inspecting replacement or deep renovation of windows to the energy saving level indicated that in 40 residential apartment houses energy consumption was reduced on average 6.2 %, from average value 52.5 kWh/m^3 to 49.2 kWh/m^3. In these buildings, two double glazing were updated to energy saving glasses with triple glazing characterized by U-value of 1.1-1.2 W/m^2K. Also the water consumption was reduced by 6 % [17] (#cite-text-0-34). Differences in costs are influenced by the desired properties such as U- and G-values, and the material of frames. Also occupancy status of dwelling and working position have an effect; whether work is operated outside or inside the dwelling determine the price [18] (#cite-text-0-35).

()2.2.2 Heating

Heating is produced by various ways in residential buildings. Electricity is the main heating energy carrier for detached houses in North, and district heating in block of flats especially in Sweden, Finland and Russia [1] (#cite-text-0-0). Other heating systems are based on the usage of gas, coal, oil, renewable energy sources such as wood combustion, wind, solar and geothermal energy. In buildings constructed 1960-1970 the district heating system is approaching the end of the lifecycle and requires refurbishment or replacement. The change of heating form may be considered if savings are gained with new system. Also additional heating sources can be adopted, such as solar panels or heating recovery systems to complement district heating [19] (#cite-text-0-37).

Heat and hot water are provided by district heating systems to almost all urban populations and industry in Russia [20] (#cite-text-0-38). Inadequate maintenance and low investment made in 1990's have been reflected as lower level of reliability of supply. Reduction of losses by improved energy efficiency measures and enhanced efficiency of heating plants could aid in achieving significant energy savings. According to IEA data and Russian energy experts, approximately 3 % and 20-30 % of the generated heat is lost in transmission and distribution processes. Major repair of replacement is needed for roughly 60 % of the district-heating network [20] (#cite-text-0-38). Poor insulation around heat pipes causes large heat losses. Flow is not controlled or measured in transmission/distribution lines in most heating networks, and uneven distribution lead to situation of overheating buildings in upstream and under-heating others in downstream [20] (#cite-text-0-38). Heat limitations set to certain radiator restricts the stream to other radiators of the same building, caused by system design. Meters were not used for residential and commercial customers and the charging based on equation including floor space is paid as part of the rent. Industrial use is charged based on the heat consumed and higher tariff is set for the use exceeding amounts defined in the supply contract [21] (#cite-text-0-41) [22] (#cite-text-0-42).

With the improvements on air tightness and energy efficiency the heating need is decreased but simultaneously cooling need is increased in buildings especially in summer time [23] (#cite-text-0-43). Passive cooling methods include awning blinds, eaves, shades installed outdoor and with curtains and blind shades from the inner-side of the windows. Also, sun protection glazing and thin films for the outer glasses can be used [10] (#cite-text-0-18).

Space and water heating/cooling can be provided by heat pumps. In reversible systems heating and cooling can be alternated, and in hybrid systems they occur simultaneously. Chillers, simple or reversible air conditioners are examples where heat pumps form prevailing technology [24] (#cite-text-0-45). They extract renewable energy from the surrounding phase, e.g. ambient air, water or ground, and with the provided energy (electricity or gas) the temperature is adjusted to higher or lower level depending on the heating or cooling needs [24] (#cite-text-0-45). The technology is highly efficient and aid in producing carbon savings. The ability to transfer primary energy to desired temperature is dependent on the used electricity production.

In residential sector standard technologies for air conditioning are air-to-air central, split and room air conditioners. These are available in reversible form; heating and cooling can be alternated. Air-to-water-heat pumps, or air source heat pumps (ASHP) operate until – 25 degrees without need to install expensive ground or water loops. Water-to-water and water-to-air heat pumps are often more efficient than ASHP. Heat is extracted from or absorbed to available water source. Ground-source heat pumps (GSHP) have higher efficiencies than ASHP in cold climate. There brine-to-water or brine-to-air heat pumps are coupled with heat exchanger loop located underground.

Although the technology is mature and heat pumps have been available for decades, the current proportion of the world-wide heating market is small. In residential sector, approximately 800 million heat pumps were installed in 2010 [24] (#cite-text-0-45).

Ekonor-heating guarder is one example of the advanced technology that recognizes the real temperature within the apartment. It adjusts the incoming district heat according to real indoor temperature instead of outdoor temperature, such as traditional methods operate.

In an example case Housing Corporation that owned two residential apartment buildings built in 1975 changed the district heating system to geothermal heat. After installation, the heating energy saving was 20 000 € during the first year, resulting payback time of 13 years with front-end investment of 225 000 € [25] (#cite-text-0-48).

In the other example the energy cost was reduced to one fourth of the original value after the replacement of oil heating system with geothermal heat, giving payback time ten years or less depending on the growing development of oil price. Also heating cost saving of 80 000 € per year has been reported for apartment houses along the adoption of geothermal heat [26] (#cite-text-0-49).

()2.2.3 Ventilation

In the design phase of the building project the appropriate air flow volumes are scaled to meet requirements. Information regarding the purpose of the facilities and number of becoming users are required already in planning phase to enable scaling the ventilation so that healthy, safe and comfortable indoor air quality are met. Adequate quantity of air ventilation is dependent on the sources of impurities, e.g. number of humans. Measurement can be done by using monitoring elements in the channels or the component included in the air supply unit. Also building automation can be utilized in inspecting air flows.

When energy efficiency of existing building stock is aimed to improve, the indoor air quality and envelope structures with suitable moisture and technical performance must be sustained [10] (#cite-text-0-18). Air ventilation must be accommodated according to air tightness level of building. If machinery air ventilation without heat recovery is installed in building with low airtightness, energy saving potential is lost and no major improvements occur on the indoor air quality. Replacement of natural ventilation by machinery ventilation often require the installation of new ventilation system on the place of old exhaust air duct.

Under-pressure must be maintained in the building. This can be induced by 10-30 % slower flow of incoming air in comparison to exhaust air circulated by ventilation [13] (#cite-text-0-27). The basic adjustment of ventilation ensures that it operates according to guidelines. Improvement can be performed also with the existing technology. Roof-installed extractor is the most common solution in residential buildings of 1970's and 1980's. In older buildings natural ventilation prevails.

In block of flats also apartment-specific incoming and exhaust air ventilation system equipped with heat recovery can be installed. In this case incoming and exhaust air flow must be adjusted equally high to prevent back flow from ducts of other natural ventilation systems. Incoming air is derived from the wall of building via particular pipe. Planar heat recovery system can be installed if incoming and exhaust air machines are positioned in the same place. In case they locate in different spaces, water-glycol-based system is more suitable option. Exhaust air heating pump removes the heat form the exhaust air with special vapor or solvent-based battery. The collected energy can be used for heating the incoming air or -service water, or be utilized in heating network. The equipment can be used also for cooling purposes in summer time [13] (#cite-text-0-27).

According to estimates, total value over 20 GWh/a heat energy saving in apartment buildings could be gained by heat recovery. For attached and detached houses around 3-5 GWh/a saving could be reached. Heat recovery is one of the most powerful methods to decrease the heat loss from ventilation, but is used at relatively low percentage in all the building types [7] (#cite-text-0-14). Heat pumps are available in various forms; e.g. geothermal-, air-, water based.

In EPBD, inspection schemes were required for heating boilers and/or air conditioning systems. Variation appears between countries in implementation and overall data is still rather scarce.

In an example case heat recovery system for exhaust air was installed in seven-floored and 35 dwelling consisting apartment building constructed in 1969. Before the installation, the quantity of purchasable heating energy was 338 500 kWh and after operation 190 330 kWh per year. By heat recovery system the amount of purchased heating energy decreased by 43 % and the investment payback time was eight years. Subsidies are granted for the 15 % of the total costs [27] (#cite-text-0-54).

Heating recovery system was installed into the other residential building of 60 apartments, constructed in 1971. Heating energy consumption decreased by 37 % in one year which produced savings of 17 000 € [28] (#cite-text-0-55).

()2.2.4 Lighting

Along the tightening of the energy-related Directives and national level regulations to achieve desired energy savings until 2020 and 2035, lighting sector forms one of the most potential target to reduce energy consumption. Although municipal parties have responsible to operate as leading examples in renewing the lighting technology, also significant savings can be derived from residential sector.

Lighting sector consumes approximately one fifth of the total amount of generated electricity. Worldwide, this exceeds the production of hydro or nuclear power plants (Lighting). One third of the lighting electricity, 811 TWh, is associated to residential sector in 2005. [29] (#cite-text-0-56)

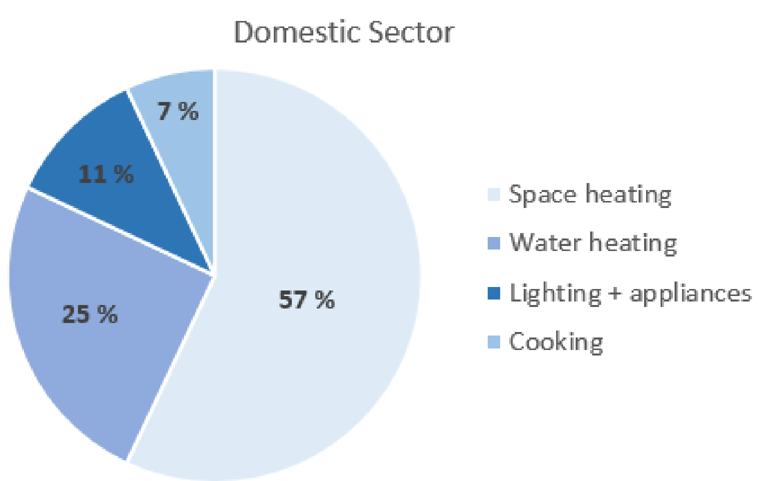


FIGURE 2-2. Energy consumption in European residential sector [30] (#cite-text-0-57)

Generally in EU lighting is the second largest energy end-user after space and water heating. Roughly 11 % of the energy is consumed for lighting in residential sector (Figure 2-2). This corresponds to 18.3 % of residential electricity consumption. The share of lighting of total electricity consumption varies from 6 % to 18 % in residential buildings among EU-15 Member States [30] (#cite-text-0-57). In developing countries the share is much higher. For example in Tanzania the proportion of lighting electricity out of total electricity consumption is 85 % [31] (#cite-text-0-59). In non-IEA countries increasing rates of lighting electricity are consumed, and the trend is expected to continue in becoming years. Per capita consumption of electric light varies in different regions of the world (Figure 2-3).

The household energy consumption for lighting ranges largely. Lighting consumed 77 TWh of electricity in the EU-15 states and 13.6 TWh in ten new member states [32] (#cite-text-0-60). In Germany is the lowest annual consumption of lighting electricity with 310 kWh per household. The highest consumption is in Malta with 1172 kWh. Average value for European household is 561 kWh [29] (#cite-text-0-56) and US household 1946 kWh [33] (#cite-text-0-62). In Russia and other non-OECD countries lighting energy consumption is lower than in OECD member countries. The average for Russian household is 394 kWh and Chinese 181 kWh [29] (#cite-text-0-56). Increase in the lighting energy usage is expected to occur in Russia due to rising income of households.

At the building level, the annual lighting energy consumption per square meter ranges between 20 and 50 kWh/m² [34] (#cite-text-0-64) [30] (#cite-text-0-57).

Electricity consumption of lighting is aimed to be reduced annually below 10 kWh/m². Besides of utilizations of daylight, alternative manners to reduce lighting associated electricity include the lowest possible level of power density, utilization of light sources with high luminous efficacy, the introductions of lighting control systems [30] (#cite-text-0-57). However, in upgrading and reducing the installed power for lighting the quality of light must remain the same.

In many European countries, electric lighting is one of the main factors in inducing peak electricity demand. It is evaluated that the quantity of lamps in households will be increasing, quality of lighting will be improved and the number of fluorescent lamps are growing [35] (#cite-text-0-67).

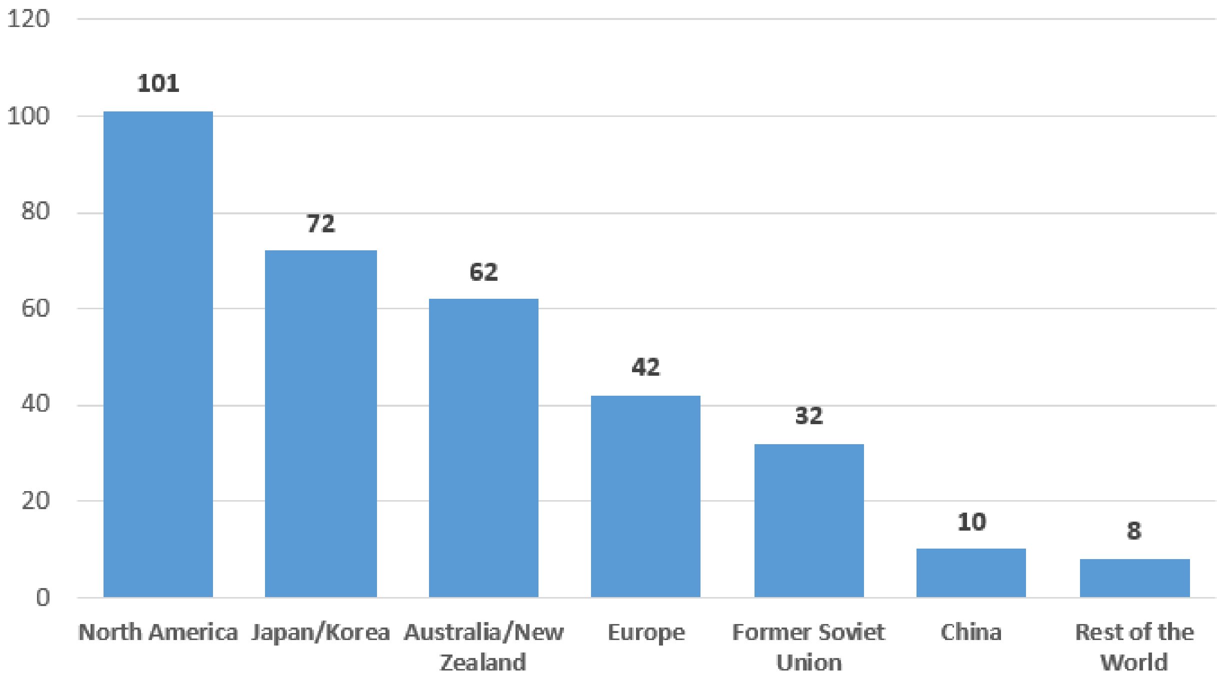


FIGURE 2-3. Per capita consumption of electric light according to estimations in 2005 (units are Mlm/h) [29] (#cite-text-0-56)

In IEA countries majority of residential lighting is conveyed by inefficient incandescent lamps. Compact fluorescent lamps (CFL) and Lighting Emission Diode (LED) - lamps are gradually increasing their share. In US residential buildings incandescent lamps comprise 86 % of the used 4.6 billion lamps. Still total lumen output was only 69 % because of the weak luminous efficiency although these lamps accounted for 90 % of the total lighting electricity consumption [33] (#cite-text-0-62). In Japan fluorescent lamps prevail in residential sector with 65 % proportion. In Russia 98 % of the lamps are incandescent lamps in residential sector [29] (#cite-text-0-56) [30] (#cite-text-0-57).

EcoDesign Directive aims to confirm ecological design of energy using equipment and imposes that light bulbs are excluded from the market at the latest 2012, import of mercury lamps into the market is prohibited since 2015 and connection devices must be included in new fluorescent lighting systems since 2017. Due to rapid evolvement of LED lamps, the Directive can be updated in 2015 [36] (#cite-text-0-72).

Indoor lighting is regarded to have largest technical energy saving potential among energy efficiency of electrical appliances in Finland [35] (#cite-text-0-67). Energy saving potential was estimated across years 2006, 2015 and 2020 when electricity consumption was evaluated with the approaches as Business As Usual (BAU) and Best Available Technique (BAT) (see Table 2-3). In BAU the prevailing lamp stock is mainly formed of incandescent lamps that are changed to fluorescent lamps after termination of the lifecycle. In BAT all incandescent lamps are replaced by fluorescent lamps and since 2015 LED lamps are partially adopted. More than half of the energy saving potential becomes from indoor lighting sector in 2015 and 2020. The results of the scenarios can carefully be generalized also to other countries.

TABLE 2-3. Electricity consumption in residential sector in 2006, and technical energy saving potentials estimates for years 2015 and 2020 [37] (#cite-text-0-74) [35] (#cite-text-0-67)

		BAU	BAT	BAU	BAT	Saving potential	
	2006	2015	2015	2020	2020	2015	2020
	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Refregeration appliances	1 627	1 405	1 028	1 227	767	377	459
Cooking	653	683	618	693	577	65	116
Dishwasher	261	288	266	290	268	22	22

Entertainment electronics	834	1 177	888	1 076	860	289	215
Computer appliances	408	323	121	240	87	202	153
Sauna heater	852	930	930	971	971	0	0
HPAS-appliances	669	741	545	809	566	196	243
Under floor heating	206	221	221	227	227	0	0
Car heating	218	221	221	225	225	0	0
Indoor lighting	2 427	2 233	843	2 002	845	1 389	1 157
Outdoor lighting	89	95	21	99	22	75	77
Others	2 572	2 600	2 600	2 650	2 650	0	0
Total	**11 207**	**11 336**	**8 657**	**10 931**	**8 412**	**2 669**	**2 519**

Depending on the building, energy saving of 30-70 % can be reached by renewal of the old lighting technology, implementing modern control system and by specifying lighting targets [36] (#cite-text-0-72).

Usage of lights only when needed by using automatic control systems is among the most important manners to reduce energy consumption. Otherwise energy consumption depends on lamps, lighting, placing of lighting, connection devices and users themselves [36] (#cite-text-0-72).

The amount of light produced from a light source is decreasing along the aging. Lumen maintenances can be calculated for luminaires after certain amount of usage hours. Lumens of brand new light are compared to lumens produced by light source usage hours, e.g. 30 000 hours. For example lumen maintenance L70 indicates that of the output lighting 70 % of the lumens are maintained [13] (#cite-text-0-27). Differences are observed in the lumen maintenance of light sources, for example between incandescent and LED lamps. By replacing lamps according to maintenance plan drafted by lighting designer, adequate illumination level can be maintained and electricity bill reduced [36] (#cite-text-0-72).

()2.3 Concepts

By renovation concepts costs can be reduced, less time used and quality better inspected. Prefabricated wall elements have controlled quality, lower price as result of mass production and can be installed easily. For example, the concept for advanced renovation of envelope is developed by company Profin. In their product called "Five in One-system" the entire wall can be renovated at once in short time, e.g. within one day. The measure allows simultaneous occupancy of residents. In Germany various renovation concepts have been exploited in several regions, such as in Berlin where 90 % of dwellings locate in multi-family houses.

()2.4 Challenges

Household owners might not consider renovation as option to reduce energy costs if the payback times are long. Also migration influence on the implementation; if house is going to be changed within the next few years critical point may be reached for upgrading the energy efficiency levels.

Often, lack of awareness regarding the life cycle costs of advanced renovation and the immediate positive consequences in the form of cheaper energy bills, better security of energy and protection against increasing energy prices are missing information for majority of estate owners [1] (#cite-text-0-0). According to studies, two-stage renovation provides most energy-efficient and economic option among residential apartment buildings [1] (#cite-text-0-0) [22] (#cite-text-0-42). This reduces the initial investment costs for the owners of buildings.

Although some front-end investments have to be made, the overall maintenance costs of energy efficient house are much less than that in ordinary house [6] (#cite-text-0-12).

Improvement of energy efficiency often induces problems from the point of view of structural physics. For example, when insulation is enhanced, the heat passage through the structures is reduced thus causing the cooling of outer shell. This induces the weakening of moisture-technical function of the shell. In this condition even the small building technical errors can induce the growth of mold and risk for moisture-related damages [38] (#cite-text-0-84).

Holistic perspective on the compatibility of renovated parts and existing building technology are required from the professional conducting the upgrades. Comprehension on interaction between heating systems, envelope characteristics and ventilation are needed in providing high energy performance buildings with high indoor environment quality. For example, adjustments of the heating and air-conditioner systems might be required after improving the insulations and air tightness. Concepts that are adequately examined and experienced in practice are expected to increase among residential building in the near future.

Increase in the need for cooling is due to better insulation especially in summer time. Significance of ventilation is highlighted as the shell becomes more air tight. Harmful air pressure and –flow differences over the structures should be avoided as they can carry moisture on the shell and bring microbes and other foreign matters into the indoor air.

In Europe, current average renovation rate of existing building stock is rather low, only 1 % [1] (#cite-text-0-0) [39] (#cite-text-0-86). Regional variations can occur within states and also between country differences exist. In order to achieve set energy- and carbon dioxide saving goals via enhanced energy efficiency of buildings until 2020, more financial incentives and information sharing campaigns are required.

3 Non-residential buildings

Non-residential buildings constitute 25 % of the building stock in Europe [1] (#cite-text-0-0). According to estimates, in 2030 approximately 60 % of the floor area locates in commercial buildings constructed in 2008 or earlier [40] (#cite-text-0-88). At that time, the highest energy and carbon saving potential is gained by retrofitting and renovating the existing building [41] (#cite-text-0-89).

Non-residential building sector is even more complex and heterogeneous than residential. Diversity in form of building typologies is high (e.g. shops, schools, offices, hospitals, hotels, supermarkets, universities, sport centers and restaurants) and additional complexity is brought by between country differences.

In Europe the largest portion, 27 %, of the non-residential building stock is formed of wholesale and retail buildings with 28 % (Figure 3-1). Usually these building types have large floor areas and often spaces are used for storing. Differences between wholesale and retail and other categories are expected regarding cooling and heating conditions. In this sector, homogeneity is missing when sizes, usage patterns and construction styles are considered [1] (#cite-text-0-0).

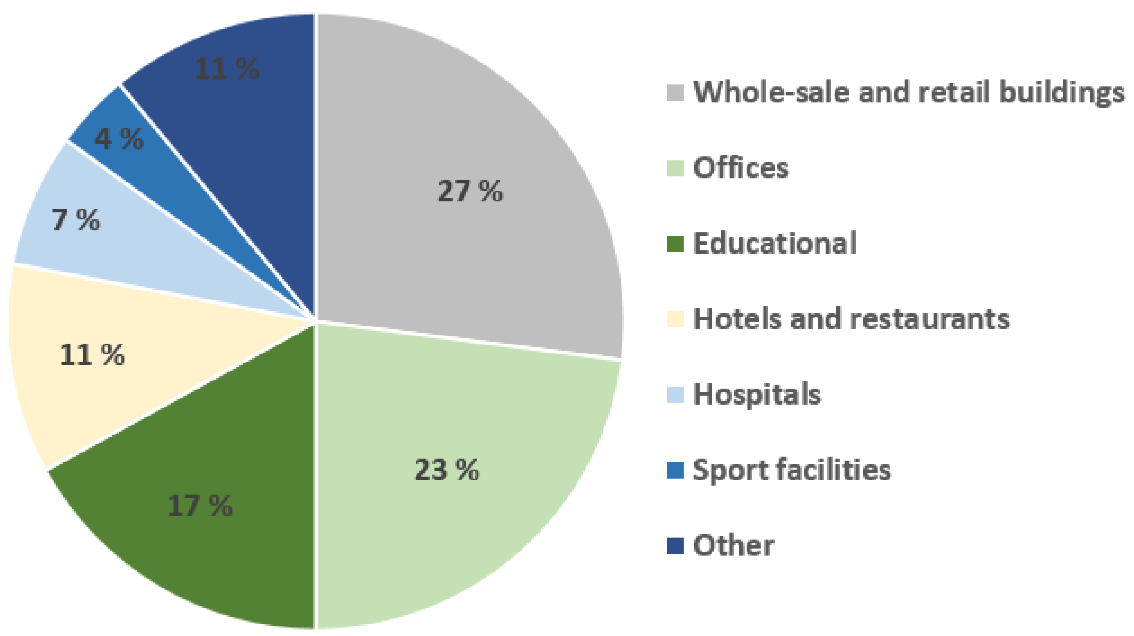


FIGURE 3- 1. The proportions of non-residential building types as units in Europe [1] (#cite-text-0-0)

Office buildings, as second largest category, form one quarter of the non-residential floor area. Similarities to residential buildings are observed in heating and cooling systems, although the use-times are shorter in offices. Educational buildings, which account for 17 % of commercial building stock, resemble office buildings from this aspect (Figure 3-1 [1] (#cite-text-0-0)).

Oppositely, the usage pattern for building technology is continuous in hospitals and can alter in respect to energy demand. For example consultation rooms have different energy need than surgery room regarding the need for cooling, ventilation, lighting, air conditioner etc.

Proportion of building category "Other" is rather large in many EU countries and reflects further need to disperse floor area to other categories (Figure 3-2 [1] (#cite-text-0-0)).

FIGURE 3-2. Division of non-residential floor space in European countries [1] (#cite-text-0-0)

Average specific energy consumption 280 kWh/m² is 40 % bigger than in residential buildings. Between country and -building type difference can be extensive [1] (#cite-text-0-0). For example hospitals use rather low proportion of overall non-residential energy consumption although they are continuously occupied and represent high-energy intensities. Instead, office, retail trade and wholesale buildings consume more than half of the energy used by non-residential sector (see Figure 3-3).

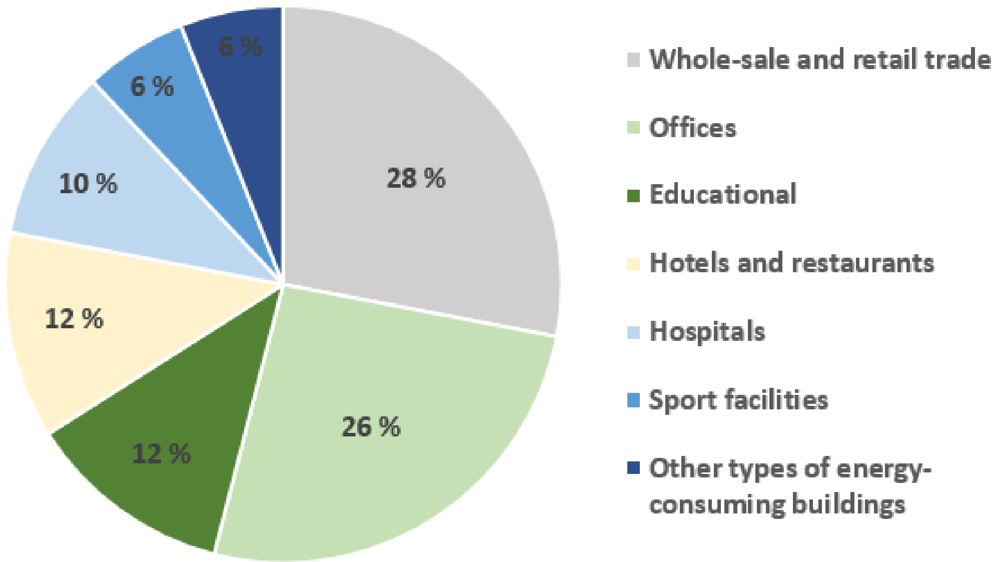


FIGURE 3-3. Proportion of total energy use per building type [1] (#cite-text-0-0)

3.1 Requirements

In becoming decades the better energy efficiency will be required in existing commercial buildings [42] (#cite-text-0-97). The main directive guiding the building energy use is Energy Performance of Buildings Directive (EPBD) which aims to reach overall view of building energy use including requirements also for technical systems. Therefore shift from maximum permitted U-values to more holistic perception change also the approach for classifying building codes. In following, some major energy saving directives in EU are presented.

()3.1.1 Directives and national legislation

Energy saving potential in European buildings is guided by some main directives; Energy Performance of Buildings Directive 2010/31/EU (EPBD, recast of 2002/91/EC), Eco-design Directive of the Energy-Related Products Framework Directive 09/125/EC, The End-use Energy Efficiency and Energy Services Directive 32/2006/EC, and The Labelling Framework Directive 2010/30/EU (recast of 75/1992/EC). The same directives are in large extent applicable both residential and commercial sector.

According to Energy Efficiency Plan and EPBD, renovation rate of 3 % is recommended and new buildings should be of nearly-zero energy level until 2018 [1] (#cite-text-0-0). Public buildings are used as leading examples in the improvement of energy performance. Energy performance certifications of non-residential buildings are estimated against population sizes in each country (Figure 3-4).

In EPBP minimum standards are given for energy performance of new buildings and for the ones undergoing major renovation. Framework for methodology is given to calculate integrated energy performance and energy certification for new and existing buildings. Minimum energy efficiency requirements are given for each building type. Inspection of boilers and air conditioning systems became obligatory. Nearly Zero Energy Buildings (nZEB) requirements directed to newly constructed buildings restrict the energy use on nearly zero energy level and the used energy must be to a large extent from renewable sources. National plan is required for implementation of nZEB. Cost-optimal levels of building energy efficiency are achieved by using comparative methodology framework in calculations.

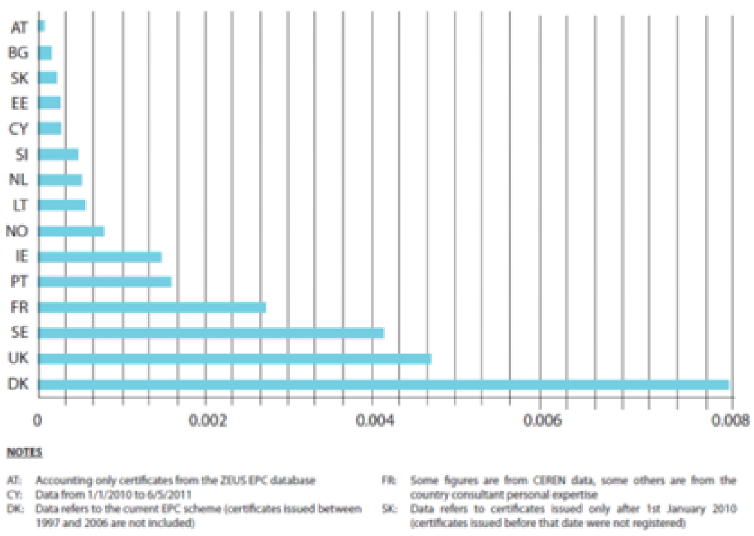


FIGURE 3-4. Registered energy performance certificates for non-residential buildings [1] (#cite-text-0-0). Denmark, UK and Sweden and France have the highest share of certified non-residential buildings.

()3.1.2 Requirements for different building elements

Element-based requirements (e.g. maximum U-values, minimum/maximum indoor temperature, requirements for minimum ventilation rates) related to building energy codes may vary different countries.

In general, rather similar performance characters (e.g. U-value, air tightness) are observed for non-residential buildings than for residential buildings built during the same period. Hence also same renovation concepts are applicable.

3.2 Techniques

Energy end-use within non-residential building sector varies largely between building categories. Lighting, heating, cooling, refrigeration, ventilation, appliances and IT-equipment are typical end-users of energy. During the past 20 years electricity consumption has increased 74 % in non-residential sector. This is associated to advances in technical development. For example, air conditioning system and IT equipment have become more popular and are generating continuously growing electricity demand [1] (#cite-text-0-0).

Due to enhanced electricity use of the sector, more weight will be given for implementation of smart energy management network [1] (#cite-text-0-0). For example, office lighting is among the highest end-use in non-residential sector. In 2007 it was estimated to be 164 TWh in enlarged EU region [32] (#cite-text-0-60). Efficient automated lighting control systems and replacement of old incandescent lamps by CFLs have substantial potential to produce adequate annual energy savings to reach targets set until 2020 [1] (#cite-text-0-0).

()3.2.1 Envelope

The roofs, walls, foundations and windows are not considered to have large proportion in providing energy savings in non-residential buildings. For example, window films were estimated to have minor cost-effective value. The replacement of single-glazed window to high performance glass gave energy saving potential approximately 2 percent of the total potential for the researched commercial building stock [42] (#cite-text-0-97).

()3.2.2 HVAC equipment

Heating, ventilation and air-conditioning systems are often discussed simultaneously. Generally, heating accounts for 70 % of the final energy use in buildings.

Heat pumps

Basic technologies for heat pumps correspond to the equipment in residential sector. Often implementation is performed on larger scale. Essential issue is the integrated design of the building envelope and the HVAC system. In temperate climate, small offices usually utilize reversible-air-to-air systems. Large commercial buildings use ground-source heat pumps together with thermal storage technologies to heating and cooling purposes [24] (#cite-text-0-45).

In service sector, buildings usually utilize cooling technologies such as packaged air conditioners, chillers, thermally driven adsorption or absorption chiller or desiccant dehumidification. In *packaged air conditioners* all parts such as heat exchanger, compressor, evaporator and condenser can be included in one cabinet which is placed on the roof. *Chillers* produce cooled water that chills the air in the building. Adsorption- or absorption chillers may use fossil fuels, solar thermal or waste energy. The efficiency is lower than in electrically driven heat pump. *Desiccant dehumidification* technology is based on the removal of moisture from the outdoor air with the usage of moisture-holding, desiccant, material in air conditioner before it enters a conventional air conditioner systems and conditioned space. The efficiency of heat pumps has been improving, for example commonly used measure coefficient of performance (COP) has grown to the level of 6-7 for best air conditioners. Although COPs are not directly comparable between countries due to different climates, technical specifications and test procedures, the increase in efficiency has been observed in many countries [24] (#cite-text-0-45). This is also due to better performed system integration and improvements in individual components.

Thermal energy storage

Thermal energy storage systems can hold cold or heat for relatively long times, from days to several weeks. In building sector, the major reasons to use thermal energy storages relate to improvement of system efficiency, demand shifting to reduce peak loads and enhanced use of renewable energy [24] (#cite-text-0-45). Along the increased use of various renewable energy sources in electricity production, need for energy storage, peak load reduction and flexible systems are expected to be increased. For example, larger solar systems are enabled when surplus heat can be stored for the usage during colder season [24] (#cite-text-0-45).

Thermal energy storage technologies are mainly based on sensible heat storage, latent heat storage and thermo-chemical storage. First two are classified as mature technologies. In sensible heat storage technology storage medium is heated or cooled, which leaves relatively low energy density. Latent heat technology is based on the phase change of the substance and the associated energy release. Energy density is 5 to 15 times higher than in sensible storages. New application possibilities are generated by the advanced phase change materials (PCM) that can be embedded in building material, for example wall boards, brick or flooring. These are especially appropriate in cooling where relatively low temperature differences are required for energy release. Thermo-chemical storage is utilizing reversible chemical reactions in storing energy and can reach up to 20-fold higher energy densities than sensible heat storage [24] (#cite-text-0-45).

Regarding thermal energy storage technologies, costs of many high-density storage applications in buildings are still rather expensive. Among the focuses of becoming research and development projects are methods to bring prices to more user-friendly level.

()3.2.3 Lighting

Lighting forms one of the single largest electricity end-users in non-residential building sector. EIA member countries and service sector use approximately half of the world´s lighting electricity. According to estimates, totally 1133 TWh of electricity was consumed by commercial lighting in 2005. Industrial sector consumes 16 %, street and other lighting 8 % of this lighting electricity.

In commercial buildings; warehouses, retails, offices and educational buildings, hotels, healthcare, the share of lighting is 30 % of the total electricity consumption.

In office buildings, lighting forms half of the electricity consumption, and 30-40 % of the total energy consumption. The corresponding electricity shares for lighting are 20-30 % in hospitals, 15 % in industries and 10-15 % at schools [13] (#cite-text-0-27).

Due to occupancy level differences, large annual variation can occur between commercial buildings regarding lighting energy consumption. For example, in health care buildings, the average lighting electricity consumption is high due to long operating periods [13] (#cite-text-0-27). In addition to efficiency and above mentioned length of operating period also lighting practices such as lighting levels provided, have effect on lighting energy consumption per unit area. Generally in European, Japanese and Australian commercial building, operating hours are shorter than in North America (13.5 hours). In 2001, average lighting energy consumption in US commercial buildings was 60.9 kWh/m² [13] (#cite-text-0-27), in Canada 80.2 kWh/m² in 2003 [29] (#cite-text-0-56) and in non-OECD country 24.1 kWh/m² in 2005 [29] (#cite-text-0-56) [13] (#cite-text-0-27).

In 2005 fluorescent lamps, and especially linear fluorescent lamps (LFL), delivered most or 77 % of the light in commercial buildings in OECD countries. Open spaces for shopping or work and implementation of various energy efficiency programs has enhanced the use of the lamp type (Lighting). The rest 23 % consist compact fluorescent, candescent and HID lamps [29] (#cite-text-0-56).

Also in European office buildings fluorescent lamps (LFL) are majority. However, between country differences are observed. For example, in Germany LFL dominate the offices whereas in Spain large numbers other than fluorescent lamps prevail [43] (#cite-text-0-117).

The share of lighting electricity out of the total electricity consumption in industrial sector varies also between countries. For example, value is 7.6 % in Australia and 13.9 % in Russia [29] (#cite-text-0-56). Generally, lighting energy consumption per unit ranges from 37 to 107 kWh/m² between industrial buildings. In US industrial sector fluorescent and HID lamps provide 67 % and 31 % of the lighting energy and only 2 % is due to incandescent lamps. In OECD countries, fluorescent lamps account for 62 %, High Intensive Discharge (HIDs) for 37 % and others 1 % of industrial illumination [29] (#cite-text-0-56). In Russian industrial buildings lighting is in large extent (56.3 %) provided by HID lamps. The share of LFL lamps is 36.5 %. Average source-lumen efficacy is 61 lm/W in Russian industrial lighting sector while corresponding values are 81.9 and 80.4 lm/W for Europe and America [29] (#cite-text-0-56).

In lighting systems, part of the input electrical energy is released as heat energy. Also room surfaces are adsorbing or absorbing the visible radiation and portion is reflected. Therefore, heat produced by lighting is indirectly associated to further consumption of energy for cooling and heating purposes. Changes in lighting energy use can be seen as alteration in energy requirements of the indoor space. Also local climatic conditions, building characteristics and operating conditions influence on the energy demand. In winter time the reduced heating load may be required in regions of cold climate due to lighting released heat [13] (#cite-text-0-27).

Large savings can be gained in heating or cooling energy consumption by reducing lighting energy levels in commercial buildings, such as hospitals, hotels and offices. Oppositely savings were more minor in schools and warehouses due to lower level of lighting energy use [44] (#cite-text-0-122).

Lighting in commercial sector has important influence on the formation of peak in the electricity demand as it coincidences with the usage of other electrical systems. By improving energy efficiency of lighting peak demands could be flattened as it has indirect influences on the air-conditioning loads [13] (#cite-text-0-27).

()3.2.4 Automatic control and intelligent electricity network

Installation of automated controls and sensors along with building commissioning provide additional potential to lower energy consumption in commercial buildings. Possibly with the usage of automation, additional 5 % to 20 % technical energy saving potential could be achieved [42] (#cite-text-0-97).

In non-residential buildings the share of smart energy management systems is expected to increase as the sector is using high share of the electricity. For example efficient lighting control system for office lighting, which is highest end-user in the sector with 164 TWh in European countries in 2007, has substantial potential for energy saving. As single stand-alone measure, by replacing incandescent lamps with fluorescent lamps in offices and street lighting is estimated to have energy saving potential of 38 TWh per year until 2020 [1] (#cite-text-0-0).

The advantages are significant and vast that are derived by utilizing building technology in producing energy efficiency. Building technology automation is related to almost all subsystems of building technology and ensure energy efficiency while in use [45] (#cite-text-0-126).

Many of the faults causing complications can be repaired by adjusting the amount of air, by replacing thermostats and valves in radiator system, and balancing the radiator network. The costs are minor when problem can be solved by adjusting a single value in building automation system. In more complex cases e.g. when quantity of users, purpose of use have changed, lifecycle is reaching the end or the air quality is weak, single setting renewals might not be adequate. Larger scale maintenance, for example replacement of air ventilation machines or changing channeling increase the costs. When making modifications to facilities, the building technology requirement should be taken into account to check the influences of changes on indoor climate. Essential stages are problem identification by recognizing the deviation in desired conditions or energy consumption, mapping reasons by inspecting the function of building technology systems, plan for removal of the problems and studying the role of building technology in generating the problems.

Generally, the current practice in arranging property maintenance is too focused on maintaining the sole technical system rather than investigating conditions that are produced by these systems [46] (#cite-text-0-127). Single device or technological system can be fully functional but the influence of their operation to indoor climate or co-operation to other systems are not recognized and researched. For example, temperature of incoming air in supply air unit can be within the set values, still the uncertainty exist whether desired temperature is correct in proportion to facility conditions and the operation of heating system. Therefore expertise, knowledge and resources are required to discover real sources of problems and in performing necessary repairs [46] (#cite-text-0-127).

Building or equipment can be used either energy saving or wasting manner. In energy inspections often large scale energy and cost reductions can be reached by adjustment of equipment and systems to prevent also becoming damages. This may indicate the lack of interest by real estate managers and owners to focus on reducing energy costs, or lack of competence among occupational group [45] (#cite-text-0-126). Adjustments can be done for heating systems, e.g. district heating network, boiler rooms, oil pans and ventilation systems.

Facile monitoring of conditions promote the performance of regular inspections in large buildings. For example, implementation of condition measuring units to building automation system at construction stage is relatively easily and of low cost. The easy follow-up of indoor climate conditions by maintenance personnel allow discovering deviations and the underlying reasons. Essential is the preset reference values to which measured conditions can be compared. As a rule of thumb, if desired indoor climate is reached with the allowed energy consumption, systems are operating in a desired manner. Whether deviation appear, the reasons behind should be investigated.

In public buildings the most energy is consumed by outmoded heating equipment and ventilation systems. For example adjustment of water flow in taps and setting of decompression valves bring savings. Although estates form large portion of the municipally owned building stock, they are often maintained from the perspective of repairing occurring problem rather than controlling and preventing the rise of troubles.

Among the most essential non-energy related advantages of re-commissioning is improved air quality. The sensation of comfort is affected by the indoor environment temperature. The quantity of ventilation is linked to concentration of impurities in the air, which in worst case induce sick house syndromes such as headache [47] (#cite-text-0-130). At high and fluctuating temperatures people are distracted from their work and general well-being is disturbed. Reduced levels of concentration and motivation may result which weaken the productivity of the work. Along the energy efficiency targets temperature can be adjusted according to usage and non-usage periods. In case when indoor temperature are set on lower level, notification of users prevent increased number of calls to maintenance [47] (#cite-text-0-130). Productivity can be regarded as one indicator of building performance level, as salaries form highest operational cost in building. With better productivity both building and company gained values are increased.

3.3 Challenges

Challenges in implementing energy efficiency plans include various objects. Financial barriers, e.g. lack of funds or payback expectations and mostly the attitude to consider upgrading as profitable measure are regarded as major challenges. Commercial estate owners might not be interested on the non-core business investment that is not paid back within the next five years. As with residential sector, lack of awareness regarding short- and long-term costs and benefits are influencing on the decisions. Advances in the form of lower energy costs, better energy security and protection against increasing energy prices that are related to improved energy efficiency are not adequately known among property owners [1] (#cite-text-0-0). Notably, market or technical barriers are not regarded as latent barriers which have not yet became active. This is because of the other most important barriers that are not solved yet.

4 Comparison

In Europe, residential buildings form three quarters and non-residential one-quarter of the building stock (Figure 4-1). Residential buildings have rather comprehensive dataset comprising also detailed data about quantities of different building types. Contrarily, the information regarding non-residential is far less complete and often statistical tracking of the existing typology is challenging. This is indicated by relatively large share of "other buildings" in non-residential sector (see Figure 4-1).

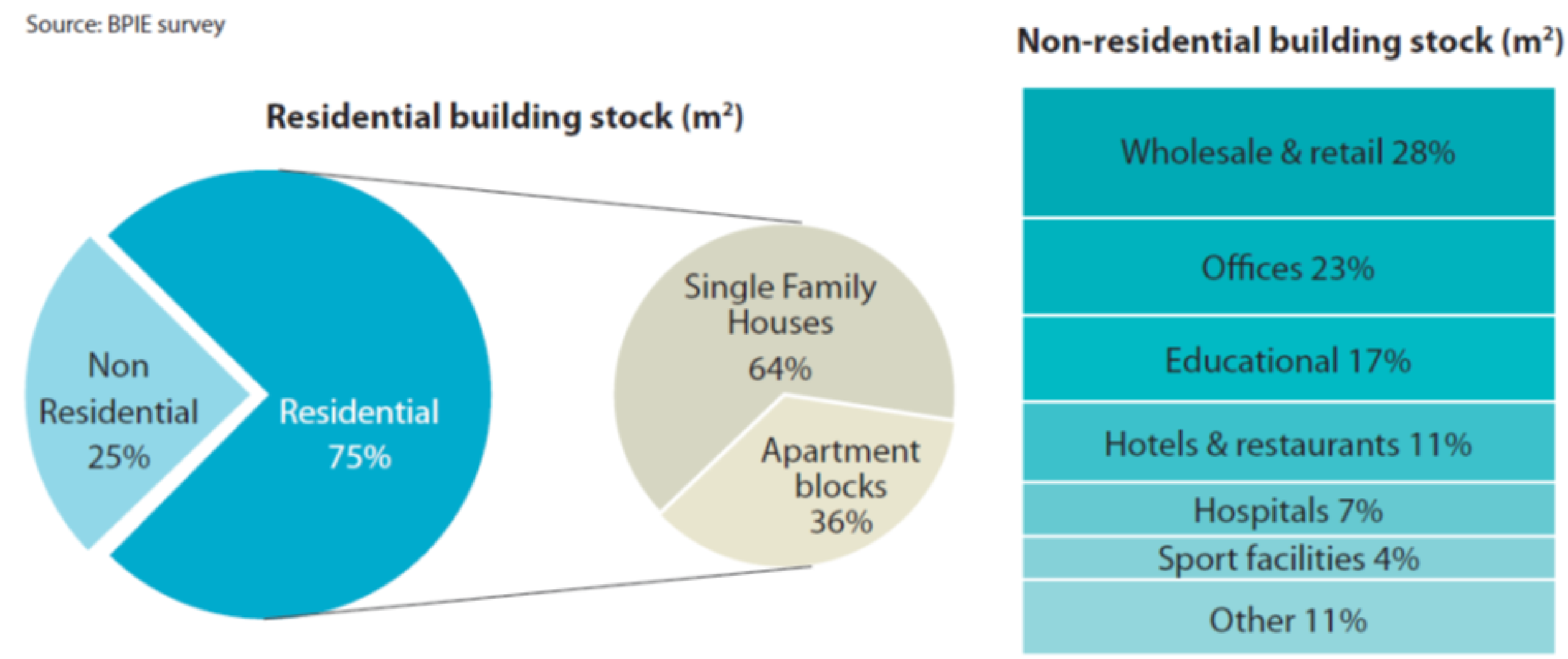
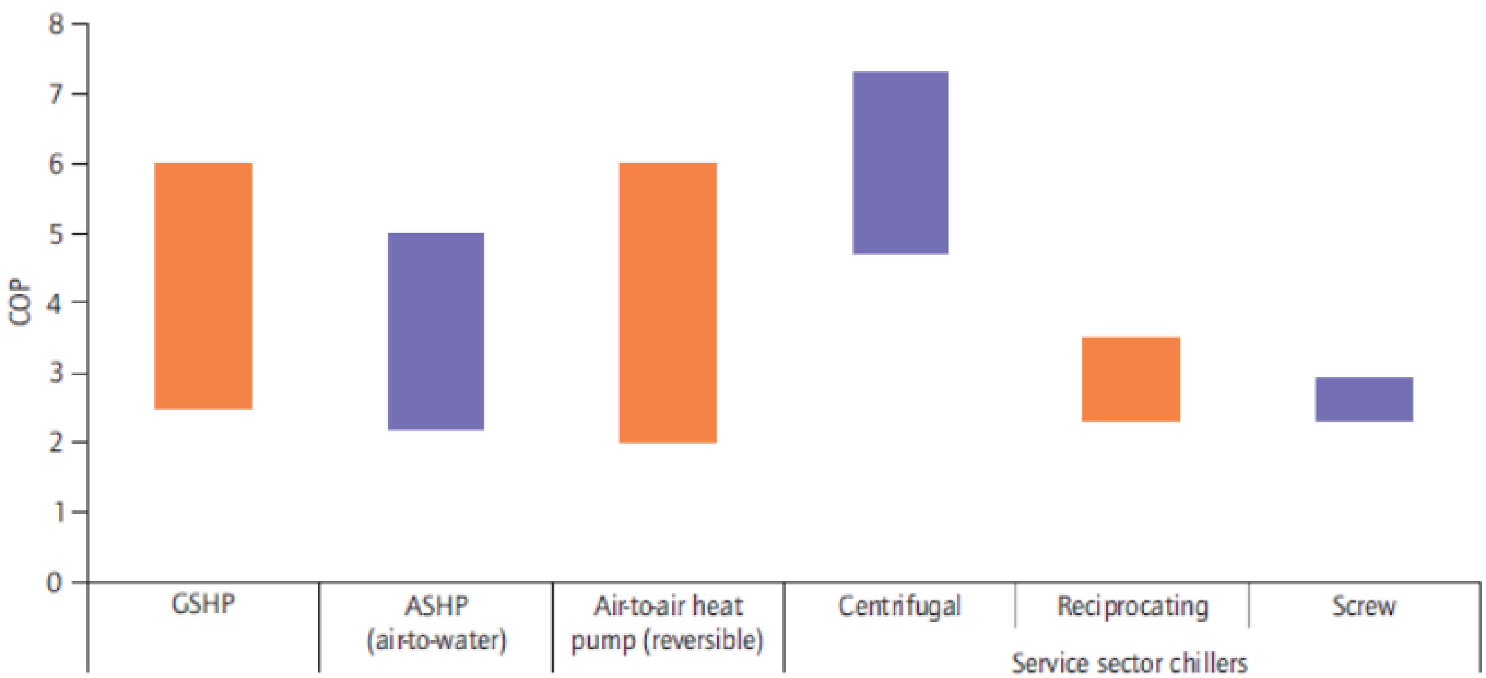


FIGURE 4-1. European buildings divided into residential and non-residential sectors [1] (#cite-text-0-0)

In residential sector, enhancing insulation and gap treatment at connection points between elements improve air tightness of the building envelope. It is estimated that even with the current air tightness levels, leakages in envelope can induce additional heating need of 5-20 kWh/m² in moderate climate [1] (#cite-text-0-0). Non-residential buildings are constructed with same techniques than residential thus giving similar energy performance levels (U-values, air tightness)) for both building types constructed in the same period [1] (#cite-text-0-0). Hence renovation concepts of residential buildings are expected to be applicable also to non-residential sector.

In the Action Plan for Energy Efficiency [48] (#cite-text-0-136) building sector was defined to have most cost-effective energy saving potential until 2020. Approximately 27 % and 30 % energy savings could be gained in residential and commercial buildings. For residential buildings largest saving potential resides in retrofitting insulation of walls and roofs, whereas for commercial buildings enhancement of energy management systems is more important [1] (#cite-text-0-0).

Along the requirements set by international and national level legislations, higher energy performance levels are expected especially in new residential and non-residential buildings. Public sector is obligated to lead the development by having nearly zero energy level in new buildings by end of 2018. Also renovation rate at least 3 % is desired [1] (#cite-text-0-0). In Blue Map Scenario, developed by IEA totally 50 % reduction of carbon dioxide emissions are gained until 2050 from 2007 levels, and energy reduction of 710 mtoe with the usage of strong policy measures and retrofitting of existing buildings [24] (#cite-text-0-45). Notably, until 2050, the quantity of households are expected to increase by 67 % and floor-space of service sector doubled.



Source: IEA Heat Pump Programme and US DOE/EERE (2009).

FIGURE 4-2. Efficiency ranges for heat pumps in cooling and heating modes classified according to technology [24] (#cite-text-0-45)

Despite of these predictions, when implementing the blue map-scenario, energy use is expected to increase only 5 % from the level in 2007. With great proportion this is enabled by energy-efficient heating and cooling systems operated with low-carbon fuels and improvements performed for the outer shell. For example, thermal energy storage technologies and smart energy networks could provide flexibility and cost-effectiveness for the increased use of renewable energy sources to avoid expensive electricity storage [24] (#cite-text-0-45).

Two-thirds of energy saving potential becomes from residential buildings and one third from service sector. The largest energy saving potential among residential buildings is space heating by 25 % and lighting in service sector with 14 % [24] (#cite-text-0-45).

The major difference between residential and commercial buildings is the cost-effective target that brings largest energy savings. In former case, it could be adjustment of boilers and thermostats of radiators and also proper sealing of the windows and doors. In commercial buildings, the largest energy saving potential and most cost-effective measure relates to lighting; by replacing old incandescent bulbs with led-lights tremendous savings can be obtained [42] (#cite-text-0-97). Also the enhancement of refrigeration systems and components bring significant energy saving potential. Quite oppositely, the traditional envelope upgrading option that is among the most important measure in improving energy efficiency among residential sector, has little effect on the energy saving among non-residential building sector [42] (#cite-text-0-97).

Large energy saving potential can be gained with usage of heat pumps, and their proportion is expected to increase in becoming years [24] (#cite-text-0-45). Seasonal performance factors for heat pumps are shown in Figure 4-2. Climatic conditions, required temperature lift and differences in technology specifications widen the range of values. Determination of the actual in-use SPF-values enables evaluation of performance and optimization of the system to reduce energy consumption [24] (#cite-text-0-45). Heat pumps and CHP units (Combined Heat and Power) are available in different sizes, ranging from 1 kW to several Megawatts, and are also highly modular. Space heating, cooling and sanitary hot water can be provided by one integrated unit of heat pump.

In EU, lighting is the second largest energy end-user after space and water heating. Out of the total amount of generated electricity, lighting sector consumes approximately one fifth part [29] (#cite-text-0-56). Worldwide, this exceeds the production of hydro or nuclear power plants (Lighting). Of the lighting share, portion of residential sector was 33 %, or 811 TWh in 2005 [29] (#cite-text-0-56). It is estimated that solely EIA member countries and service sector use approximately half of the world´s lighting electricity. According to estimates, totally 1133 TWh of electricity was consumed by commercial lighting in 2005.

The share of electricity used for lighting of the total electricity use of residential buildings is rather low when compared to commercial buildings (see Figure 4-3). Totally, service sector consumes half of the total world-wide lighting electricity. The shares of residential and industrial sectors are 28 % and 16 %. Street lighting together with other lighting form proportion of 8 % [31] (#cite-text-0-59).

In industrial sector HID lamps (High Intensity Discharge) dominate in Russia with 56 %, whereas fluorescence lamps have the highest proportion with 62 % and 67 % shares in Europe and US [29] (#cite-text-0-56).

In US commercial buildings lighting is the leading energy consumer with 25 % portion before the space cooling 13 %. In residential buildings, heating space and water, and cooling are the primary energy users before lighting. In Europe, both residential and non-residential sectors have space heating as main energy user with shares 52 % and 57 % (Figure 4-3). Lighting electricity use varies between building types. For example in offices half of the total electricity consumption is due to lighting [13] (#cite-text-0-27).

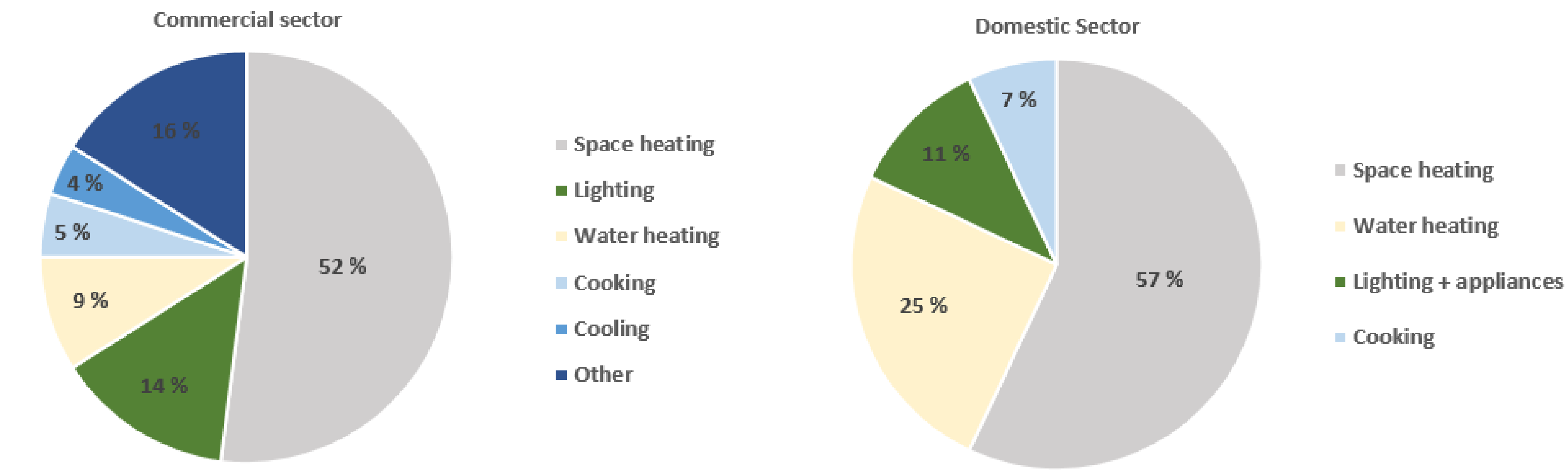


FIGURE 4-3. Energy end-use in European non-residential and residential buildings in 2007 [13] (#cite-text-0-27)

In electrified rural areas of developing countries nearly all of the electricity used by households can be directed to illumination [49] (#cite-text-0-153) [13] (#cite-text-0-27). In general, the most inefficient lighting technology, often incandescent lamps, are used by residential buildings rather than by commercial and industrial buildings.

Electricity use has increased in non-residential sector by 74 % during the last 20 years. This is due to technological advances where IT equipment and air conditioning systems are used at increasing rate. The average energy use is 280 kWh/m², which is at least 40 % higher than corresponding value in residential sector. In residential sector, overall energy consumption has been flattened during the last 20 years although correlation between heating degree days and fuel consumption are obvious indicating the connection between yearly climate changes and heating needs [1] (#cite-text-0-0). In residential sector electricity use has increased steadily by 38 % in the past 20 years. Growing usage of appliances by households explains partly the trend [1] (#cite-text-0-0).

It is estimated that residential and commercial sector bring cost-effective energy saving potentials of 91 mtoe and 63 mtoe energy use until 2020 [48] (#cite-text-0-136). Retrofit of the insulation of walls and roof bring most energy saving in residential sector, whereas enhancement of energy management systems provide most of the potential potential among commercial buildings.

Energy performance certification rates vary between EU countries. In some states, certain requirements existed regarding certification manners and thermal insulation requirements. Currently, this can be seen as higher share of performed certifications, for example in non-residential buildings in Denmark, UK and Sweden. Similarly in residential sector highest ranks are possessed by Netherlands and UK. In the first stage, majority of certificates are done for new buildings because of other already operating building approval processes. Certification costs have large range between countries. Generally expense vary from 100 € to 300 € for residential buildings whereas the full cost range is 50-2000 €. For non-residential buildings not so detailed information is available but the known value vary between 0.5-3m². The available data aid in monitoring and analyzing the measures to enhance energy efficiency most optimal manner. Roughly two third of the countries have set penalties in case of non-compliance with certification process.

TABLE 4-1. Old energy efficiency classes of lamps in comparison to incandescent lamp and the energy saving potential [50] (#cite-text-0-158)

Lamp technology	Energy savings	Energy class
I. Incandescent lamps	-	E, F, G
II. 1 Conventional halogens (mains voltage 220 V)	0–15 %	D, E, F
II. 1 Conventional halogens (low voltage 12 V)	25 %	C
II. 2 Halogens with xenon gas filling (mains voltage 220 V)	25 %	C
II. 3 Halogens with infrared coating	45 %	B (lower end)
III. CFLs with bulb-shaped cover and low light output	65 %	B (higher end)
III. CFLs with bare tubes or high light output	80 %	A

TABLE 4-2. Energy saving potential and measures in Finnish buildings [5] (#cite-text-0-10)

Measure Code	Measure	2010 GWh/a	Estimate 2016	Estimate 2020

			GWh/a	GWh/a
RA-01-YM	Energy effiency regulations for new construction, 2003, 2008, 2010 and 2012	1 560	4 550	6 710
RA-02-YM	Energy subsidies for residential buildings	282	1 005	1 005
RA-03-TEM	Heat pumps for single-family dwellings	2 326	5 310	6 960
RA-04-TEM	Heat pumps for terraced houses and blocks of flats	228	446	471
RA-05-YM	Mandatory water meters for homes	0	74	128
RA-06-TEM	Energy labelling of windows	59	80	129
RA-07-TEM/YM	Höylä III energy efficiency agreement - oil-heated single-family dwellings	2 099	2 722	3 085
RA-08-YM	Energy efficiency agreement for the property sector - residential lettings association	26	194	78
Total energy savings - ESD area		**6 580**	**14 381**	**18 566**

5 Discussion

Lifecycles of buildings are generally long, estimates varying 50–150 years or 25–200 years [2] (#cite-text-0-2). The design planning phase in the beginning of the project is relatively short but has long-lasting effects as it mainly determines the energy performance level of the house. For example, consideration of the access of solar radiation in terms of light and heat depends on decisions regarding number of windows and positioning of a building on the lot in relation to cardinal points, which create further foundation for additional requirements regarding electricity-based lighting and overall heating/cooling need.

Literature and data sources emphasize need for establishment of guidelines and requirements for collecting more extensive and consistent data regarding building typology in non-residential sector. Additional efforts are also needed in classifying residential building stock [1] (#cite-text-0-0).

Energy use in buildings has grown by 50 mtoe since 1990, and is currently 450 mtoe in Europe. World-wide electricity consumption has been increasing even more rapidly due to versatile production and consumption manners. In 2006, the global electricity use was 16 378 TWh that corresponds to 12 % of the world´s total primary energy use [51] (#cite-text-0-162). The actual share is even larger because of the losses in generation processes, and estimates give share of 40 % of the globe´s primary energy supply [52] (#cite-text-0-163).

Energy saving potential has been defined in multiple manners. Often technical, economical or market adoption potential are inspected, which are further valuated according to cost/benefit or resource cost/benefit. By comparing costs and benefits implemented in different target buildings, final estimation of energy efficiency potential can be achieved [42] (#cite-text-0-97).

Two-thirds of energy saving resides in residential buildings and one third in service sector. The largest energy saving potential among residential buildings is space heating with 25 % and lighting in service sector with 14 % [24] (#cite-text-0-45). In Europe, lighting is the second largest energy end-user after space and water heating in both residential and non-residential sectors. In US commercial buildings lighting constitute the largest share before cooling. Part of the electricity used for lighting is released directly or indirectly as heat thus affecting the overall heating and cooling needs in the buildings. For long time, inefficient incandescent lamps were main light sources in residential sector in Europe, US and Russia [29] (#cite-text-0-56). Energy use of incandescent lamps is relatively high and luminous efficiency poor in comparison to fluorescent and LED lamps. Fluorescent and LED lamps are gradually increasing their share as new legislation inhibits the production of incandescent lamps. By using fluorescent lamps in offices and street lighting estimation of 38 TWh energy saving potential per year until 2020 will be gained [1] (#cite-text-0-0).

Other potential cost-effective energy saving targets are adjustment of boilers and thermostats of radiators, insulation and sealing of windows and doors in residential buildings. Quite oppositely, the traditional envelope upgrading options have little effect on the energy saving among non-residential building sector [42] (#cite-text-0-97). Instead, the enhancement of refrigeration systems and components can bring significant energy saving potential. Also smart energy management systems, such as efficient lighting control system for office lighting, have substantial potential for reducing energy use.

In residential sector, the age of those buildings that have not undergone renovation, is largely associated with energy consumption level. Ownership and tenure structures of residential and non-residential buildings influence on the ability to renovate buildings of old or modern period; before 1960 to 1990 [1] (#cite-text-0-0). Larger share of public ownership allow implementation of refurbishment while private owners are encouraged with incentives, subsidies and obligations to perform energy efficient renovation in the context of basic upgrading. Energy performance of buildings is on the responsibility of millions stakeholders. Building owners, decision makers; developers and managers are in essential role in deciding the energy efficiency of especially commercial and public buildings and multi-family buildings [1] (#cite-text-0-0). Cost-effective potential to improve energy performance of buildings is huge that has not yet been exploited entirely.

The major obstacle for increasing the energy performance of buildings is multiplicity and nature of barriers (Figure 5-1). Among the listed challenges are financial, institutional and administrative issues, awareness and separation of expenditure and benefit. Market and technical barriers as latent barriers are missing from the list because the above mentioned barriers have so far prevented their emergence or appearance [1] (#cite-text-0-0).

Regarding financial barriers, besides lack of funds or variations in payback expectations, the biggest difference is seen on the attitude to profitability of renovations. Financial barriers are seen as highest ranking category in the majority of EU countries. Generally high initial investment costs are seen as obstacle for consumers to make energy saving decisions. Commercial estate owners might not be interested on the non-core business investment that is not paid back within the next five years. On the other hand, household owners may think they move home in the next few years. Lack of interest is mainly due to Lack of awareness regarding the life cycle costs of advanced renovation and the immediate positive consequences in the form of cheaper energy bills, better security of energy and protection against increasing energy prices are missing information for majority of estate owners [1] (#cite-text-0-0).

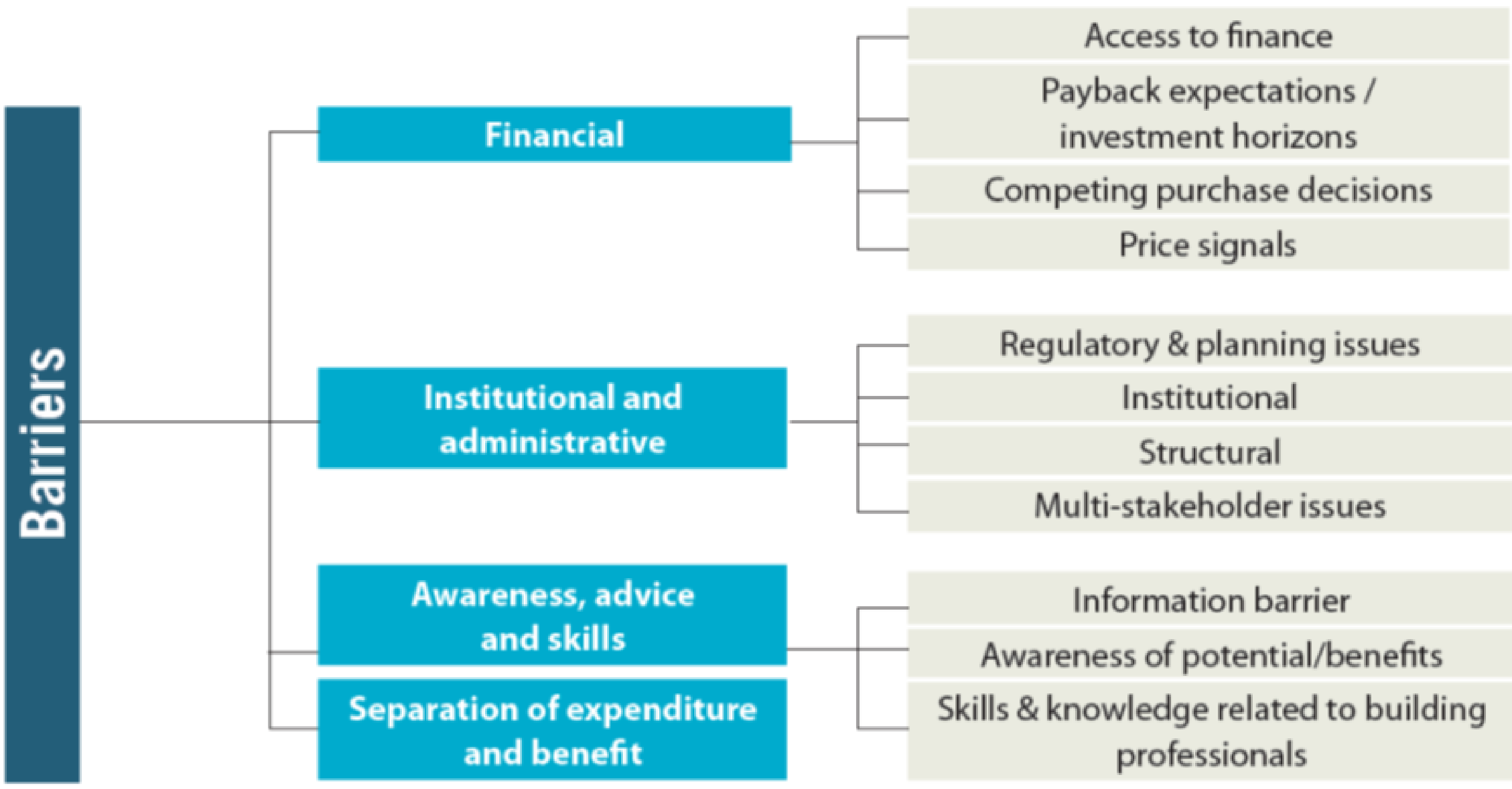


FIGURE 5-1. Barriers for implementation of renovation measures are classified into the major groups [1] (#cite-text-0-0)

Only 3–4 % of the total income of households is consumed by energy bills. Often environmental and climate-change associated costs of producing energy are not fully included to the prices. Thus energy is not the major concern of households in EU, which induce lack of motivation for consumers to decrease their consumption levels. Investment on equipment improving social status such as new kitchen or bathroom or some latest electronic gadgets, with rather low cost-effective value, might compete with decision on investing real energy-saving measures that are cost-effective [1] (#cite-text-0-0).

Institutional and administrative barriers consist large variation in implementation rate of energy efficient measures among Member States. For example fragmentation, delay and gaps in transposing regulations according to public planning have prevented public sector to be leader for enhanced energy performance of buildings.

Ownership and tenure status of residential dwellings are listed among barriers in promoting different levels of renovations. Majority of the dwelling are privately owned, with 80 % share in Europe and 90 % share in Russia [1] (#cite-text-0-0) [21] (#cite-text-0-41). More limited data are available for residential sector, but on the basis of data from 15 countries, large variations were revealed in percentages of private ownerships where values fluctuated between 10 and 90 %.

In residential sector, complexity of ownership structure especially in apartment building may prevent the formation of consensus regarding implementation of energy efficient renovation. Multiple owners or occupiers of buildings create challenges in forming agreement also regarding renovation measures, as generally 75 % consensus is required. Age of the existing building stock and low demolition rate create pressure for lifting the energy performance of buildings. Due to high upfront investment cost and incentive caps, renovations tend to extend for longer time period [1] (#cite-text-0-0).

Rather fast technological development in the area of energy efficiency solutions requires attention also from professionals to keep track of the best practices. Lack of awareness or comprehension regarding effectiveness of specific technologies may confuse consumer especially in the context where two professionals have conflicting advices on best ways to renovate. Correspondingly, shortage of skills and knowledge among professionals toward specifying low energy renovation is generated. Demonstrations and information campaigns have important roles in educating people to understand the entire end-to-end process and related solutions consisting various products and services. Overall, need to construct new buildings could be decreased by one third which would give savings of 1.5 billion euro [2] (#cite-text-0-2). With this money number of designers could be hired to plan new buildings that last corresponding length on average 40 years, the target that could be achieved with better design and construction of old buildings. Potential unemployment that could result from decreased need to invest on new buildings could be avoided for example by educating and orientating professionals towards export markets [2] (#cite-text-0-2).

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