Guidelines for climate proofing energy efficiency projects:

focusing on renovation of multi apartment buildings in the Baltic Sea Region

Prepared by: Daina Indriksone, Irina Paegle, BEF-Latvia

Contributors: Prof. Dr.sc.ing. Anatolijs Borodinecs, Riga Technical University, Latvia and based on contributions from project partner organisations

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Contents

List of abbreviations

BREEAM	British Research Establishment Environmental Assessment Method
BSR	Baltic Sea Region
CAMS Platform	Interreg Baltic Sea Region Programme project “Climate Adaptation and Mitigation Synergies in Energy Efficiency Projects” (2019 – 2022)
CO_2	Carbon dioxide
DGBN	Deutsche Gesellschaft für Nachhaltiges Bauen/German Sustainable Building Council
EMAS	Eco-Management and Audit Scheme
EU	European Union
GDP	Gross domestic product
GHG	Greenhouse gas
GPP	Green Public Procurement
IPCC	Intergovernmental Panel on Climate Change
LED	Light-emitting diode
LEED	Leadership in Energy and Environmental Design
PV	Photovoltaic

Summary

Buildings are responsible for approximately 40% of EU energy consumption and 36% of EU greenhouse gas emissions thus contributing to climate change processes. At the same time buildings themselves are vulnerable to climate change and that the related impacts are resulting in shorter building lifetimes. In order to achieve the target of making Europe climate-neutral by 2050, renovation of buildings is considered to be an important initiative to increase energy efficiency in the building sector, to reduce greenhouse gas emissions and at the same time to improve the resistance against climate change events.

Capitalising on the results of several EU Interreg and other EU energy efficiency projects, the “Guidelines for climate proofing energy efficiency projects: focusing on renovation of multi apartment buildings in the Baltic Sea Region” have been developed within the frame of project “Climate Adaptation and Mitigation Synergies in Energy Efficiency Projects” (CAMS Platform) financed by Interreg Baltic Sea Region Programme. The aim of these Guidelines is to support national, regional, and local authorities responsible for planning and implementing climate and energy policies, as well as the developers of energy efficiency and climate adaptation projects aiming to achieve co-benefits and synergies between adaptation and mitigation measures. The Guidelines are intended to raise awareness and provide advice on how to prepare renovation of buildings so as to obtain not only energy saving gains, but also higher resilience of the buildings to future climate change, as well as improving the cost-efficiency of the projects. The Guidelines focus on existing residential multi apartment buildings located in the Baltic Sea Region.

The Guidelines include recommendations to be considered for application during the renovation of multi apartment buildings via the implementation of climate proofing energy efficiency projects. The Guidelines highlight synergies of measures for climate change mitigation and adaptation in building renovation. Recommendations are related to building envelope; building materials; energy supply; heating, ventilation, air conditioning, lighting; water supply and use of water; building surroundings, as well as management, quality control, monitoring of results and promotion of renovation of multi apartment buildings. Most aspects and measures tackled by the Guidelines are also relevant and applicable for other building types and for new constructions.

Introduction

The building sector is one of the largest energy consumers in Europe and is responsible for more than one third of the European Union's greenhouse gas emissions. At the same time, buildings face major risks of damage from the impacts of climate change. Depending on regional variation in the intensity and nature of such impacts, buildings are already experiencing an increase in extreme weather effects particularly during the recent decades resulting in shorter building lifetimes.[1]

The European Union (EU) ambitions to limit the global temperature raise are consistent with the Paris Agreement on Climate Change. Improvements in energy efficiency and in energy mix have been the main driving forces behind the reduction of EU greenhouse gas emissions by 24% already achieved between 1990 and 2019, while the economy has grown by around 60% over the same period.[2]

To reach the 55% emission reduction target by 2030 and achieve a climate-neutral Europe by 2050, additional measures must be implemented. Europe's commitment to reach climate neutrality by 2050 achieving net zero greenhouse gas emissions for EU countries as a whole (mainly by cutting emissions, investing in green technologies, and protecting the natural environment) and to accelerate efforts regarding climate change adaptation is emphasised in a set of policy initiatives under the framework of the European Green Deal.[3]

To pursue this ambition, as part of the European Green Deal, the European Commission in October 2020 published a new strategy to boost renovation of public and private buildings called "A Renovation Wave for Europe – Greening our buildings, creating jobs, improving lives" (COM(2020)662).[4] The Strategy aims to take further action and create the necessary conditions to scale up renovations by doubling annual energy renovation rates in the next 10 years and reap the significant saving potential of the building sector. Alongside reducing Europe's greenhouse gas emissions, these renovations will enhance the quality of life for people living in and using the buildings.[5, 6]

In order to support the EU climate policy framework to reach its various goals, the European Commission launched the first package of its 'Fit for 55%' measures in July 2021, which comprised amongst others of: (i) the amendment of the Energy Efficiency Directive,[7] setting a more ambitious binding annual target at EU level, raised from 32.5% to 36%; (ii) the amendment of the Renewable Energy Directive[8], setting a new 2030 target of 40% (up from 32%) energy use from renewables by 2030 and strengthening bioenergy sustainability criteria; (iii) the revision of the Energy Performance of Buildings Directive[9] expected at the end of 2021.[10]

Energy efficiency and the related demand management measures can also address some of the energy sector's vulnerabilities to climate change impacts, for example counteracting the increased demand on and decreased output of power plants due to higher temperatures; counteracting the increase in peak demand due to increased use of air conditioning and addressing the uncertainties of possible power cuts and failures in generation and consumption due to extreme weather; climate proofing buildings against extreme weather events by using the right orientation and refurbishment materials, as well as using cool or green roofs; switching to distributed generation secures of electricity which are less subject to grid outages due to extreme weather events. Digitalisation and automatization may increase vulnerability of building maintenance and operation.

The **"Guidelines for climate proofing energy efficiency projects: focusing on renovation of multi apartment buildings in the Baltic Sea Region"** have been developed within the frame of project "Climate Adaptation and Mitigation Synergies in Energy Efficiency Projects" (CAMS Platform) financed by Interreg Baltic Sea Region Programme. The project is being implemented in 2019 – 2022 by project partners from Sweden, Estonia, Latvia, Poland, Germany, and Russia. The aim of CAMS Platform is to learn from existing projects, investigate and facilitate the co-use of energy efficiency measures to increase resilience of the housing and services sector. Capitalising on the results of several EU INTERREG and other EU energy efficiency projects, CAMS Platform advances energy auditing, the qualification programme of housing renovation, and policy dialogue for mitigation and adaptation synergies in both sectors.[11]

The aim of these Guidelines is to support national, regional, and local authorities responsible for planning and implementing climate and energy policies, as well as the developers of energy efficiency and climate adaptation projects aiming to achieve co-benefits and synergies between adaptation and mitigation measures.

The Guidelines will raise awareness and provide advice on how to prepare renovation of buildings so as to obtain not only energy saving gains, but also higher resilience of the buildings to future climate change, as well as improving the cost-efficiency of the projects. The Guidelines focus on existing residential multi apartment buildings located in the Baltic Sea Region.

Recommendations on how building renovation projects could deliver higher energy savings and increase resilience of buildings themselves and their tenants have been prepared based on the results of various energy efficiency projects, as well as on the exchange of project partners experiences, including those of ongoing and past projects carried out by CAMS Platform project partners. The recommendations consider the outcomes of mapping the methodologies, options, and best practices where resilience to climate change is increased by implementing energy efficiency measures in the buildings sector in the Baltic Sea Region[12] as well as the Study guide for energy efficient buildings[13].

The training workshop on strategies and methodologies for merging climate change adaptation into energy efficiency projects and nature-based solutions in cities (held on 3 June 2020) as well as other national and international events held in 2020-2021 have provided new knowledge and gave additional inputs for preparation of the Guidelines. Within the frame of CAMS Platform project, a webinar "Policy Dialogue on Energy Efficiency: Climate-proofing Renovation in Baltic Sea Region" was organised on 10th November 2021 to present and discuss climate change mitigation and adaptation concept and best practices in the Baltic Sea Region (about 40 experts and stakeholders were participating at the event).

1. Renovation of the existing building stock

Buildings are responsible for approximately 40% of EU energy consumption and 36% of EU greenhouse gas emissions.[14] More than 30% of the EU building stock is over 50 years old. Being built before the introduction of strict energy performance requirements, about 75% of the building stock can be considered as energy inefficient. It is estimated that up to 95% of today's buildings will still be in use in 2050. Accordingly, applying energy saving measures in the building sector, for example during the renovation process has high potential, providing an opportunity to reduce CO_2 emissions from energy consumption, helping to meet the EU Climate change mitigation targets.[15, 16]

Renovation of public and private buildings is considered to be a key initiative to increase energy efficiency in the building sector and to reduce greenhouse gas emissions. Nevertheless, estimations indicate that only 1% of buildings undergo energy efficient renovation every year. In practice, the market is dominated by step-by-step renovations, where only a few measures are implemented, leading to little primary energy savings per step.[17] Measures that are typically applied during the energy renovation of buildings (energy and cost efficiency logic applies in most cases) include:

- replacement of windows, building entrance doors;
- installation of thermal insulation on the façade, roof, ground plate, attic's floor, inside basements;
- replacement or first-time installation of a space heat generator, water heater (incl. solar thermal collector on the roof), radiator, floor heating system, mechanical ventilation system, space cooling system (air- conditioner), changing of heating source;
- technologies for adjusting heating and ventilation;
- installation of a photovoltaic (PV) system e.g., solar modules for electricity generation on the roof;
- automatic or non-automatic shading system for windows to avoid overheating in summer;
- new lighting installations (e.g., energy efficient light bulbs).

It has been assessed that in terms of affected floor area, deep renovations (resulting in more than 60% energy savings) only occur sporadically in the EU-28. The annual number of deep renovations is only around 0.2% on average[18], with small variation between individual Member States though their share is increasing. Calculations show that the relative annual primary energy savings per residential renovation (comparing the performance of the building before and after renovation), taking the average of all energy renovations across the EU28 that took place between 2012 and 2016, is estimated to be at around 9%.[19, 20]

In order to achieve the target of making Europe climate-neutral by 2050, an essential measure to be fostered is the renovation of buildings to improve energy efficiency, reducing greenhouse gas emissions whilst simultaneously increasing their climate resilience.[21] In 2018 and 2019, as part of the "Clean energy for all Europeans package"[22] the EU legislation requirements on energy efficiency and on energy performance of buildings were amended:

- the Directive on Energy Efficiency (2018/2002)[23] establishes a common framework of measures to promote energy efficiency in order to ensure that the EU 2020 targets on energy efficiency of 20 % and its 2030 headline targets on energy efficiency of at least 32,5 % are met. It also paves the way for further energy efficiency improvements beyond those dates;

- the Directive amending the Energy Performance of Buildings Directive (2018/844/EU)[24] introduces new elements and sends a strong political signal of the EU's commitment to modernise the buildings sector, considering technological improvements and increasing building renovations.

A new strategy **"A Renovation Wave for Europe – Greening our buildings, creating jobs, improving lives"** (COM (2020)662)[25] was launched on 14 October 2020, aiming at doubling the annual energy renovation rates in the next ten years.[26] All EU countries must establish a strong long-term renovation strategy[27] aiming at decarbonising their national building stocks by 2050, with indicative milestones for 2030, 2040 and 2050. The strategies should contribute to achieving the energy efficiency targets of each EU Member state, as reflected in their respective national energy and climate plans.[28]

The EU Member states are requested to support the modernisation of all buildings with smart technologies. The request includes requirements regarding the installation of building automation and control systems, and devices that regulate temperature at room level. A clearer link is made to clean mobility and the health and well-being of building users is addressed e.g., through the consideration of air quality and ventilation.

EU countries must draw up lists of national financial measures to improve the energy efficiency of buildings and to accelerate the renovation of existing buildings by 2050.[29] The EU countries must make energy efficient renovations to at least 3% of the total floor area of buildings owned and occupied by central governments.[30,31,32] The European Commission has also published a series of recommendations on the building renovation (EU)2019/786[33] and building modernisation (EU)2019/1019[34] aspects of the new rules.[35]

At the same time, it must be acknowledged that buildings themselves are vulnerable to climate change and that the related impacts are resulting in shorter building lifetimes. Climate change may have a negative effect on indoor climate and reduce comfort for tenants. The European Commission is aiming at increasing the climate resilience of buildings and the related infrastructure. In 2021 the European Commission adopted its **new EU strategy on Adaptation to Climate Change**[36] setting the directions for adaptation to the unavoidable impacts of climate change, setting the target of becoming climate resilient by 2050. Amongst other issues, it states that additional efforts have to be undertaken to prepare Europe's building stock to withstand the impacts of climate change. The resilience of existing buildings to current risks and future climate changes has to be assessed and upgraded accordingly, e.g., to cope with temperature extremes.[37] The Cohesion Policy is used to support the increase of building resilience.

The existing building stock in the Baltic Sea Region is quite heterogenous. Residential buildings form a major part of the floor area of the building stock while the proportion of multifamily houses and single-family houses differ. Residential buildings built before 1979 are the most prevalent.[38]

This chapter presents a brief overview of the existing building stock, key requirements for the renovation of multi apartment buildings, experiences – successes, challenges and plans for building renovation in the CAMS Platform project partner countries – Sweden, Estonia, Latvia, Poland, Germany, and Russia (with a focus on the St. Petersburg Region). The material is prepared based on the inputs provided by project partners and relevant literature sources in 2020 with minor upgrades in 2021.

1.1. Sweden

In Sweden, there are over 8 million buildings, of which 37% are residential buildings.[39] Most of them were built during the period 1945–1980. The heated area amounts to 641 mil.m^2. Residential buildings comprise 77% of the total building stock (floor area). Detached single family houses are most prevalent and only 35% of residential buildings is comprised by multi apartment buildings in 2016.[40] The majority of single-family houses are privately owned, while a significant proportion of multi apartment buildings belong to the rented sector.[41] The majority of multi apartment buildings and detached houses are heated with district heating. Numerous buildings represent a combination of heat sources.

The housing and service sector accounts for close to 40% (c.a. 140 TWh) of Sweden's total energy use. Energy use for heating and hot water is around 126-128 kWh/m^2 of heated area. Sweden has set a target for the reduction of energy intensity in terms of energy supplied in relation to GDP, aiming to reduce energy intensity by 20% between 2008 and 2020. Energy consumption must be 50% more efficient by 2030 than it was in 2005.[42]

In Sweden many multi apartment buildings have been inadequately maintained and have seen little renovation. About 75% of residential buildings need renovation before 2050. About 320 000 buildings require deep renovations in the short term. Accordingly, there is considerable potential for energy savings in the housing sector. Although the renovation rate for apartment blocks has increased over the past ten years, when compared with the previous decades, the renovation deficit of the building stock is still increasing, and the value of the building stock is not being protected. Apartment buildings are estimated to have a renovation cycle of 40-50 years. Provided that apartment buildings follow their renovation cycle, this means that, for those erected from the 1950s onwards, apartment buildings will need further major renovation within 20-30 years and apartment buildings erected during the period 1961-1975 within 10-20 years.[43] There is no official statistical data available on number of renovated multi apartment buildings.

Various requirements exist for the energy performance of different types of buildings and heating sources in Sweden. As opposed to requirements for new buildings, there are no legal requirements requesting the implementation of adaptation measures during the renovation of existing houses. The quality control of renovation is performed by the building owner, who checks if the work has been done according to contract, and that procurement and legal building requirements have been met, which includes evaluating energy performance. There are specific templates, contracts and models for this. For major renovation when a building permit is required, renovation process is controlled and reported by an external construction supervisor. National Building Code constitutes requirements i.e., maximum energy consumption kWh/m^2/year for renovated buildings. There are also requirements for heat insulation, heating systems, ventilation units, efficient electricity use and measurement systems for energy use. According to the National Building Code, a building's energy use must be sequenced and reported 24 months after the building has been commissioned. To ensure that energy performance will really be achieved, a follow-up system is required.

There are several promotion incentives to stimulate renovation of buildings: (i) economic incentives e.g., carbon tax, energy tax, green loans; (ii) administrative incentives e.g., building regulations, certification systems and (iii) informative incentives e.g., energy certificates, energy labelling, LÅGAN database, energy agencies, information materials. There are incentives to produce energy from renewable energy sources. For example, since 2021 private building owners can apply for a 15 % tax deduction for all costs of installing solar energy plants.

1.2. Estonia

According to the National Register of Buildings, in 2020 178 000 apartment buildings (155 150 single-family houses and 22 600 multi apartment buildings). Surface area of single-family houses comprise 20 mill m^2, while multi apartment buildings have a total surface area of 28.4 mill m^2.[44] The study performed in 2016 indicates that in Estonia 73% of the total building stock (floor area) are residential buildings; more than half of which (54%) is made up of multifamily houses.[45] 96% of residential buildings are privately owned. Most residential buildings were constructed between 1960 - 1990. At this time, mainly standardized buildings were constructed. Brick and panel type buildings were among the most widespread. According to regulations that existed during Soviet times, a standard thermal resistance of building envelopes was calculated accounting for climate conditions and building envelope thermal inertia. In Estonia's climate conditions, the standard thermal conductivity for exterior brick walls was on average 1.33 W/m^2K and for exterior expanded-clay concrete walls: 1.18 W/m^2K, which is at least 3 times less than the values specified in the current Estonian standard. Moreover, in the installation process of building envelopes, a correct sequence of operations was not often observed, and technology was not duly supervised. Taken as a whole, all of these factors result in high costs for upkeep of buildings, especially when current high energy costs are taken into account.

In Estonia, each building can have more than one heating system e.g., district (central) heat supply, electrical heating, ground heating, heat pump heating, stove, or fireplace heating. The main source of heating in Estonia is provided by district heat supply systems. In total, about 60% of housing stock is connected to district heating. Residential buildings in Estonia are one of the essential heat consumers during the heating season. The residential sector in Estonia consumes 70% of all heating energy produced. The average annual specific heat consumption for space heating of Estonia residential buildings is 153 kWh/m^2 and for hot water supply: 42 kWh/m^2.[46]

According to the Estonia's 2030 National Energy and Climate Plan[47], and the National Development Plan of the Energy Sector until 2030[48], measures for the building sector are set regarding reconstruction of private houses, apartment buildings, central and local government buildings. Additional measures (in case of additional financial resources) comprise investments in street lighting reconstruction, additional reconstruction of public and commercial buildings as well as additional reconstruction of private homes and apartment houses. Energy efficiency of buildings must be increased through the renovation activities. The Specific quantitative target for multi apartment buildings to be reached by 2030 is that 50% of apartment buildings should have energy class C. The yearly renovation rates have been calculated based on national targets. The yearly renovation rate e.g., for apartment buildings (number of buildings) was calculated to be 0.7 % (reconstruction rate of net floor area of apartment buildings per year 1.3%).[49]

It has been assessed that the technical energy saving potential of Estonian buildings is up to 80% of the current energy use. The technical potential for heat is extremely high - 9.3 TWh/y and the potential for electricity is almost zero - 0.2 TWh/y. There is very little potential for saving electricity because indoor climate (ventilation) and the use of heat pumps replace electricity savings achieved through insulation. The technical energy saving potential of buildings is about 10 TWh/y, which accounts for almost one third of the total final energy consumption (33-34 TWh/y) in Estonia.[50]

Minimum energy performance requirements for renovated buildings have been set with the National Government Act on Minimum Energy Performance Requirements for Buildings[51]. The Annex 2 of this Act[52] set the limit of 150 kWh/m^2/y for the energy performance of multi apartment buildings undergoing major renovation (125 kWh/m^2/y for low energy multi apartment building; 105 kWh/m^2/y for nearly zero energy multi apartment building).

According to information provided by Mr. Kalle Kuusk, an expert on the energy efficiency of buildings from KredEx, 1114 multi apartment buildings (total area of 2.8 million m^2) have been awarded a grant for renovation since 2010. In addition to the subsidy granted by KredEx, the renovation of buildings has been financed privately by apartment owners, but there are no official statistics on the total number of multi apartment buildings that have been renovated. It has been assessed that renovation reduces heat consumption by an average of 50-60%, however electricity use increases by 5-10% (due to the addition of the ventilation system). The total energy saving of the buildings which got a grant between 2010-2014, was 60 GWh. Between 2015-2019 buildings are expected to save 80 GWh. Savings in monetary terms are difficult to calculate - in addition to direct energy savings, other essential works related to the use and safety of the building are being carried out e.g., change of electrical system, change of water and sewerage system, repair of balconies. Presently, the main problem is uneven support measures and unstable funding. The interest of apartment associations to renovate is larger than the resources available from public funding. Regional and local differences occur due to huge price gaps in real estate, caused by depopulation of rural settlements and deindustrialised shrinking towns. In relation to the renovation technologies, factory-produced technologies as pilots have been introduced in 2021.

In Estonia, funding for renovation of buildings is provided mainly by KredEx - a foundation set up by the Ministry of Economic Affairs and Communications in 2001 with the aim of providing financial solutions based on the best practices in the world. KredEx reconstruction aid provides partial financial support (up to 50% based on building type) for multi apartment buildings and single-family homes in Estonia built before 1993 (there are specific requirements for the applications). About 80-100 multi apartment buildings per year receive the apartment building loan guarantee from KredEx (8-9 million EUR per year). There is a list of specific requirements/measures that must be implemented for the building to receive support from KredEx. The projects funded must hire a certified technical consultant whose main task is to advise the cooperative on technical issues, first and foremost before the start of the reconstruction, but also at a later stage, and therefore the contract between the cooperative and the consultant must be valid until the end of the reconstruction. The technical consultant makes sure that all the required technical aspects have been implemented and performs constant quality checks. The final recipient (i.e., apartment associations) is required to submit to KredEx an energy performance certificate based on the measured consumption data of the calendar year following the end of the reconstruction of residential building. The Apartment Associations shall submit an energy performance certificate before the reconstruction and a new energy performance certificate after the reconstruction. After the reconstruction, the label shall be provided for the full year following the reconstruction. The subsidy/grant is based on the achievement of an energy performance class C (higher subsidy) or class D (lower subsidy).

In connection with the COVID-19 pandemic situation, clogged, poorly ventilated buildings have been on the agenda, starting with both the ventilation system and the related renovations.

1.3. Latvia

In Latvia there are ca. 1.4 million buildings in total (total floor area is about 206.6 million m^2). Of them about 1 million are non-residential buildings and ca. 364 000 are residential buildings (310 000 single dwelling houses (ca. 36 million m^2) and ca. 54 000 multi apartment buildings (54 million m^2).[53] The largest proportion of residential buildings (89%) are privately owned, 11% belong to the state and municipalities and 2% belong to apartment cooperatives. By number, most residential buildings were constructed in the period from 1965 to 1990. Brick is the most prevalent construction material for the external walls of dwelling houses. At that time the building standards related to energy performance were much lower than the current requirements, and installation of envelopes was not duly supervised. The main source of heating in Latvia is provided by district heat supply systems. In total about 65% of the housing stock is connected to district heating.[54,55] Residential buildings in Latvia are one of the essential heat consumers during the heating season, for example, the average specific heat consumption of multi apartment buildings is 124 kWh/m^2 (in 2020). [56]

The targets for renovation of buildings are set in the National Energy and Climate Plan of Latvia 2021–2030[57] and in the Long-term strategy for the renovation of buildings,[58] where it is predicted that from 1 January 2021 onwards, the energy performance of multi apartment buildings after renovation should not exceed for 80 kWh/m^2 and 90 kWh/m^2 for 1-2 apartment buildings. According to the Directive 2012/27/EU, Latvia has an obligation to renovate 3 % of the total floor area of central government buildings each year. The estimated savings are 1.690 GWh/year, and average energy consumption for heating should be 120 kWh/m^2. Moreover, use of local renewable energy sources in district heating should be promoted, reaching a 60% share of renewable energy in district heating by 2023.[59] About 20 000 households should have improved their energy performance. Additional capacity produced from renewable energy resources should be 0.86 MW. Estimated annual greenhouse gas savings are 15 227 tonnes of CO_2 equivalent.[60]

According to the Ministry of Economics, 741 residential buildings have been renovated within the period from 2009 to 2015 resulting in an average of 45% energy savings. Since 2016, about 500 renovation projects have been started, but are not yet finished. This illustrates the small number and slow speed of renovations. During the period from 2016 – 2023, the allocated funding support for renovation of buildings is ca. 166 mill. EUR.[61,62,63] The funding available for renovation of residential buildings from the European Regional Development Fund is administered by ALTUM (a state-owned development finance institution, which offers state aid for various target groups with the help of financial tools).[64]

1.4. Poland

The total number of buildings in Poland exceeds 14.2 million, of which ca 6.2 million are buildings used predominantly for residential purpose. 420 thousand buildings serve public administration or public utilities, while 5.2 million buildings are for business use, and 2.5 million represent different other non-residential use.

In terms of the type of buildings - single family houses are most prevalent, making up 40% of all buildings in Poland. This house type makes up 90% of residential buildings, but in terms of space used, the multi apartment buildings comprise just over one third of all stock floor area of Polish housing.[65] The housing stock in Poland is relatively young - ca. 1/3 of currently used flats are in buildings constructed after 1989 (i.e., the year when market economy transformation started, over 30 years ago), but ca. 52% were built before 1979, i.e., are over 40 years old, with energy consumption at the level of 200 - 400 kWh/m²/y.

In 2019, households were responsible for the second highest share (26.3%) of energy consumed in Poland, behind transport (33.0%). About 65% of energy consumed in households is used for space heating, predominantly in old and non-insulated houses constructed in times with no (or very low) energy performance standards for buildings. Low energy performance of existing buildings (especially single-family houses) and the use of old coal fired boilers create environmental concerns.

The draft "Long-term Renovation Strategy of building stock in Poland" prepared in February 2021 estimates that 30% of multi apartment buildings still need basic renovation in energy terms. Another 30% of such buildings are in need of deeper (next stage) energy renovation, generally scheduled for after 2030. As in Germany, there is no definition of "renovation" in the Polish building code (as complex or staged refurbishment with a focus on energy efficiency), but a quite similar term of "thermic modernisation" has already been enforced since 2008 and has been implemented more and more broadly in multi apartment housing and public buildings. There are no mandatory requirements in terms of the yearly programme for this kind of building renovation, or any other implementation of goals to mitigate climate change related risks in the buildings sector in general. When renovation is planned for certain parts of a building (including thermic modernisation of envelope elements), these elements must achieve a very low thermal transmittance e.g., since January 2021 for external walls, U-value must be 0.20 W/m²K, and for external ceiling or flat roof – 0.15 W/m²K.

Since 2014, in terms of regulatory framework, Poland has been gradually increasing ambitions and technical requirements in the field of energy efficiency of buildings, at the same time moving towards climate change mitigation. Many public programmes (especially those co-financed with EU funds) and specific thermic modernisation funds mostly tackle projects involving the improvement of energy efficiency and/or highly efficient energy (co-)generation in multifamily buildings.[66]

Since 2018, the national priority program "Clean Air" has been available and very extensively used to support similar energy renovation tasks of single-family houses. This facility, together with two other programmes (Stop Smog, and "My Current") supports the energy transition of this substantial sector into low-carbon sources of energy e.g., PV panels and solar collectors, as well the most modern gas boilers. The draft national Long-term Renovation Strategy of building stock recommends a scenario in which 2/3 of the residential and public utility building stock should reach very low energy performance by 2050, at the level of below 50 kWh/m² of primary (non-renewable) energy. This requires deep renovation of 3% of this stock yearly in the decades after 2030. For the current decade, the envisaged path is much slower – 1% of respective stock should be subject to deep renovation each year, and far more buildings should use the cost-effective measures to improve their energy performance at the basic level, as well as changing their energy supply sources. The National Recovery and Resilience Plan for Poland offers 3200 million EUR for energy efficiency and renewable energy investments in the housing sector. It also defines an extensive range of updates in the regulatory framework, alongside specific administration measures.

1.5. Germany

In Germany there are about 21 million buildings in total (ca. 19 million residential buildings, comprising 66% of the total building stock floor area). Single family houses (detached and semidetached buildings) prevail and less than half of residential buildings (40%) were multifamily houses in 2016.[67] Different materials, but mostly brick, have been used for construction. More than 60 % of buildings were built in times without any energy efficiency regulations and have energy consumption of 200 - 400 kWh/m²/y. Less than 5% of multifamily houses have over 13 flats, and due to compactness, their energy consumption is about 100 kWh/m²/y. Most residential buildings are privately owned by private persons and private companies, and about 50% of flats are for rent.

By 2020, Germany is aiming to reach 40 % of primary energy savings compared to 1990, and 80% of primary energy savings by 2050. The overall goal for renovation states that 2% of building stock must be renovated annually, but no specific target for different types of buildings is set. However, there is a lack of clear definition of “renovation,” whether it means complex refurbishment or implementation of certain single measures. There are no mandatory requirements for renovation of buildings in terms of energy efficiency, or for implementation of adaptations for climate change related risks. When renovation is needed for certain parts or building elements, these parts or elements must achieve a certain thermal transmittance e.g., for external walls, U-value should be 0.24 W/m²K. There are incentives for voluntary measures, e.g., special loans (Kreditanstalt für Wiederaufbau, KfW Bank). Special grants and loans are offered by the KfW Bank e.g., grants for professional construction supervision by a technical expert, 50 % of the costs for the supervision of construction up to a maximum of 4 000 EUR, to fund the implementation of higher requirements for the renovation of building elements e.g., U-values for external walls 0.20 W/m²K.

Quality control is mandatory for building renovations if grants and loans of KfW Bank are applied. This special supervision tackles planning, procurement, and the construction phase. To monitor the achieved results, a voluntary system has been established – a database[68] where fact sheets on renovation projects, energy savings, lists of applied measures, and total renovation costs can be found. With permission from a building owner, planners, energy auditors or craftsmen can promote their projects in this database.

1.6. Russia

In Russia, the existing residential building stock consists of the buildings constructed in the following periods:

- Before 1917 – „Pre-revolutionary buildings". As a rule, these are historical buildings on federal or regional levels protected by the state. Reconstruction of these buildings, including energy efficiency measures, must be carried out as individual projects that must first be approved by bodies for the protection of architectural monuments. Such buildings often have wooden floors and are renovated to replace floors and engineering systems, and to improve energy efficiency.
- 1950s – „Stalin style". These buildings have 3 to 7 floors and are usually made of brick. They have high ceilings up to 3.5 m and large comfortable kitchens up to 15 m². The total area of the apartments is up to 110 m² for three-rooms and up to 40 m² for one-room. The rooms in these apartments are isolated, the bathrooms are separate, and stairwells large.
- 1960s – „Khruschev style". Panel mass building houses with small and often irrational sizes of kitchens and living rooms, narrow corridors and stairwells, low ceilings, passage rooms, combined bathrooms, poor sound insulation, insufficient heat insulation. Estimated service life of 25 years. They were built as a temporary solution for the restoration of housing stock destroyed during World War II.
- 1970s – „Bredgnev style". Large-panel 9-, 12-, 16-storey houses. Mass building on typical projects aimed at improving indoor living conditions without considering energy efficiency.
- 1980s, 1990s – large-panel series of buildings up to 22 floors. An increase in the variety of typical building projects, the focus is still on improving the comfort of housing, energy efficiency is considered as an additional option.
- 2000s – panel buildings, monolithic buildings, brick, and monolithic houses for individual projects. Combined with comfort, energy efficiency becomes one of the main characteristics of a building.

As a rule, multi apartment buildings are connected to district heat supply systems. Independent heating systems for multi apartment buildings are used as an exception in cases where connection to the existing district heat supply system is economically ineffective, e.g., it requires significant modernization due to insufficient capacity.

In Russia the term "renovation" *(in Russian "реновация")* means complex development of the territory by demolishing dilapidated houses (as ruled by the Khrushchev type) and construction of modern buildings on this site. Under the program "Development of Built-Up Territories in St. Petersburg", the city will replace the buildings - built in the mid-20th century and currently being in critical (emergency) conditions, with new and comfortable houses. These old buildings will be demolished, and new ones will be built in their place. The relevant law No. 238-39 on the renovation program was adopted on May 6, 2008 in St. Petersburg. The main goals of the renovation are as follows: provide citizens with comfortable and safe housing; improve the social and economic parameters of urban housing stock; use urban space more effectively, update the city infrastructure. In total, 1073 buildings from 22 quarters of 9 districts participate in this program.[69]

Renovation i.e., reconstruction *(in Russian "реконструкция")* of existing buildings in St. Petersburg is carried out as a part of the building overhaul program, which is updated annually. The program is divided into city districts. For example, in 2020, the reconstruction of 144 buildings with a total area of 752 884 m^2 was planned in the Admiralteysky district of St. Petersburg. Reconstruction requirements depending on building types and purposes are presented in "Energy efficiency recommendations of residential and public buildings", as stated by the Committee on Construction of Saint-Petersburg on April 2, 2019. On January 1, 2020, the National standard of the Russian Federation R ISO 14090-2019 "Adaptation to climate change. Principles, requirements and guidelines" was introduced.[70]

So far, there is no centralized information system that provides open data on the results achieved. The updated information system GIS Energy Efficiency, which collects data on the energy efficiency of buildings, is planned to be launched in the 3rd quarter of 2021.

Financing of building reconstruction projects is carried out at the expense of payments for overhaul reconstruction, which must be paid monthly by the owners of all residential premises, regardless of the year of their construction (special type of targeted tax). The collection of this tax is one of the challenges for financing reconstruction projects.

The overall quality control of reconstruction projects in St. Petersburg is carried out by the Non-profit organization "Fund - a regional operator for the overhaul of common property in apartment buildings".[71] The focus is on financing, procurement and performance checks at the end of the project. Monitoring of the achieved energy efficiency targets is only carried out within the framework of energy performance contracts which are relatively rarely used. For reconstruction projects, this type of monitoring is applied selectively, e.g., to assess and compare the effectiveness of heating equipment installed in the buildings during reconstruction. In this case, energy audits are conducted in these buildings. Achievement of energy efficiency standards is a prerequisite for reconstruction and no incentives are applied to stimulate for example energy production from renewable energy sources along with reconstruction of multi apartment buildings.

2. Impacts of climate change affecting buildings in BSR

As stated by the Intergovernmental Panel on Climate Change (IPCC) Working Group I in the Report "The Physical Science Basis" - climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes. Addressing the most up-to-date physical understanding of the climate system and climate change, the report presents the findings *inter alia* for Europe. It highlights the increase in hot extremes, heavy precipitation in Northern, Western and Central as well as Eastern Europe and the increase of agricultural and ecological drought particularly in Western and Central Europe. Projections show that at 1.5- 2°C global warming, heavy precipitation and associated flooding are projected to intensify and be more frequent in Europe. Mean precipitation is projected to increase in northern Europe.[72]

Potential climate change trends particularly in the Baltic Sea Region (BSR) have been explored in several studies.[73,74,75] It is assessed that in the Baltic Sea Region **temperature** will increase during winter, particularly in the northern parts of the region. **Precipitation** is expected also to increase mainly in winter, while there is a higher uncertainty about summer precipitation – in southern parts of the region a chance of drought is larger than in the northern parts. In general, the amount of **snow** is expected to decrease; snowmelt episodes will become more frequent. Projections indicate a slight increase in average **wind speed** over the Baltic Sea. **Climatic extremes** (e.g., high/low temperature, precipitation) are expected to be more common and severe. Due to climate change, the water temperature in the Baltic Sea will rise, while the ice cover as well as salinity will reduce due to increased precipitation and river runoff.[76] Over the last three decades, relative sea level has increased by 1.5–2.5 m along the Baltic Sea coast. [77]

It has been assessed that urban built-up areas are often more vulnerable to climate change impacts than buildings in rural landscapes. Various risks and impacts to the existing and building stock in the BSR can be associated with certain climate change variables e.g., precipitation, temperature, wind, flood and sea-level rise, water scarcity and droughts.[78,79] A summary of the most common climate change related impacts relevant for existing buildings in the BSR are highlighted here in a concentrated form (see Table 2.1).

Table 2.1. Climate change related impacts on existing building stock in the Baltic Sea Region.

Climate factors	Negative impacts	Positive impacts
Precipitation	• Higher humidity damaging building facade materials and increasing the corrosion of steel. • Heavy rains putting additional load on external walls and windows • Penetration of moisture in building (insulation) materials reducing their effectiveness.	• Increased energy generation in solar electricity panels (PV) during winter season • Decrease of snow cover reduces the need for cleaning solar panels thus increasing their energy output. • Reduced snow accumulation load on roof tops.

Climate factors	**Negative impacts**	**Positive impacts**
	• Risk of pooling of rainwater on flat roofs and penetration of rainwater into building structure. • Growth of moss and fungi in building structures causing biological corrosion of materials and exposing residents to mildew and mould spores. • Additional drainage is needed in surfaced built-up areas. • Increased precipitation can cause landslides in hilly areas.	
Temperature	• Reduced lifespan of building facade materials e.g., paints, varnish, plastic, wood, and rubber. • Increased indoor temperature during hot extremes requires investing in cooling systems.	• Reduced need for heating at homes. • Reduced freezing and degradation of concrete and brick building structures. • Larger variety of possible plant species for green roofs and facades.
Storm and wind	• Increased heating needs during storm periods, additional windbreak technologies are necessary • Additional pressure on roof and other structures, strengthening stability standards would be required	
Flood and sea-level rise	• Moisture damage to construction materials of buildings walls and basement. • Need to install appropriate local drainage system around the foundation. • Need for soil and surface planning over a larger area	
Droughts	• Need for more drought-resistant plants in urban greenery.	

As indicated in the Table 2.1., climate change impacts for buildings can be either positive or negative. Considering this large variety of possible impacts, appropriate **measures** shall be implemented during renovation of buildings for climate change mitigation, at the same time increasing their capacity for climate resilience and last but not least ensuring the well-being of the respective residents. Measures for climate change mitigation are generally universal and should be focussed on reduction of GHG emissions e.g., by increasing energy performance of multi apartment buildings. Selection of adaptation measures is more dependent on the location of buildings, local circumstances and particular climate change risks related to the area. In practice, there is less choice of possible measures that can be applied during renovation of buildings in comparison to possible solutions for new constructions. Studies show that the application of climate change mitigation measures in the building renovation process is more prevalent. Implementation of these measures has a greater impact on climate change adaptation, than vice versa. In cases where adaptation measures have been included or combined with mitigation measures, it has been acknowledged that this was more a coincidence than an intentional decision. Such practice could be explained by the fact that specific climate change mitigation objectives of the EU and national co-funded projects do not focus on adaptation as a particular issue.[80]

3. Recommendations

This chapter provides recommendations to be considered for application during the renovation of multi apartment buildings via the implementation of climate proofing energy efficiency projects. Nevertheless, most aspects highlighted here are also relevant and applicable for other building types and for new constructions. These recommendations are derived from the knowledge gained during the implementation of various EU funded projects, good practice examples from renovation projects of buildings in the project partner countries, which considered both climate change mitigation and adaptation aspects. The list of all recommendations presented in this chapter is available in Annex II.

Measures for mitigation of climate change – measures that are taken to reduce greenhouse gas emissions.

Measures for adaptation to climate risks – measures that reduce the vulnerability or avoid the negative consequences of climate change events e.g., high temperatures, heat waves, flooding, backwater intrusion into the building, water leakage, snow and frost and storm damage, landslides.

Renovation - the process of improving or modernising an old, damaged, or defective building.

Major renovation – renovation of a building when the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25% of the value of the building, excluding the value of the land upon which the building is situated; or more than 25% of the surface of the building envelope undergoes renovation.[81]

Deep renovation - renovation reducing primary energy consumption over 60%; — medium (between 30 % and 60 %); and — light (less than 30 %).[82]

Climate proofing energy efficiency renovation projects - building renovation projects that apply measures that help to reduce greenhouse gas emissions and adapt to the effects of climate change at the same time.

While measures for climate change mitigation focus on reduction of energy consumption and the related GHG emissions, implementation of climate change adaptation measures are required to ensure the long-term integrity and successful operation of the built environment.[83] Utilising synergies of measures for climate change mitigation and adaptation in building renovation helps to increase the energy performance of the building and at the same time improves the resistance against climate change events. While a large variety of options and innovative measures can be applied to address climate risks and reduce greenhouse gas emissions when constructing a new building, building renovation poses certain limitations when it comes to creating a set of measures that can be utilised due to conditions of the existing building stock, geographical peculiarities, legal requirements etc. Measures to be considered during energy efficient and climate proof renovation of multi apartment buildings can be related to building envelope; building materials; energy supply; heating, ventilation, air conditioning, lighting; water supply and use of water; building surroundings, as well as management, quality control and monitoring of results. The list of measures in all categories can be extended and upgraded according to real, introduced, and incubated technologies. Possible measures to promote renovation of multi apartment buildings are also included in this chapter. Nevertheless, it must be admitted that not all measures are universally applicable - application of solutions depends on current structure of a building. Cost-effectiveness also needs to be considered in each case individually.

3.1. Building envelope

A building envelope is often described as a 'shell' of a building that keeps the outside separate from the inside. It can be considered as a sub-system of the whole building combining several elements (basement, walls, roof, windows, doors, and external shading elements e.g., shutters) ensuring structural integrity, light, moisture, temperature, noise control, air pressure boundaries into a single design strategy of a building. An additional important aspect of the building envelope is its fire resistance.[84, 85]

Table 3.1.1. Measures related to building envelope and their possible implications for climate change mitigation and adaptation.[86]

Measure	**Adaptation**	**Adaptation with implication for mitigation**	**Mitigation with implication for adaptation**	**Mitigation**
Stronger walls and roof structure	✔			
Moisture removal	✔			
Gutter sizing	✔			
Elements fastened to buildings	✔			
Moisture-proof building materials	✔			
Reflective materials		✔		
Green roofs		✔		
Air tightness			✔	
Insulation			✔	
Glazing technologies			✔	
Shutters			✔	

The external walls and roof of a building function as a climate shield to protect tenants against high or low temperatures, precipitation, strong winds, fire etc. **Stronger load-bearing walls and roof structure** help with adaptation to extreme weather conditions (storms), however at the same time may mean higher carbon footprint of materials.[87]

1\. **During renovation of a building, the embodied energy of various construction materials should be considered, so that the gains from improving the load bearing of a building can be compared to the related carbon footprint.**

Hygrothermal performance and moisture safety are important aspects to be considered during building renovation.[88] Excessive accumulation of moisture within the building increases the likelihood of structural damage as well as reducing the indoor comfort for tenants. Therefore, it is important that appropriate **moisture removal** measures are implemented. Water leakage from water pipes, heating systems and the roof should be prevented wherever possible and, if it occurs, should be eliminated as soon as detected. Inside the building relative humidity should be kept between 30% and 60% for indoor environments. Long periods of relative humidity below 30% can cause drying of the mucous membranes and discomfort for many people while relative humidity above 60% for extended time periods promotes indoor microbial growth. Most excess moisture production can be removed by the ventilation system.[89]

2\. **Renovation of a building should ensure that excessive accumulation of moisture is prevented, whilst at the same time ensuring sufficient vapor permeability to allow dry-out of constructional moisture.**

A gutter is part of a building's water discharge system. It is a trough or channel that runs around the perimeter of a roof, and collects rainwater runoff from the roof, discharging it to rainwater downpipes and conveying water to a drainage system. The gutter system protects the building envelope from damp and potentially suffering damage. Appropriate **gutter sizing** for each specific building can be calculated by considering the area of the roof and the anticipated rainfall intensity.[90]

3\. **Appropriate gutter systems have to be installed during renovation of multi apartment buildings.**

Stronger attachment of **elements fastened to buildings** (gutters, antennas, and lights) enhance the adaptation of existing buildings to changing climate impact.[91]

4\. **During renovation, stronger attachment of various elements fastened to buildings will increase the resistance against the impact of storms.**

Floods, storms, and heavy rains increase the risk of water penetration into the building. Excessive moisture has a negative impact on building, as well as on indoor climate, causing health problems for tenants. Therefore, measures must be taken to prevent water intrusion and condensation in areas of a building that must remain dry. Construction elements must be able to withstand water pressure or current so that the water is able to run off or be pumped away easily.[92] Application of **moisture proof building materials** can help the building construction to resist moisture, to prevent the growth of mould and to increase the lifetime of the building.

5. **During renovation of multi apartment buildings, materials specifically designed to resist moisture and mould should be incorporated and applied for basement, external walls and roof, insulation.**

Reflective materials can be applied to different types of building components e.g., outdoor finishing and painting of external walls, roofs, thus helping to reduce heat gains from solar radiation and also to reduce energy demand accordingly, by minimizing the air conditioning need to cool buildings. Due to their optical properties, reflective materials stay cooler than standard materials under the same conditions. Highly efficient technologies include light-coloured polymeric paints, reflective coatings, and inclusion of reflective pigment within the material, which all help buildings to remain cooler during summer days. Besides improving indoor comfort and reducing energy consumption by decreasing air conditioning needs, application of reflective materials decreases temperature of building elements which may extend their service duration. Nevertheless, the cost effectiveness of reflective materials depends on the type of climate and the building insulation. Moreover, in warm, moist locations, cool roof surfaces can be more susceptible to algae or mould growth than hot roofs, meaning appropriate roof treatment with chemicals might be necessary. In cold climates, roofs can accumulate moisture through condensation, and it is possible that cool roofs might be more susceptible to accumulating moisture than dark roofs of the same design. Proper design techniques are required to avoid condensation.[93]

Reflective materials can also be applied indoors, for example, to reduce heat loss during refurbishment of buildings, a cheap and effective measure is to install behind the heaters heat-reflective screens made from foil materials.[94]

6. **Cost effectiveness of application of reflective materials on the exterior of a building during renovation process should be evaluated, taking into consideration local climate conditions and type of the building.**

Green roofs are multi-layered systems that cover the roof of a building with vegetation and/or green landscaping over a drainage layer. Installing green roofs offers an opportunity to adapt our buildings to the effects of climate change and extreme weather events, helping with the absorption of rainwater, provision of insulation for our homes, as well as the further greening of cities and towns.

Typically, green roofs comprise a surface vegetation layer, substrate, geotextile filter layer, and an aggregate or geo-composite drainage layer. The green roof materials are underlain by a waterproof membrane, with an additional layer of insulation between that and the roof itself. Green roofs are designed to intercept rainfall flowing through the vegetation and a drainage layer. The application of green roofs is possible for all types of buildings and they can be grown on any pitch of roof (roofs with a pitch greater than 1 in 3 may require additional support and may have other specific design requirements). Green roofs can capture stormwater and return it to the atmosphere through transpiration and evaporation. Plants remove air pollutants and greenhouse gas emissions, as well as helping to reduce air temperature. Due to their thermal efficiency and acting as natural shade and a heat-absorber for a building, green roofs help to reduce the energy use for heating in the winter and cooling in the summer. Therefore, green roofs, but also roof gardens as semi-natural environmental elements can serve both as an adaptation and a mitigation measure and help against heat waves and urban heat islands.[95,96,97] Roof gardens and green façades can also "soften" hot extremes, along with CO_2 sequestration and energy saving potential. However, it must be admitted various restrictions and possible implications must be considered prior to installation of green roofs and integration in the building renovation project.

There are several good practice examples of the installation of green roofs on new and existing buildings in Europe, e.g., in Hamburg and Helsinki. For example, in Hamburg there is a subsidy program for new buildings and renovations which incentivises builders and building owners to green their roofs.[98,99]

7. **Consider possibility of installing green roofs, roof gardens during renovation of multi apartment buildings.**

One of the preconditions of high energy efficiency is to ensure an excellent **air tightness** of the whole building. The external building envelope should be airtight to prevent uncontrolled cold air infiltration. In practice, there is no air infiltration through the massive building wall. The main source of air leakage is poor quality construction of wall/windows, roof/wall, ducts intersecting walls, and panel junctions. Such areas should be properly sealed to avoid air leakage. This will prevent draught, protect against moisture damage, and minimize energy losses. The change of air rate is determined by division with the internal air volume of the building. Values for the air-change-rates (n50) are usually defined by national building codes. However, an airtight building has both positive and negative properties. The negative impact is the lack of natural air supply and additional costs for equipment and use of mechanical ventilation. [100]

8. **To minimise heat loss, during renovation, the air tightness of a building should be ensured, along with planning for air exchange by an appropriate ventilation system, preferably, recovering heat from the exhaust air.**

An excellent **insulation** helps to minimize heat loss through the building and in addition, thermal indoor comfort is increased. The design and installation of insulation largely depends on climatic conditions and the selected method of construction. An important aspect of insulation materials is their fire-resistance properties. It must be ensured that insulation materials used are waterproof or properly protected against moisture. Concerning energy efficiency, several values characterise the insulation properties and can be used to compare insulating values of different materials[101]:

Values	Description
Thermal conductivity, λ, [W/mK]	Measure of how easily heat flows through a specific type of material, independent of the thickness of the material in question. The lower the thermal conductivity of a material, the better the thermal performance - the slower heat will move across a material.
Thermal resistance R-value, [m^2K/W]	Measure of resistance to heat flow through a given thickness of material. The higher the R-value, the more thermal resistance the material has and therefore the better its insulating properties. The total thermal resistance of the entire wall is calculated by adding the thermal resistance of each separate layer.
Thermal transmittance U-value, [W/m^2K]	Measure of how much heat is lost through a given thickness of a particular material, including the three major ways in which heat loss occurs – conduction, convection, and radiation. The lower the U-value is, the better the material is as a heat insulator. The U-Value is the most common way to judge a material's insulating ability, considering all the different ways in which heat loss occurs.

Insulation of walls. An insulated wall system represents the greatest opportunity to protect the building envelope against energy loss (external walls show the greatest levels of heat losses, followed in importance by ceilings, windows and the floor slab). Insulating cavity walls is a relatively straight-forward process that involves filling the cavity with insulation. Insulating solid walls involves insulation of either the inner or outer surface of the wall. Fire safety requirements have to be taken into account when choosing insulation materials.

Insulation of roof. As hot air tends to rise, uninsulated buildings can lose a substantial amount of heat through their roof. There may also be significant heat gains through roofs during the summer. Insulating a roof, loft, or attic is an effective way of reducing heat loss, the size of heating and cooling systems, energy usage, and the related CO_2 emissions. Selection of the type of roof insulation depends on the roof design, climate, space availability, access, and whether the roof is pitched (sloping) or flat etc.

Insulation of windows. It is necessary to pay attention to the insulation of windows and docking between the walls.[102]

Insulation of doors. Inefficient doors can lose the heat generated in building due to poor insulation. Fiberglass, wood cladding, and steel with polyurethane foam core are among the most energy-efficient door materials.

Insulation of foundation and basement. Foundation and floor slabs should be properly insulated, and the insulation of the foundation walls and basement floor can assist in saving heat. The building perimeter is in rather unfavourable humidity conditions, being subject to both ground and rainwater. For this reason, materials that have zero water absorption and can protect thermal insulation properties in a damp environment are used for perimeter thermal insulation of the basement. Extrusion foam plastic with closed pores fully meets these requirements. In many cases an individual heating unit, networks of hot water supply and heating are located or go through the basement, providing warmth to the first-floor slab in the cold season. It is nonetheless recommended to properly insulate the pipes and the cellar ceiling.[103]

Insulation of hot water pipes. The additional heat losses in pipes usually result in unnecessary overheating of unoccupied spaces, e.g., basement, staircases, and attics. Insulation of all warm water pipes in unheated areas inside the building is necessary to increase energy efficiency of the heating system in a building.[104]

9. **Depending on climate conditions and construction method chosen, a proper insulation of foundation and basement, floor slabs, walls, roof, windows, doors as well as hot water pipes should be properly planned prior renovation (considering heated and non-heated areas) and ensured during renovation of a building. Application of prefabricated (wall) insulation elements shall be considered.**

Windows in multi apartment buildings can be a source of significant amounts of heat loss. According to rough estimations, windows account for 15-25% of the total heat losses of a building. Window components - glass, frame and hardware are all acting together to provide a certain level of energy performance. Over the last fifty years **glazing technologies** for buildings have undergone radical changes and extended the functions and applications. There have been continuous improvements in thermal insulation performance, combined with new methods of modulating solar heat and light transmission. The market is offering high-performance glazing systems regarding the characteristics of thermal insulation, with U-values less than 0.9 W/m^{2}K for double glazing and 0.4 W/m^{2}K for triple glazing. Thus, the smart use of efficient glazing solutions during renovation can ensure positive contribution for energy efficiency reaching low energy or passive building level as well as provision of sufficient daylight to reduce artificial lighting needs.[105, 106] However, to minimise the heat loss potential from windows, aside from glass, the thermal transmittance of window frame has to be taken into account. Moreover, when selecting appropriate window, additional parameters e.g., tightness, rainwater permeability, durability against wind, sound protection, etc. [107,108] Providing new and well insulated glazing, affects the natural ventilation and air exchange of rooms which requires supplementary measures to be implemented in parallel.

10. **During renovation of multi apartment buildings it is recommended to replace old windows with modern, high performance energy efficient windows which provide 20-25% more efficiency due to improvements in both frames and glazing.**

Application of **shutters** can help to increase thermal resilience of tenants. Several types and shapes of shutters are available on construction market having different durability, cost efficiency and functionality. Insulated shutters provide an additional insulating layer to the window during the night, thus increasing thermal resistance when it is most needed.[109] Although installation of shutters on multi apartment buildings (preferably outside of the building) increases shade and helps weather resistance, nevertheless, potentially negative impacts shall be considered i.e., installing external shutters may impede the building's fire safety and resistance. More and more shutters are applied in countries of the Baltic Sea Region, thus learning from building traditions and technologies applied in Southern Europe should be helpful. Along with application of shading elements as part of a building frame, planting trees around the buildings may help to minimise overheating.

11. **Along with installation of shutters on high-rise multi apartment buildings to increase the thermal resilience, fire safety requirements have to be taken into account.**

3.2. Building materials

The selection of building materials for construction and insulation to be applied during renovation of multi apartment buildings during implementation of climate proofing energy efficiency project has a substantial impact on climate change mitigation efforts (see Table 3.2.1.).

Table 3.2.1. Measures related to building materials and their possible implications for climate change mitigation and adaptation.[110]

Measure	Adaptation	Adaptation with implication for mitigation	Mitigation with implication for adaptation	Mitigation
Building life cycle assessment				✔
Energy efficient building materials				✔
Building material durability improvement		✔		
Climate-proof building materials			✔	

Construction, insulation and finishing materials applied during building renovation bring energy savings and help to reduce the GHG emissions. However, to avoid an "eco-balance rebound effect" which counteracts possible energy savings, a separate **life cycle assessment** for each material should be taken into consideration. The eco-balance rebound effect occurs if the energy consumption is shifted and occurs elsewhere. For example, although insulation materials can contribute to a significantly decreased energy demand of buildings, the production of certain types of insulation material, such as polystyrene or glass wool (in comparison to e.g., cellulose flakes) requires a lot of primary energy. Thus, the energy consumption is shifted from the using phase of the residential building to the production phase in the life cycle of the insulation material. In this context, an important parameter to be assessed is the embodied energy of a material. The embodied energy refers to the energy that is consumed during the life cycle of a material, encompassing extraction, manufacturing, maintenance, and disposal, and it can cause GHG emissions in all of these stages. The energy balance of a refurbishment measure should be positive: the insulation system should save more energy over its lifetime than the energy used in the production chain.[111] Different approaches and methods for application of life cycle assessment of building renovation have been described.[112]

The energy efficiency of a renovated building is largely influenced by the performance of energy efficient building materials. For example, the market offers a wide range of insulation materials. Due to the application of new technologies, thermal characteristics of insulation materials are being improved. Therefore, recommendations for the best solutions must be updated constantly. As a general concept, insulation materials should be light-weight and should have minimal thermal conductivity λ. Insulation materials have conductivity values significantly below 0.1 W/mK. Typical thermal conductivity values of common insulation materials are λ = 0.045 W/mK for natural materials, λ = 0.035 W/mK for mineral fibre and λ=0.030 W/mK for artificial foams. A vacuum isolation panel is a relatively new material and has values as low as λ = 0.005 W/mK. This means it is five to ten times better than conventional insulation materials.[113] Besides thermal conductivity, also moisture resistance of the insulation material must be considered.

12. **Insulation and other building materials that have low embodied energy, are lightweight and have minimal thermal conductivity, considering the life-cycle assessment e.g., disposal and various other environmental concerns, should be selected for renovation. Modern materials with extended climate parameters and improved durability are already available and should be applied.**

3.3. Energy supply

Meeting climate policy targets require fundamental transformation of energy (electricity and heat) supply and demand sides. Several climate change mitigation measures related to energy supply can be implemented during major renovation of multi apartment buildings, which having implications for adaptation. Few measures can be primarily intended to increase resilience towards climate change, whilst at the same time creating a synergy with climate change mitigation (see Table 3.3.1).

Table 3.3.1. Measures related to energy supply and their possible implications for climate change mitigation and adaptation.[114]

Measure	Adaptation	Adaptation with implication for mitigation	Mitigation with implication for adaptation	Mitigation
Smart grids		✔		
Changing temperature coping heating systems		✔		
Energy efficient heating systems, including low-temperature heating systems			✔	
Renewable energy heat systems			✔	
Installation of photovoltaic and solar heating		✔		
Automated indoor climate			✔	
District heating				✔
Waste heat utilisation				✔
Green power purchase schemes				✔

Smart grids contribute to both climate change adaptation and mitigation by enhancing system reliability and resilience, as well as increasing low-carbon electricity production. Electricity networks are being permanently modernised by the introduction and refinement of new technologies. Smart grids can be defined as electric power networks that utilizes two-way communication and control technologies, distributed computing, and associated sensors, including equipment installed on the premises of network user. It should cost-efficiently integrate the behaviour and actions of energy generators and consumers to ensure economically efficient, sustainable power systems with low losses, high levels of quality, and security of supply and safety.[115] Resilience to power cuts should be covered by risk assessment providing alternative operating modes.

13.

It is advisable to link the possibilities that are provided by smart grids with introduction of smart metering, reliability of automatic system in case of power cuts, and green power purchase schemes during renovation of buildings.

Regulation of heat consumption by **heating systems that cope with changing temperature** can be performed on a central, local, or individual (at each radiator) level. Qualitative regulation in the water heating system is carried out by changing and maintaining the temperature of the water directed to the devices, which provides a required temperature regime in a room. Quantitative regulation of heat flow of a heating device is provided by changing the amount of a heat carrier (water). Automatic control of the heat carrier temperature in the thermal unit of the building is carried out either by a change in outdoor temperature (in most cases) or room temperature. Individual control systems are

designed to maintain the desired temperature in a room. For individual manual control of a heat flow, heating devices and valves are used. Automatic thermal regulators are installed on the supplying leads of heating devices and water entrances in the heating devices during the reconstruction of heating systems to regulate the indoor temperature. Automatic regulators allow the required room temperature and the level of air exchange in the apartment to be set separately for day and night-time. Temperatures can also be reduced during long absence of tenants. Installation of block valves allows the connection or disconnection of a flat or a riser from the heating system. When the temperature in the apartment is below the value set by the resident, the system automatically opens the block valve of the unit, providing the flow from the heating system to the flat heaters. When the temperature in the apartment exceeds the value set by the resident, the system automatically closes the block valve of the unit and disconnects the apartment from the heating system of the building. [116]
The new generation low temperature heating systems with automated controls improve the efficiency as well these are more adaptive to the changing dynamic weather conditions.

14. **It is recommendable to balance the heating system during renovation of a building, including placing balancing valves, valves on risers or heating devices, depending on how they are connected. Automatic thermal regulators should be installed on the supplying leads of heating devices and water entrances in the heating devices during the reconstruction of heating systems to regulate the indoor temperature.**

Individual heat substations ensure the hot water preparation and the optimal temperature regime of heating systems according to the building specifics and the requirement for thermal comfort. There are two main types of building heating systems - single pipe system and double pipe systems. During a refurbishment, an **energy efficient heating system** has to be installed. For example, as a minimum, it is strongly recommended to exchange old heaters, as it will lead to the reduction of buildings´ heat consumption. A double pipe heating system ensures uniform distribution of heat within the building and provides the possibility for individual temperature regulation. There are not too many ways to implement decentralized heating systems in multi apartment buildings. The two main possibilities are the installation of individual gas boilers or small flat heat substations in each apartment. Both solutions significantly reduce the length of distribution pipes for heating and hot water systems. Heat losses and the resulting exploitation costs can be minimized by application of heat insulation materials on heating and hot water pipes.[117]

Several **renewable energy heat systems** can be applied to ensure the main heating needs or at least to provide a supplementary energy source:

- <u>Solar thermal collectors</u> (both flat-plate and evacuated-tube collectors) are becoming more frequently used renewable energy technologies in the Baltic Sea Region. They should be oriented in the best possible way to capture the solar energy. Filling liquid e.g., plain water is used to carry the heat away for the storage and use. It is possible to achieve operating temperature up to 125°C. Solar collectors can be placed on new and already built houses.

- Biomass boilers work by burning of wood pellets or chips to generate heat for building. Wood fuel is automatically fed into the boiler from the storage area where an electric probe ignites the material. The produced heat is monitored and controlled by thermostats that adjust both fuel supply and fan speed. The hot gasses produced during the burning process flow to the heat exchanger where the heat is passed into the water used for the heating system. Water circulates through a central heating system while heating the building.

- Heat pump technology utilizes the solar heat stored in the ambient air, in the surface water bodies, in the ground or in ground water. Energy is extracted via heat exchange systems and then concentrated in a heat pump cycle. Here the temperature of circulating fluid is raised to 30-50/60°C. Some external energy is required to drive the heat pump – the process of contraction and circulation is driven by electricity (environmentally preffered solution could be electricity produced from renewable sources e.g., photovoltaic). The coefficient of performance (COP) as the ratio of heat output to the amount of energy input is important. Efficient heat pumps work in range COP=3-4. If needed, the heat pump cycle can be reversed and used for space cooling as well.

- Combination of renewable energy technologies. In addition to the renovation of multi apartment buildings, combined renewable energy systems for room heating and preparation of hot water have been applied. For example, a combi-system consisting of flat plate solar thermal collectors mounted on the roof top of a building and a pellet boiler placed in a container type installation outside the building, or solar thermal collectors and a ground source heat pump (ground loop in vertical boreholes) are a few examples implemented in Latvia. [118, 119] Combined systems are more and more widely introduced as it can optimise the costs as well improve energy security and supplies.

15. **Consider installation of a renewable energy technology or combination of them e.g., solar thermal collectors, photovoltaic and biomass boilers as the main or supplementary heating source for the multi apartment building during major renovation project.**

A building's envelope is not only used as a passive, protecting shell, but also as an energy producer. The roof and/or the walls could be enforced with **photovoltaic installation.** Photovoltaic (PV) is the direct conversion of sunlight into electrical energy using special semiconductor components - solar panels. To increase capacity of a plant, several solar elements are usually combined in modules using solar batteries. Solar modules based on silicon crystals convert from 13 to 18% (max 25%) of solar energy into electricity. The overall efficiency of the solar panel system is composed of several factors. During conversion of direct current generated by the solar cell into alternating current, a portion of the energy is lost in the inverter. In the case of an independent power supply, input energy is usually stored in batteries. In this case, the losses occur while charging the batteries.

The length of electrical supply network also affects the power loss. Electricity produced by photovoltaic cells can be used primarily for self-consumption needs and for selling the photovoltaic energy surplus to the grid.[120] Optimal panel layout and energy production (kWh/m^2) can be calculated by using simulation software. [121, 122]

16. **Consider installation of photovoltaic batteries to supplement self-electricity supply of the building during power supply failures.**

The perceived comfort in an apartment or a room depends on various factors, but mainly on indoor air temperature, humidity, and air quality. A healthy climate is vital for our well-being, efficiency, and productivity. In new modern so called 'active houses,' indoor climate regulation is automated. Possible technical solutions for **automated indoor climate** include e.g., effective, and fully automatically and remotely controlled system of movable shadings to react quickly to direct sunlight, thus achieving good summer comfort; hybrid ventilation systems (combining automated window operation, mechanical ventilation, and manual window operation) operating depending on outside temperature. If there is a mechanical ventilation with heat recovery of exhausted air, automated systems can also combine these functions with the regulation of the level of air exchange. [123, 124] At the same time, it is also important to install surge protection, UPS devices, data backup systems and cloud storage solutions that help to deal with power interruption, errors or outage, etc.

17. **When reconstructing residential heating systems, automatic and remote control of indoor climate in each flat or room should be provided.**

District heating plays an important role in heat supply for multi apartment buildings in many countries of the Baltic Sea Region. District heating systems typically consist of a heat generation plant (boiler house, co-generation plant), a network of pipelines and individual heat substations installed in each building. High efficiency co-generation plants can achieve substantial emissions savings compared with traditional plants. Peak load management has to be considered on a heating service providing utility as well as on a building level. Renewable sources such as biomass can be used for combined heat and power which would contribute to the targets set out in the Renewable Energy Directive.[125]

18. **Connection to highly efficient district heating particularly if powered by renewable energy sources can be considered e.g., if many buildings in an area require refurbishment of the existing individual heating system.**

Waste heat occurs in almost all thermal and mechanical processes. The most significant amounts of waste heat are lost in industrial and energy generation processes. Even in modern high-efficiency boilers, waste heat in the exhaust gases is lost to the atmosphere via the boiler flue. In classic boilers, water vapor from exhaust gases condenses in the chimney and is drained away. **Waste heat recovery and utilisation** play an important role in reducing energy consumption and CO_2 emissions. Various methods exist for heat recovery e.g., gas (or vapour) to liquid heat exchange, air-to-air heat exchange, liquid-to-liquid heat exchange, direct ducting of hot air, use of steam power blowdown, heat captured during phase change, and heat recovery from condensers. For example, condensing boilers have extra heat exchanger surfaces to extract heat from exhaust gases and supply it to heating systems. Recovered waste heat can be re-used for several applications e.g., heating water, pre-heating fresh air for building ventilation systems, drying processes, power generation, and pre-heating combustion air for furnaces, boilers. [126, 127, 128]

Moreover, it has been assessed that the application of a combination of solutions e.g., heat recovery and low temperature heating along with automatization and peak optimisation increases energy efficiency and reduces environmental impacts. However, it must be noted that the application of these solutions during renovation of buildings depends on case specific conditions e.g., available space for installations.[129]

19. **Renovation of multi apartment buildings should include installation of waste heat recovery systems and further utilisation possibilities in the building. The optimal regime of operation is critically important to avoid excess energy use.**

Distributed generation is becoming more and more attractive from an electricity customer perspective, due to increasing retail electricity prices and decreasing technology costs. Electricity customers can choose to produce some of the electricity required to meet their needs using their own power plant (e.g., rooftop solar PV system) instead of purchasing it from the supplier. Distribution networks are used to inject excess production and withdraw electricity when self-production is not sufficient to meet own needs. Such an approach helps to meet renewable energy targets, to reduce network losses, to improve demand response and to contribute to CO_2 emissions reduction. It has been acknowledged that there is an important potential for renewable energy production in apartment buildings by applying micro and small-scale renewable energy systems, with an installed electricity capacity below 500 kW. Business models and financial instruments need to be developed to make self-consumption widely accessible to consumers. Commercial arrangement, net metering and net billing are the most common used **green power purchase schemes**.[130, 131] Green power tariffs are becoming less costly, but being rather a powerful incentive for decarbonisation.

20. **New business models and financial instruments which function as green power purchase schemes to promote prosumer practice at multi apartment building level should be applied.**

3.4. Heating, ventilation, air conditioning, lighting

Along an air-tight building envelope, energy efficient heating, ventilation, air conditioning and lighting are prerequisites for a successful result in climate proof energy efficient projects. Most of the measures that can be implemented during the renovation of multi apartment buildings mainly have an impact on climate change mitigation, but many of them also help to increase the climate change resilience of the building (see Table 3.4.1.).

Table 3.4.1. Measures related to heating, ventilation, air conditioning, lighting and their possible implications for climate change mitigation and adaptation.[132]

Measure	Adaptation	Adaptation with implication for mitigation	Mitigation with implication for adaptation	Mitigation
Thermostatic valves and smart meters			✔	
Efficient air conditioning			✔	
Natural ventilation			✔	
Heat recovery ventilation			✔	
Moisture removal in ventilation units		✔		
District cooling		✔		
Upgraded lighting system				✔
Storm proof electricity system	✔			

In multi apartment buildings, heating is typically provided by central heating systems, in which heat is distributed from a central source to individual apartments, however, localised heating systems are also commonly used. It goes without saying that everyone has their own preferred indoor temperature where they feel most comfortable. Therefore, it is good if heat from radiators can be adjusted according to individual needs during the heating season. **Thermostatic valves** allow radiators to be turned on and off when temperatures rise or fall to certain levels. They also regulate the way water flows through the radiators they are attached to but they do not directly control the boiler. Thermostats with remote sensors are used in cases where air circulation is limited and there are hot or cold air pockets (for example, heavy curtains, low internal surface wall temperature or frequent, lengthy window opening).

A digital thermostat makes it possible to program room temperature for long time periods (week, month) according to the needs of the inhabitants. It is possible to program automatic temperature reduction during the day and night. The digital thermostat automatically ensures temperature increase before apartment dwellers wake up in the morning or return home from work in the evening. Special thermostats which include a room temperature sensor are available for floor heating. According to the set temperature, the thermostat regulates heat supply. This kind of thermostat can be used in combination with the water system and the electric system.[133]

21. **Providing the opportunity to adjust room temperature in each room by installing thermostatic valves on every radiator during renovation of multi apartment building increases indoor comfort for tenants.**

Strong prerequisites for encouraging flat owners to implement energy saving measures include providing them with the means to adjust indoor temperature and monitor household heat consumption, as well as making payments depend on the level of individual consumption (instead of just depending on the total space of heated area of the apartment). Devices commonly known as "**smart meters**" are available to ensure accurate, real-time measurements, and appropriate billing; this information can be communicated through a customer display. There are two possible solutions that can be applied during renovation of a building in cases when is it likely that either renovation of the heating system or construction of a completely new heating system will be required. The heat consumption in apartments can be monitored by:

1) direct heat metering that can be implemented on double-pipe systems with loop distribution in apartments. Direct heat meters measure the amount of consumed heat by measuring the water flow and temperature difference between supply and return water. This kind of meter has to be installed in each apartment within the building - it measures the overall heat consumption of a flat, but not in single rooms. Individual heating costs are calculated by aggregating the cost of the measured heat consumption of the apartment, heat consumption resulting from the heat loss from heating pipes and heating of staircase. It measures the actual heat consumption in easy-to-understand units (in kWh) and it is simple to split the costs among apartments, meaning that a complicated calculation method is not required. The meter should be regularly inspected e.g., once every 2 years. Some parts of a meter are in contact with the heating fluid, thus there is a risk that these parts will become damaged. If the meter is installed outside the apartment e.g., in the staircase, it is easy to obtain the measurement data.

2) electronic devices called heat cost allocators that provide data for the billing of individual residents' usage of the heating system. Heat cost allocation is an accurate way to distribute heating costs where conventional metering is not possible. Heat cost allocators are suitable both for single-pipe as well as for two-pipe heating systems. They can be installed on practically all types of radiators – on new panel type radiators made of steel as well on section type radiators e.g., on old cast iron radiators (the exception being floor heating systems). Heat cost allocators do not measure real heat consumption but define each heating element's share of the building's total heat consumption. The total heat consumption of the building is measured by a direct heat meter in the heat substation. The total costs are divided between all heat cost allocators according to their share; thus, these devices must be attached to all heating elements in the building. A heat cost allocator system works automatically and there is no need to control the operation of devices from the residents' side. The cost for heating for residents in multi apartment buildings consists of the cost for heat consumption in the flats and for the heating of staircases and risers. [134, 135]

Of course, neither heat energy meters, nor heat cost allocators, directly reduce heat consumption, but rather encourage consumers/users to pay more attention to their heat consumption habits. Nevertheless, it can result in significant energy savings of 20-35% in buildings connected to a district heating network.[136]

22. **Include the possibility for tenants to pay according to their own heat consumption by installing heat energy meters or heat cost allocators.**

It is typically assumed that overheating starts at an indoor air temperature above 28°C. Instead of traditional air conditioning systems with compressor and halocarbon refrigerants, modern **efficient air conditioning systems** can be used for space cooling in summer. Nevertheless, it should be kept in mind that even energy efficient air conditioning systems still consume a lot of energy, thus installation of an air conditioning systems should be the last resort (not the first choice).[137]

23. **During renovation of multi apartment buildings the favoured options should be the application of passive methods to prevent overheating i.e., installation of proper external shading devices e.g., different blinds and curtains rather than air conditioning appliances.**

Ventilation (air exchange) is necessary to replace the exhausted indoor air (including removal of air pollutants e.g., carbon dioxide (CO_2), moisture and odours) by fresh air from the outside. Almost all existing apartment buildings have **natural ventilation** systems. Fresh air flows into apartments through gaps between the window frame and the window itself or by opening the windows. Sealing a building to increase energy efficiency significantly reduces the natural ventilation. Decreased ventilation can lead to accumulation of water vapour in flats (ca. 8 - 15 litres per day). Abrupt changes of air temperature can transform water vapour into moisture that condenses on the walls. Poor air exchange, high humidity and air stagnation promote the growth of mould. Mould can spread extensively – on the plaster, concrete, plastic, and may cause growth of mould on surfaces. Moreover, poor ventilation stops CO_2 from flowing outside and oxygen from flowing in to replace it. Thus, a poorly ventilated building will have a higher concentration of CO_2 than a building with good ventilation. For maintaining good indoor quality appropriate ventilation rate (the volume of air in a house being replaced each hour) shall be followed. Low values may cause a risk of not removing contamination properly, while high ventilation rates may require more active room heating.

A climate proof energy efficient renovation project should include an air exchange concept that guarantees a certain amount of fresh air independent of the tenants' ventilation practices. Controlled ventilation systems are technical solutions to provide fresh air, to minimize the risk of moisture and mould and, finally, to minimize ventilation heat losses. Window/shaft ventilation is one of the simplest possible concepts of natural ventilation that can be applied during the renovation of a multi apartment building. In this case, fresh air comes in through very small artificial openings between the frame and the window. These openings are optimized in a way that the air can circulate without getting too cold. The exhaust air will vent to existing shafts in the bathrooms.[138]

However, to maintain an appropriate indoor environment, climate proof energy efficient building renovation projects should preferably include the installation of a controlled mechanical **ventilation system with heat recovery** (if possible, e.g., due to historic or other limitations). Heat recovery ventilation systems offer a solution by allowing fresh air to enter a building without letting cool air affect the inside temperature. Heat recovery ventilation units provide a constant source of fresh air to homes while extracting moist and stale air. Heat recovery ventilation units enable buildings to retain their existing heat, unlike passive vents or windows. They use an internal heat exchanger which transfers heat energy from the outgoing airstream to the incoming airstream. As a result, households using heat recovery significantly reduce the energy costs associated with heating. Heat recovery ventilation units create a self-contained environment where the air is kept at a constant temperature.[139] Such systems can be easily implemented in multi apartment buildings during the renovation process. Crossflow, rotary, and counter-flow heat exchangers are usually used to ventilate multi apartment buildings.[140]

A cost analysis of different ventilation strategies (natural ventilation through windows, natural ventilation using inlet valves with natural exhaust, hybrid ventilation with inlet devices in walls and mechanical exhaust, decentralized mechanical ventilation with room based heat recovery, decentralized mechanical ventilation with apartment based heat recovery and building based centralized ventilation system) for multi-story apartment buildings in Latvia and Estonia has been performed by comparing installation costs, annual running and maintenance costs. The results show that the most cost-effective system over a longer period is centralized ventilation system which serves whole building.[141]

24. **During renovation, it is advisable to install a centralized ventilation system which serves the whole building, preferably with heat recovery, if possible.**

There can be several reasons for water penetration into a building e.g., a leaky roof, ruptured pipes, flooding, etc. In homes where the humidity level rises above 60%, moisture can start building up around the vents. Growth of mould is the main concern related to excessive moisture and penetration of water inside the ventilation units. The air ducts provide all the necessary sustenance for a mould outbreak. As a result, the mould spores are spread rapidly throughout the home via the vents, thus reducing indoor air quality and triggering health problems in tenants. Keeping the vents clean and dry and keeping the home's humidity level below 60% helps to maintain a comfortable indoor climate.[142] Aside from mould growth, moisture inside the air ducts can over time reduce the efficiency of insulation, leading to energy loss. Besides, water damage to the walls, ceilings and roof can result from moisture inside the air ducts. Excess moisture can gradually be a cause of corrosion or decay in these materials. If left unaddressed for prolonged periods, the structural ruin can compromise the integrity of the building.

Clean, dry air ducts are instrumental in efficiently moving heated or cooled air throughout a home. Therefore, when water intrudes, it is critical to promptly **remove moisture in ventilation units** e.g., air ducts and vents.[143]

25. **It is advisable to monitor the humidity inside the home e.g., by hygrometer, and implement long-term solutions to attack the source of the moisture problem within the air ducts. Mould problems in air ducts can be dealt with by using air scrubbers and hydroxyl or ozone generators to scrub the air.**

Due to climate change, there are already buildings in which the cooling load is higher than the heating load in the Nordic and Baltic climate conditions. Moreover, buildings without appropriate cooling systems may lose their market value. Traditionally, comfort cooling is based on electricity to run the individual appliances. Consequently, electricity demand grows with the expansion of traditional air-conditioning.[144, 145]

Since recent years, **district cooling** is complementing traditional district heating and combined heat and power production in cogeneration. District cooling provides chilled water for indoor cooling purposes to industrial, commercial, and residential buildings through a closed loop pipe network in the high-rise and dense urban districts. Functionally and technically, it is like district heating. The cold water used in a district cooling system can be produced from local natural resources e.g., sea, lakes, rivers, or ground water, or it can be produced from sources like waste heat with the use of steam turbine-driven or absorption chillers or electric chillers. The efficiency rate is 5-10 times higher than that of a traditional cooling system and can reduce cooling energy consumption by 50% through its higher energy utilization. A network with electric chillers for cold storage helps reduce peak electricity demand for cooling in a city by shifting production to periods of the day or night when there is less run on the electrical network. Because of its combination of renewable and surplus energies, district cooling emits significantly less CO_2 than conventional cooling systems and emits no hazardous refrigerants.[146] An alternative could be the installation of air-to-air heat pumps as an additional heating system which could then provide cooling during extreme heat days.

26. **During renovation of a multi apartment building consider connecting it to district cooling, if technically possible.**

Upgrading lighting system e.g., in staircases during the implementation of multi apartment building renovation brings additional energy savings for tenants. Electricity in the staircase is usually only needed for a relatively short period of time - mostly when walking on stairs, shutting, or opening the apartment doors, etc. Electrical switches are often in inconvenient places in multi apartment buildings and residents can forget to switch them off when leaving the building or when entering the apartment. There are several solutions. The simplest option of replacing incandescent light bulbs with more energy efficient halogen, fluorescent and LED bulbs is already a common practice.

Additionally, there are solutions that require certain installation works meaning implementation during building renovation is preferable:

- switches equipped with a time relay which automatically switches off all the light bulbs in the staircase after a certain amount of time has passed. They need to be installed by the main entrance door and on each floor. The main disadvantage of this solution is that if the simplest version is put in place, the switch will simultaneously turn on all light bulbs on all floors, which is not always necessary.
- motion sensors which turn on the bulbs in response to motion and turn them off a short time after the movement has stopped. Use of motion sensors is straightforward because there is no need to look for a switch or to turn it on and off. The bulb only lights up when someone opens the door

and moves in a staircase. The sensitivity and shutter time of motion sensors can be adjusted. It is important that the sensor covers a large enough area and responds not only to the movement of people, but also to the opening of apartment or elevator doors. A motion sensor must be installed at the entrance and on each floor. Installation, of course, requires additional costs, but the benefits are the ease of use and electricity savings. If motion sensors are used, the traditional incandescent light bulbs can be replaced with halogen or LED bulbs as they light up instantly and are not sensitive to being frequently switched on and off. [147]

27. **Consider upgrading the lighting system e.g., by installing motion sensors and energy efficient light bulbs during renovation to bring additional energy savings. It can be implemented independently of deep renovation.**

A warming atmosphere is giving extra energy to storms, thus making them more intense today than they were in the past. This trend is projected to accelerate in future. These stronger storms are more likely to cause power outages. **Storm proof electric systems** can maintain some level of operations during storms, and quickly recover from storm-related damage. To promote system efficiency and resilience, electric utilities are deploying "smart grid" sensors and control technologies, which can pinpoint line segments with power failures and reroute power flows, thus helping to speed up restoration efforts. Other possible solutions include distributed energy sources, e.g., solar photovoltaic systems with electricity storage possibilities. The appropriate measures and the level of system hardening must be addressed in the context of the perceived risks from climate change at a local or regional level along with e.g., demand for electricity for heating, cooling, and lighting. [148, 149]

28. **Consider installing a PV system equipped with electricity storage capacities during major renovation of multi apartment buildings.**

3.5. Water supply and use of water

Water should be considered as a critical element for sustainable development and an essential resource for all human activities. Therefore, a comprehensive water management and sustainable water use concept should also be applied in the housing sector (see Table 3.5.1).

Table 3.5.1. Measures related to water supply and use of water and their possible implications for climate change mitigation and adaptation.[150]

Measure	Adaptation	Adaptation with implication for mitigation	Mitigation with implication for adaptation	Mitigation
Efficient water systems	✔			
Rainwater use		✔		
Solar water heating			✔	
Hot water circulation				✔
Drain water heat recovery				✔

Installation of **efficient water systems** e.g., water-saving toilets, taps and other water-related appliances help to reduce water consumption, thus supporting climate change adaptation. Moreover, measures for efficient use of water may include options for utilisation of so called ‘grey water’ - wastewater from non-toilet plumbing fixtures such as showers, basins, and taps. Appropriately treated greywater can be reused indoors e.g., for toilet flushing.

29. **Consider substituting existing water-related appliances in buildings during major renovation.**

Rainwater use can supplement the main water supply required for a building. Rainwater harvesting is a process of collecting and storing the rainwater that falls on a catchment surface. The roof of a building serves as an effective catchment area. This reduces demand on the mains supply, offers some resilience from local supply problems and reduces the amount of energy used for water treatment and transportation. Collection and diversion of surface run-off can also mitigate flood risk and control drainage as part of a sustainable drainage system. Rainwater is a relatively clean water source, needing only minimal treatment e.g., UV filtration. Collected water can be used for non-potable purposes e.g., flushing toilets and urinals, supplying washing machines, irrigation systems, vehicle washing, sprinkler systems. It is claimed that up to 50% of domestic and 85% of non-domestic mains water supply can be replaced in this way.

Several types of rainwater harvesting systems are available. However, it is important to keep in mind that rainwater harvesting in buildings involves various items, technology and materials. The development process of a rainwater-harvesting system in buildings comprises planning, design, construction, and maintenance. The practice of rainwater harvesting has been found to be reliable where sufficient rainfall occurs and adequate catchment is available to collect rainwater.[151, 152] Harvested and stored rainwater is also useful for watering vegetation during the draughts.

30. **Consider installation of rainwater harvesting system during building renovation.**

Solar water heating systems include solar collectors and storage tanks. Different types of solar collectors can be used for heating the water. Solar collectors use the sunlight to heat up the water passing through the inside tubes. To heat 100 litres of water, the solar plant should have 2 - 3 m^2 of solar collectors. This water heating system will provide a water temperature of 90°C on a sunny day and 50°C in winter. The most effective and popular solar water heaters can be easily integrated into existing heat and hot water supply systems. They are suitable for all climate types and are recommended for areas with low temperatures (to -50°C) and low values of solar radiation. The collector, equipped with a controller, automatically maintains the optimal parameters of circulation, has an anti-freeze mode, and provides the desired temperature. If the solar activity is insufficient, then the controller can install an additional electric heater in the storage tank.[153]

31. **Consider installation of a solar water heating system to supplement the main heat and hot water system during renovation of building.**

Instead of having to wait for the water to heat up every time when required, **hot water circulation** allows tenants to benefit from an immediate supply. At the same time, domestic hot water circulation causes substantial energy losses. It has been estimated that the total thermal losses of a domestic hot water distribution circulation loop range from 28.9 to 65.2 kWh/m^2 per dwelling area annually for different standard design buildings. During heating season, the heat losses from the hot water circulation loop are recoverable for heating needs (heat gains as part of total heating balance of the building). Therefore, a balance between comfort and energy savings should be found, e.g., by optimising the distribution network of the circulation pipes - replacing all or some of the distribution pipes with one well insulated larger diameter central pipeline; installing hydraulic flow controllers (thermostatic, self-acting, proportional valves) on each section of the domestic hot water circulation loop to ensure a balanced flow.[154]

32. **Balance comfort and energy losses by optimising the tank capacities and the distribution network of the circulation pipes during the renovation of a building. Use as much as possible heat saving (hot water).**

Drain water heat recovery systems are designed to capture the heat that is lost from hot water going down the drain. Drain-water heat recovery technology is suitable for all types of water heaters. Drain-water heat exchangers can recover heat from the hot water used in showers, bathtubs, sinks, dishwashers, and clothes washers. If complemented with a storage capacity unit, the recovered heat can be stored for later use. By preheating cold water, drain-water heat recovery systems help to increase water heating capacity. As a result, these systems reduce energy consumption for hot water preparation and respectively help to reduce CO_2 emissions (the cost-effectiveness depends on volume and other factors).[155]

33. **Consider installation of drain water heat recovery systems during renovation, which can be particularly cost effective for buildings with significant domestic heat water consumption.**

3.6. Building surroundings

Complex refurbishment measures can lead to synergies for further improvements of living conditions in buildings and their surroundings. There are several measures related to building surroundings that can be implemented during complex renovation of multi apartment buildings. Along with renovation works, it is a good moment to redesign and rearrange the surroundings of the building and to improve the layout of courtyards or entrances. Possible measures can be attributed to architectural forms, particularities of location and the related landscape in the building neighbourhood. Implementation of such measures can have an impact either on adaptation or on mitigation or create synergies (see Table 3.6.1.). The surroundings and landscaping is quite often underrated in terms of adaptation capacities, and it turns out increasing of the non-permeable surfaces e.g., for parking in a course of renovation.

Table 3.6.1. Measures attributed to the architectural form, location and landscape around the building and their possible implications for climate change mitigation and adaptation.[156]

Category/measure	Adaptation	Adaptation with implication for mitigation	Mitigation with implication for adaptation	Mitigation
Architectural form				
Passive solar heating		✔		
Shading elements		✔		
Location				
Protection against sea/river water level rise	✔			
Renewables				✔
Infrastructure of energy efficient engineering systems				✔

Category/measure	Adaptation	Adaptation with implication for mitigation	Mitigation with implication for adaptation	Mitigation
Reconsideration of mobility concepts				✓
Landscape				
Permeable pavements	✓			
Plant cover maintenance	✓			
Planned greenery	✓			
Sustainable storm water systems	✓			
Bicycle parks			✓	
Electrical charges				✓

Architectural forms

Planning of a building renovation including the implementation of a climate proofing energy efficiency projects should not omit evaluation of possible options for the utilization of solar radiation. **Passive solar radiation** raises the internal temperature of the building, helping to reduce the heat demand in winter. Using this option increases climate resilience and offers benefits in terms of energy savings for heating.

34. **Consider technological possibilities for utilisation of passive solar radiation.**

Shading elements are used to control the amount of heat and natural light that is admitted into a building. Installing and properly operating solar shading can save energy for cooling, heating, and artificial lighting. It maximizes natural light, keeps full colour rendering of transmitted light, reduces glare, and filters daylight, which helps to reduce overheating. Dynamic solar shading, which self-adjusts during the day, can generate cooling energy savings of more than 36% when averaged across all glazing types and climate conditions in Europe. These can be artificial shading elements (e.g., external blinds, curtains). During a summertime external shading options are much more efficient than indoor shading. Eaves or balconies along the southern facades are another possibility to avoid overheating in summer and to optimize solar gains in winter. Nevertheless, natural shading elements such as trees can also be used efficiently.[157] This aspect is becoming highly relevant as low-tech and related to the flexible interiors.

35. **Consider installation of external shading elements to control the amount of heat and natural light that is admitted into a building.**

Location

More extreme precipitation events under climate change conditions will mean a higher risk of sea water level rise and as well as river floods. Seemingly harmless little rivers can suddenly flood settlements during such events. Renovation of buildings located nearby water bodies in the flooding risk areas should consider the probability of **water level rise** and the related negative impacts it can have on construction during next decades. Appropriate climate resilience measures e.g., protective belts, dams, should be implemented to protect building against flooding due to sea/river water level rise, but also against floods caused by heavy rains.

36. **Evaluate the necessity of installing constructions e.g., belts, dams to protect building against flooding due to water level rise in water bodies.**

Along with increasing energy performance of buildings by improving the building envelope and upgrading the technical infrastructure, the reduced heat demand can be fully or at least partly covered by **renewable** energy produced on site. This makes it possible to reduce the dependency of buildings on conventional fuels and reduces the related CO_2 emissions. Installation of technologies for microgeneration of heat and/or electricity by using renewables is an opportunity to be considered mostly during major renovation of buildings. Utilising renewable energy requires application of smart design measures as well as appropriate technologies e.g., solar collectors for hot water supply, PV, different types of heat pumps, and wood-fuelled boilers. There is increasing progress in the development of renewable energy supply systems and climate control of buildings. The feasibility of using renewable energies onsite has to be investigated in each case separately. Biomass and solar energy are the most direct ways to use renewable resources to meet heating demands. Combined heat and power plants have become smaller, which makes them more attractive for smaller households. The use of district heating could also be a very attractive option to use renewable energies. Unlike the “direct” use of high-potential geothermal heat (hydrothermal resources), the use of surface-layer ground as a source of low-potential heat for geothermal heat pump heating systems is an option to be considered. The performance and the efficiency of such systems must be evaluated.[158]

37. **Consider the possibility for production and utilisation of renewable energies onsite.**

Renovation of buildings along with improvement of **existing infrastructure towards more efficient systems**, including new energy efficient boilers and piping technologies with reduced heat losses increase energy savings. As mentioned earlier, central heating is the main source for heat energy supply in many countries. New piping technologies can be used to reduce maintenance and line losses, and new premium-efficiency boilers/chillers and auxiliary equipment will make the system more efficient. If the buildings to be connected to the central heating system and the heating plant are close together, line losses will not be significant due to short pipe runs between the plant and buildings. Centralized plants can help to reduce energy costs by providing thermal energy storage, using economies of scale, and reducing maintenance efforts.[159]

38. **Increase the efficiency of engineering systems and technologies to reduce maintenance and line losses.**

A complex renovation of buildings may make it possible to re-think the mobility concept of the building or neighbourhood e.g., by optimising the car parking space e.g., by grouping parking places for cars in a way that leaves sufficient place for and around playgrounds, bike stands and pedestrian areas, at the same time as bringing about a reduction in GHG emissions and air pollution in the neighbourhood.

39. **Re-think and optimise the mobility concept of the building or neighbourhood.**

Landscape

A complex renovation presents a great opportunity to improve the landscape of the building neighbourhood. For example, impenetrable groundcover in the urban area (cement roads and walkways) limits the infiltration of water into the soil and then into the roots of plants. **Permeable pavements** ensure infiltration representing an important contribution to lessening the formation of urban heat islands by ensuring the evaporative cooling effect, and by providing the necessary water for the tree root growth. This leads to fuller and denser tree canopies, thus supporting resilience to climate change of the buildings in the vicinity by providing shelters and reducing the water load on basement constructions. Along with trees, additional **plant cover maintenance** and **planned greeneries** enhances such positive effect. The treatment of rainwater can lead to new ideas for the environment if it is used actively as a design element. Approaching and adopting a **sustainable storm water management system** based on water-sensitive design solutions (centralized and semi-decentralized) can help to create a healthier environment. Application of solutions relate to the landscape may require a particularly designed sub-project.

40. **Improve the landscape of the building neighbourhood e.g., using permeable pavements, plant cover, and green infrastructure for storm-water management.**

A positive effect on climate change mitigation can be achieved by creating **bicycle parks**, including parking places for scooters, which have increasingly gained popularity among the public in recent years. Implementation of such measure provides a good outcome for both the environment and residents, making it more attractive and efficient to quickly grab a bike instead of taking the car.

41. **Provide an easy-to-access space for bikes, ideally next to entrances and with adequate and safe bike stalls.**

After years of slow progress, electric vehicles are finally gaining more attention from customers. To further promote the purchase and utilization of electric vehicles instead of fossil fuel engine cars, renovation of buildings must be followed by the erection of **electrical charge points** close to the renovated building. According to the EU requirements, new residential buildings and residential buildings undergoing major renovation with over ten parking spaces should include the installation of ducting infrastructure (conduits for electric cables) for every parking space to enable the installation, at a later stage, of recharging points for electric vehicles.[160] The latest developments and standards mainstreamed by the EU and national systems should be followed.

42. **Install the ducting infrastructure for electrical charge points for electric vehicles.**

3.7. Management

The management of climate proofing energy efficiency projects related to the renovation of multi apartment buildings requires dealing with complex systems and complex processes. A single building is already composed of many closely interrelated subsystems and elements. Moreover, besides the building itself, renovation projects can include additional elements and measures ensuring the sustainability of the renovation project, awareness raising among tenants, and capacity building for builders. Implementation of these measures also has certain implications for climate change mitigation and adaptation (see Annex I).

Table 3.7.1. Renovation management related measures and their possible implications related to climate change mitigation and adaptation.[161]

Measure	Adaptation	Adaptation with implication for mitigation	Mitigation with implication for adaptation	Mitigation
Complexity assessment	✔			
Benchmarking, certification and energy management system	✔			✔
Citizens/inhabitant courses		✔		
Special courses for builders			✔	

Complexity is a key characteristic of renovation projects, which are in fact even more complex than new build schemes. The complexity of refurbishment involves technical, technological, ecological, social, comfort and esthetical aspects of a building and its surroundings. A **complexity assessment** should include assessment of measures for adaptation of a building and its tenants to extreme weather conditions, as well as various other aspects.

43. **To tackle both climate change mitigation and adaptation issues, a complexity assessment should be implemented prior to the decision on measures to be implemented during the building renovation project.**

Benchmarking and certification play an increasingly important role in a climate resilient built environment – they help to understand the current situation and indicate the objectives and targets that should be met to achieve the climate policy targets. Benchmarking can be performed by using simple expert analysis in the feasibility phase, energy labelling, auditing, in the framework of technical design and environmental impact assessment.

A certification scheme for sustainability in buildings – **BREEAM** (British Research Establishment Environmental Assessment Method) is a voluntary green building sustainability rating system established in the UK for assessing the environmental performance of buildings, master-planning projects, and infrastructure. It ensures compliance of buildings with respect to sustainable construction, operation, and design, and is fit to be used to assess both renovation schemes and new constructions. BREEAM is seen as the benchmark standard when it comes to sustainable development as well as increasing environmental awareness. BREEAM does this through third party certification of the assessment of an asset's environmental, social, and economic sustainability performance. The following categories and criteria are considered: ecology, pollution, waste, energy, management, water consumption, health and wellbeing, efficiency, materials, transport. BREEAM rated developments are more sustainable environments that enhance the well-being of the people who live and work in them, help protect natural resources and make for more attractive property investments. The BREEAM Refurbishment and Fit Out standard enables real estate investors, developers and building owners to assess and mitigate sustainability-related impacts during the design and works of a refurbishment or fit out project. Through the assessment and certification process, the standard recognises and reflects the performance of the building once improvements have been made to the external envelope, structure, core services, local services, or interior design of a building. The standard can be used to assess the renovation and fit-out of most types and uses of existing buildings including residential buildings. The standard includes specific assessment criteria for heritage buildings that consider the constraints on these types of projects.[162, 163] The BREEAM Refurbishment and Fit-Out standard is currently being used across Europe and there are certified assessments in the UK, France, Italy, and Poland.[164]

Another widely used and globally recognised green building rating system is **LEED** (Leadership in Energy and Environmental Design) developed by the U.S Green Building Council. It includes a set of rating systems which aim to help building owners and operators be environmentally responsible and use resources efficiently. LEED certification is applicable for all building types and all building phases.[165]

The **DGNB certification** (Deutsche Gesellschaft für Nachhaltiges Bauen/ German Sustainable Building Council) refers to German codes and standards and is based on three main paradigms - life cycle assessment, holistic sustainability (environment, economy, and society), and the performance-based orientation. The DGNB certification system is applicable for different types and phases of buildings, districts, and interiors.[166]

Based on Swedish standards and legislations, the Sweden Green Building Council has introduced an environmental certification system **Miljöbyggnad** with three levels of certification: Bronze, Silver and Gold. It is used to certify new constructions, refurbished buildings, and existing buildings of different types of uses. It assesses energy consumption, indoor environment, materials, and chemicals.[167]

44. **Consider including a requirement to obtain BREEAM, LEAD, DGNB or equivalent certificate for climate proofing energy efficient renovation projects.**

Eco-Management and Audit Scheme (EMAS) is a voluntary management instrument developed by the European Commission for companies and organisations to evaluate, report, and improve on their environmental performance and to communicate environmental achievements. EMAS supports organisations in finding the right tools to improve their environmental performance. Participating organisations voluntarily commit to both evaluating and reducing their environmental impact. Third party verification guarantees the external and independent nature of the EMAS registration process. Within this framework, the EU have developed Sectoral Reference Documents e.g., on construction sector, including "Best environmental management practices".[168]

45. **Consider including a requirement for EMAS for companies performing renovation of multi apartment buildings.**

Green Public Procurement (GPP) or green purchasing is a voluntary instrument that can be applied by public authorities in their purchases of goods, services and works. GPP requires the inclusion of clear and verifiable environmental criteria for products and services in the public procurement process. While the adopted EU GPP criteria aim to reach a good balance between environmental performance, cost considerations, market availability and ease of verification, procuring authorities may choose to include all or only certain requirements in their tender documents, according to their needs and ambition level.[169] The EU GPP approach is aimed to address both the overall impact of a building and the environmental characteristics of individual components. The EU GPP Criteria for Office Building Design, Construction and Management have been elaborated[170] and can be applied in procurement procedures.

46. **Consider application of the EU GPP Criteria for Office Building Design, Construction and Management for renovation of state or municipality owned multi apartment buildings.**

ISO 14091:2021 Adaptation to climate change — Guidelines on vulnerability, impacts and risk assessment gives guidelines for assessing the risks related to the potential impacts of climate change. It describes how to understand vulnerability and how to develop and implement a sound risk assessment in the context of climate change. It can be used for assessing both present and future climate change risks. Risk assessment according to this document provides a basis for climate change adaptation planning, implementation, and monitoring and evaluation for any organization, regardless of size, type, and nature. When initiated as a planned process at an early stage of project development, climate change adaptation is usually more effective than in response to already materialised impacts. A better understanding of climate risks and vulnerabilities enables organisations to plan and implement early activities to adapt to the impacts of climate change, reducing costs and illustrating possible opportunities.

47. **Consider application of the ISO 14091:2021 Adaptation to climate change — Guidelines on vulnerability, impacts and risk assessment, when preparing larger renovation and/or brownfield developments.**

Complex renovation generally increases the motivation of flat owners to take care of the building and implement further energy-saving measures. It can be observed that positive achievements increase the sense of ownership. After a comprehensive renovation of a building has been finished, a change in behaviour is needed. For example, residents of the renovated house then need to learn how to ventilate and heat correctly – they have to know how to adjust their heating and ventilation habits because the air exchange through closed windows and walls is significantly reduced and radiators can be manually adjusted in all rooms. **Courses for citizens/tenants**, informative events, and leaflets or energy advisors that explain or demonstrate procedures can all help the residents to maintain the newly renovated building appropriately. The more directly and interactively the information is conveyed, the greater the likelihood of a behavioural change.[171] Energy user profiles should be provided to understand and set the personal/induvial/ household saving roadmap. There should also be instructions on e.g., how to clean the external walls to ensure appropriate maintenance of the building façade after renovation in order to keep it resistant against weather impacts for longer, how to use heating and ventilation appropriately, etc. Active participation and engagement of tenants is a prerequisite for reaching the desired energy savings whilst keeping the indoor environment comfortable at the same time.

48. **It is advisable for house managers or construction engineers to provide targeted information to tenants of renovated buildings to raise awareness about appropriate measures and motivate behaviour change.**

New developing technologies for the design and implementation of climate proof energy efficient building renovation projects require up-to-date knowledge, skills, and permanent capacity building of building specialists. **Special courses for builders** need to be organised, aimed at implementing a quality-driven training and change process in construction thus helping to achieve the ambitious energy efficiency objectives of the construction industry. Here, it is advisable to make use of experiences from EU funded initiatives e.g., BUILD UP Skills[172] which were established to boost further education and training of craftsmen, as well as other on-site construction workers and systems installers who work in the building sector. Within the framework of the CAMS Platform project a "Qualification program on energy efficient refurbishment of apartment buildings for Baltic Sea Region" is being developed and will be made available on the project website[173] by the end of the project in spring 2022. The qualification program aims to help to increase the knowledge of construction-related stakeholders e.g., planners in municipalities or energy agencies and those that are active players in the refurbishment in the refurbishment process itself (such as contractors, building managers, staff in housing associations) to bring them to a common intermediate level so that they are able to better communicate about the communication process both internally and with external parties, and that they better understand what is current common practice in line with technology and legal requirements.

49. **Construction associations and other non-governmental organisations, as well as educational establishments should consider organising special courses for construction-related stakeholders about innovative technologies for climate proof energy efficient projects.**

3.8. Quality control and monitoring of results

In construction and renovation projects, quality control ensures that the project meets the client's needs, standards, and guidelines. This includes completing a project within the scope of work and avoiding any disputes in the process.[174] Quality control and monitoring of results have a positive impact both on climate change mitigation and adaptation (see Table 3.8.1).

Table 3.8.1. Quality control and monitoring of results and their possible implications related to climate change mitigation and adaptation.[175]

Measure	Adaptation	Adaptation with implication for mitigation	Mitigation with implication for adaptation	Mitigation
Evaluation of defects and monitoring results	✔			✔

Quality control is the responsibility of the site supervisor and the building site manager. It is particularly important to inspect components of the construction which will be immediately covered over upon their completion, and where necessary, improved or repaired. As mentioned earlier, for example, an excellent insulation helps to minimize heat loss through the building. However, apart from the thickness and material of insulation, the construction solution, and the quality of application of each material on the building envelope is important, e.g., avoiding gaps between materials and structural surfaces, thermal bridges. Moreover, climate proofing energy efficiency renovation projects should result not only in energy savings, but also ensure appropriate indoor climate for tenants. Indoor climate is characterized by thermal and air comfort. Thermal comfort is determined by certain parameters of temperature and humidity of indoor air. Air comfort is characterized by the degree of contamination with pollutants e.g., CO_2. Thermal and air comfort in residential buildings is influenced by the building envelope and engineering systems e.g., heating and ventilation.

The aim of the quality control related to renovation of multi apartment buildings shall include e.g., control of air tightness of the building and detection of thermal bridges in the construction causing uncontrolled heat losses. Buildings which are not airtight have uncontrolled cold air infiltration which requires additional heat. Air leakages lead to reduction of thermal comfort for tenants. The removal of thermal bridges is also necessary to achieve sanitary and hygienic standards, contributing to human health and creating the preconditions for long-term conservation and functional safety of buildings.[176]

A Study Guide to improve energy efficiency in residential buildings[177] suggests the following main quality control methods and instruments that can be implemented during the finalization phase of the renovation project and afterwards to monitor the renovation project results. One of them is the so-called **"Blower door testing"**. It is a fan pressurization method that serves to identify weak points regarding energy efficiency, more specifically airtightness. The Blower door test allows evaluation of constructional defects. With a blower door test, the airflow can be measured and leaks as well as the resulting heat loss can be determined. Blower door testing is to be implemented after the finalization of all construction details but before the final acceptance of works.

It is almost impossible to visually detect thermal bridges caused by engineering defects on the facade of the building; thermography makes their detection possible. Therefore, in winter, i.e., during the first heating period following the renovation project, a **thermographic examination** to identify possible thermal bridges should be scheduled. If either a new heating system or a new solar or photovoltaic system is installed, it should be tested shortly before the final acceptance of works by taking it into full operation for a short period. Thermographic images can help to identify thermal bridges and transmission heat losses through windows, doors, and other openings. They allow errors to be detected in the design and construction.

50. **Apply direct measurement and monitoring methods to evaluate the possible constructional defects during the finalization phase of the renovation project and afterwards to monitor the renovation project results e.g., related to airtightness, thermal bridges.**

Before the final acceptances of works, so-called pre-inspections need to be implemented by the building site manager and the homeowners' association/ project manager to identify and correct any defects in the construction. The final acceptance of all works should follow a joint survey of the works performed. Not just the building administrator, but also the building site manager, as well as selected building companies and their craftsmen should take part. The results of the survey and possible defects need to be recorded in the acceptance protocol. Within the framework of the final acceptance of the renovation works, an energy performance certificate shall be issued to prove the formal determination of the renovation results.

3.9. Promoting renovation

As mentioned earlier, the process of renovating multi apartment buildings in the EU is quite slow (renovation rates in all EU are estimated to be about 1% per year).[178,179] Existing studies on building renovation processes have highlighted several barriers e.g., technical, organizational, economic, financial, and behavioural barriers that hinder renovation of multi apartment buildings.[180,181] These barriers are usually overlapping and are mutually reinforcing. Promotion of renovation has a positive impact on both climate change mitigation and adaptation (see Table 3.9.1).

Table 3.9.1. Promotion of renovation and implications related to climate change mitigation and adaptation.[182]

Measure	Adaptation	Adaptation with implication for mitigation	Mitigation with implication for adaptation	Mitigation
Transparent and simple promotion	✔			✔

Naturally, in large-scale energy renovations, financing is one of the main issues to be resolved. It is directly related to the real estate market and market value of estate. Nevertheless, it has been assessed that lack of financing is not the primary reason hampering large-scale renovation. The biggest problem relates to the difficulties of flat owners in the same multi apartment building reaching a collective decision to start renovation, due to the different ages, incomes, and sizes of households within the same multi apartment building.

Difficulties appear when it comes to taking a decision on of the implementation of additional measures beyond those required by existing legislation (e.g., achieving nearly zero energy building standard, application of climate adaptation measures, introducing renewable energy technologies, using environmentally friendly materials). Besides, flat owners quite often lack knowledge on large scale renovation process. The difficulty of overcoming the above-mentioned barriers is increasing due to increasing energy poverty, population aging and shrinking, etc. To promote the renovation process, several groups of measures are applied in the EU. These are measures related to information and advice, taxation, financial incentives, access to capital and minimum standards (see Table 3.9.2).[183]

Table 3.9.2. Measures to promote renovation of multi apartment buildings.

Promotion measures	**Examples**
Information and advice	• Programs providing information and advice • Energy certificates and labels, e.g., Energy performance certificates • Feedback programs e.g., energy audits, online monitoring systems
Taxes	• Energy tax • CO_2 tax
Financial incentives	• Supplier obligations (Energy Efficiency/Energy Supply/ Energy Company Obligations), tradable white certificates • Tax incentives e.g., rebates, • Grants and soft loans, • Feed-in tariffs e.g., to encourage installation of microgeneration renewable technologies
Access to capital	• Loan guarantees, low-cost loans • Preferential mortgage rates
Minimum standards	• Minimum performance standards applied to buildings, appliances, boilers

Application of promotion measures varies in the countries. It has been assessed that all the above-listed promotion measures have a certain (smaller or larger) effect on flat-owners/tenants decision to renovate. However, in most cases there is no clear evidence on the effectiveness of these policies to date, as their impact on the decisions made by flat owners about renovation has not been empirically proven. Due to complexity of the barriers, the socio-economic situation in different countries, and many other aspects, there is no one-size-fits-all policy for the promotion of energy renovation. Nevertheless, it has been evaluated that support measures that are transparent and sufficiently simple from a household's perspective are more likely to achieve their intended impacts. Consumer trust e.g., of an authority e.g., energy agency designated to coordinate renovation process in the country, along with skilled energy renovation service supply chain leads to more sustained progress in energy renovation. For further acceleration of renovation of multi apartment buildings, new approaches considering the weaknesses of current measures must be applied, addressing the energy poverty problem and especially the connected problems with collective decision making. To create initiatives for renovation of multi apartment buildings, there should be both top-down (e.g., tax credits, grants etc.) and bottom-up strategies (e.g., an actor who takes the main responsibility and organizes the renovation of a building). The possibilities to involve the "middle actors" in both project management and engineering-technical consultancy in the energy renovation industry – small and medium-sized enterprises, e.g., energy service companies, should be considered.[184]

51. **Consider possibilities to implement simple and transparent measures to promote renovation of buildings addressing the energy poverty problem and collective decision making.**

Annex I. List of measures

List of measures whose application can be considered during the renovation of multi apartment buildings and their possible implications related to climate change mitigation and adaptation.[185]

Category/measure	Adaptation	Adaptation with implication for mitigation	Mitigation with implication for adaptation	Mitigation
Building envelope				
Stronger walls and roof structure	✔			
Moisture removal	✔			
Gutter sizing	✔			
Elements fastened to buildings	✔			
Moisture-proof building materials	✔			
Reflective materials		✔		
Green roofs		✔		
Air tightness			✔	
Insulation			✔	
Glazing technologies			✔	
Shutters			✔	
Building materials				
Building life cycle assessment				✔
Energy efficient building materials				✔
Building material durability improvement		✔		
Climate-proof building materials			✔	
Energy supply				
Smart grids		✔		
Changing temperature coping heating systems		✔		
Energy efficient heating systems, including low-temperature heating systems			✔	
Renewable energy heat systems			✔	
Installation of photovoltaic and solar heating		✔		
Automated indoor climate			✔	
District heating				✔
Waste heat utilisation				✔
Green power purchase schemes				✔

Category/measure	Adaptation	Adaptation with implication for mitigation	Mitigation with implication for adaptation	Mitigation
Heating, ventilation, air conditioning, lighting				
Thermostatic valves and smart meters			✔	
Efficient air conditioning			✔	
Natural ventilation			✔	
Heat recovery ventilation			✔	
Moisture removal in ventilation units		✔		
District cooling		✔		
Upgraded lighting system				✔
Storm proof electricity system	✔			
Water supply and use of water				
Efficient water systems	✔			
Rainwater use		✔		
Solar water heating			✔	
Hot water circulation				✔
Drain water heat recovery				✔
Architectural form				
Passive solar heating		✔		
Shading elements		✔		
Location				
Protection against sea/river water level rise	✔			
Renewables				✔
Infrastructure of energy efficient engineering systems				✔
Reconsideration of mobility concepts				✔
Landscape				
Permeable pavements	✔			
Plant cover maintenance	✔			
Planned greenery	✔			
Sustainable storm water systems	✔			
Bicycle parks			✔	
Electrical charges				✔

Category/measure	Adaptation	Adaptation with implication for mitigation	Mitigation with implication for adaptation	Mitigation
Management				
Complexity assessment	✓			
Benchmarking, certification and energy management system	✓			✓
Citizens/inhabitant courses		✓		
Special courses for builders			✓	
Quality control and monitoring of results				
Evaluation of defects and monitoring results	✓			✓
Promotion of renovation				
Transparent and simple promotion measures	✓			✓

Annex II. List of recommendations

This list provides a summary of recommendations for the implementation of climate proof energy efficient renovation projects for multi apartment buildings. Implementation of measures will be considered and evaluated separately in each case, considering geographical and climate conditions, as well as technical, financial, and legislative limitations. Recommendations listed in this Annex are numbered according to their appearance and the respective numbering in the text of the respective chapters.

Building envelope	
1.	Consider **embodied energy** of various construction materials to compare gains from improving the load bearing of a building versus related carbon footprint.
2.	Prevent **excessive accumulation** of moisture and ensure **sufficient vapor permeability** to allow dry-out of constructional moisture.
3.	Install **appropriate gutter systems**.
4.	Ensure **strong attachment of various elements fastened to buildings** to increase the resistance against the impact of storms.
5.	Apply **materials specifically designed to resist moisture and mould** for basement, external walls, and roof insulation.
6.	Evaluate cost effectiveness of applying **reflective materials** on the exterior of a building during the renovation process, considering local climate conditions and building type.
7.	Consider possibility of installing **green roofs, roof gardens** during the renovation of multi apartment buildings.
8.	To minimise heat loss, ensure the **air tightness of a building** during renovation, and plan for air exchange by an appropriate ventilation system, preferably recovering heat from the exhaust air.
9.	Prior to renovation plan properly (considering heated and non-heated areas, local climate conditions) and ensure an appropriate **insulation** of foundation and basement, floor slabs, walls, roof, windows, doors as well as hot water pipes. Consider application of prefabricated (wall) insulation elements.
10.	Replace old windows with modern, **high performance energy efficient windows** which can provide 20-25% more efficiency due to improvements in both frames and glazing.
11.	Consider **installation of shutters** to increase the thermal resilience, at the same taking into account fire safety requirements.
Building materials	
12.	Select insulation and other building materials that have low embodied energy, minimal thermal conductivity, and are lightweight, **considering the life-cycle assessment** e.g., disposal and various other environmental concerns.

Energy supply	
13.	Link the possibilities that are provided by **smart grids** along with introduction of **smart metering, reliability of automatic system in case of power cuts,** and **green power purchase** schemes during renovation of buildings
14.	Balance the heating system of a building, including **placing balancing valves, valves on risers or heating devices,** depending on how they are connected. Install **automatic thermal regulators** during the reconstruction of heating systems to regulate the indoor temperature.
15.	Consider installation of a renewable energy technology or combination of them e.g., **solar thermal collectors, PV and biomass boilers** as the main or supplementary heating source.
16.	Consider **installation of photovoltaic batteries** to supplement self-electricity supply of the building during power supply failures.
17.	When reconstructing residential heating systems, consider installation of **automatic and remote control of indoor climate** in each flat or room.
18.	Consider connection **to highly efficient district heating** particularly if powered by renewable energy sources and if many buildings in an area require refurbishment of individual heating system.
19.	Install **waste heat recovery** systems and further **utilisation** possibilities in the building.
20.	Apply new business models and financial instruments to function as **green power purchase schemes** to promote prosumer practice at multi apartment building level.
Heating, ventilation, air conditioning, lighting	
21.	**Instal thermostatic valves on every radiator** to allow room temperature to be adjusted in each room, increasing indoor comfort for tenants.
22.	**Instal heat energy meters or heat cost allocators** to allow tenants to pay according to their own heat consumption.
23.	Apply **passive methods to prevent overheating** i.e., installation of proper external shading devices e.g., different blinds and curtains rather than air conditioning appliances.
24.	Consider installation of a **centralized ventilation system** for a building serving for the whole building, preferably with heat recovery.
25.	Monitor the humidity inside the building and uptake long-term solutions to attack the source of the moisture problem within the air ducts. To deal with mould problem in air ducts, consider application of **air scrubbers and hydroxyl or ozone generators**.
26.	Consider connecting the building to **district cooling**, if technically possible.
27.	Upgrade the lighting system of a building e.g., by **installing motion sensors and energy efficient light bulbs** to bring additional energy savings.
28.	Consider installation of **PV system equipped with electricity storage capacities**.
Water supply and use of water	
29.	Consider **substitution of existing water-related appliances**.
30.	Consider **installation of rainwater harvesting system**.
31.	Consider **installation of solar water heating system** to supplement the main heat and hot water system.
32.	Balance comfort and energy losses by **optimisation of distribution network of the circulation pipes**.
33.	Consider **installation of drain water heat recovery systems** that can be particularly cost effective for buildings with significant domestic heat water consumption.

Building surroundings	
34.	Consider technological possibilities for utilisation of **passive solar radiation.**
35.	Consider installation of external **shading elements** to control the amount of heat and natural light that is admitted into a building.
36.	Evaluate the necessity of installing constructions e.g., belts, dams to **protect building against flooding** due to water level raise in water bodies.
37.	Consider possibilities for production and utilisation of **renewable energies onsite**.
38.	Increase the **efficiency of engineering systems and technologies** to reduce maintenance and line losses.
39.	Re-think and **optimise the mobility concept** of the building or neighbourhood.
40.	**Improve the landscape** of the building neighbourhood e.g., with permeable pavements, plant cover, green infrastructure for storm-water management.
41.	Provide an easy-to-access space for bikes by **creating bicycle parks** including adequate and safe bike stalls.
42.	Install the ducting infrastructure for **electrical charge points** for electric vehicles.
Management	
43.	Implement a **complexity assessment** prior to taking decisions on measures to be implemented during building renovation projects to tackle both climate change mitigation and adaptation issues.
44.	Consider including a **requirement to obtain a BREEAM, LEAD, DGNB or equivalent certificate** for climate proofing energy efficient renovation projects.
45.	Consider including a **requirement for EMAS for companies** performing renovation of multi apartment buildings.
46.	Consider **application of the EU GPP Criteria** for Office Building Design, Construction and Management for renovation of state or municipality owned multi apartment buildings.
47.	Consider **application of the ISO 14091:2021** Adaptation to climate change — Guidelines on vulnerability, impacts and risk assessment, when preparing larger renovation and/or brownfield developments
48.	Provide **targeted information to tenants** of renovated buildings to raise awareness about appropriate measures and motivate behaviour change
49.	Consider **organisation of special courses for** construction-related stakeholders on innovative technologies for climate proof energy efficient projects.
Quality control and monitoring of results	
50.	**Apply direct measurement and monitoring methods to evaluate the possible constructional defects** during the finalization phase of the renovation project and afterwards to monitor the renovation project results e.g., related to airtightness, thermal bridges.
Promoting renovation	
51.	Consider possibilities to implement simple and transparent measures to **promote renovation of buildings** addressing the energy poverty problem and collective decision making.

References

[1] Chalmers P. (2014), Climate Change: Implications for buildings, Key findings from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) on Buildings, https://www.cisl.cam.ac.uk/business-action/low-carbon-transformation/ipcc-climate-science-business-briefings/pdfs/briefings/IPCC_AR5__Implications_for_Buildings__Briefing__WEB_EN.pdf

[2] European Commission. Progress made in cutting emissions, https://ec.europa.eu/clima/eu-action/climate-strategies-targets/progress-made-cutting-emissions_en

[3] European Commission, A European Green Deal, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[4] European Commission (2020), A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives, COM (2020) 662 final, https://ec.europa.eu/energy/sites/ener/files/eu_renovation_wave_strategy.pdf

[5] European Commission (2021), Renovation Wave, https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

[6] European Commission (2021), Energy performance of buildings directive, https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

[7] Proposal for a Directive of the European Parliament and of the Council on energy efficiency (recast), 14.7.2021 COM(2021) 558 final, https://ec.europa.eu/info/sites/default/files/proposal_for_a_directive_on_energy_efficiency_recast.pdf

[8] Proposal for a Directive of the European Parliament and of the Council amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652, Brussels, 14.7.2021 COM(2021) 557 final, https://ec.europa.eu/info/sites/default/files/amendment-renewable-energy-directive-2030-climate-target-with-annexes_en.pdf

[9] European Commission, Energy efficiency – Revision of the Energy Performance of Buildings Directive, https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12910-Energy-efficiency-Revision-of-the-Energy-Performance-of-Buildings-Directive_en

[10] Interreg Europe (22.07.2021), Commission launches the Fit for 55% Package, https://www.interregeurope.eu/policylearning/news/12610/commission-launches-the-fit-for-55-package/?no_cache=1&cHash=a371af17736f1f2f09030ee45e7dd6f2

[11] CAMS Platform: Climate Adaptation and Mitigation Synergies in Energy Efficiency Projects, https://www.trea.ee/eng/projects/cams/

[12] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre

[13] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)

[14] European Commission (2021), Energy performance of buildings directive. Measures to improve the building stock, https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en#measures-to-improve-the-building-stock

[15] European Commission (2021), Renovation Wave, https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

[16] European Commission (2021), Energy performance of buildings directive, https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

[17] European Commission (2019), Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU, https://op.europa.eu/en/publication-detail/-/publication/97d6a4ca-5847-11ea-8b81-01aa75ed71a1/language-en/format-PDF/source-119528141

[18] Buildings Performance Institute Europe (2021), Deep Renovation: Shifting from exception to standard practice in EU Policy https://www.bpie.eu/publication/deep-renovation-shifting-from-exception-to-standard-practice-in-eu-policy/

[19] European Commission (2021), Renovation Wave, https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

[20] European Commission (2019), Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU, https://op.europa.eu/en/publication-detail/-/publication/97d6a4ca-5847-11ea-8b81-01aa75ed71a1/language-en/format-PDF/source-119528141

[21] European Parliament (2021), Renovation wave initiative in the building sector, https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-renovation-wave

[22] European Commission. Clean energy for all Europeans package, https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en

[23] Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency

[24] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency

[25] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives, COM/2020/662 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662

[26] European Commission (2021), Renovation Wave, https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

[27] European Commission, Long-term renovation strategies, https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/long-term-renovation-strategies_en

[28] National energy and climate plans: EU countries' 10-year national energy and climate plans for 2021-2030, https://ec.europa.eu/info/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en

[29] Streimikiene D., Balezentis T. (2019), Innovative Policy Schemes to Promote Renovation of Multi-Flat Residential Buildings and Address the Problems of Energy Poverty of Aging Societies in Former Socialist Countries

[30] European Commission (2021), Energy performance of buildings directive. Measures to improve the building stock, https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en#measures-to-improve-the-building-stock

[31] European Commission (2021), Energy performance of buildings directive**,** https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

[32] European Commission (2019), Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU

[33] Commission Recommendation (EU) 2019/786 of 8 May 2019 on building renovation (notified under document C(2019) 3352)

[34] Commission Recommendation (EU) 2019/1019 of 7 June 2019 on building modernisation

[35] European Commission (2021), Energy performance of buildings directive, https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

[36] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0082&from=EN

[37] The European Climate Adaptation Platform Climate-ADAPT: Sharing adaptation information across Europe (2021), Buildings, https://climate-adapt.eea.europa.eu/eu-adaptation-policy/sector-policies/buildings

[38] European Commission. EU Buildings Factsheets, https://ec.europa.eu/energy/eu-buildings-factsheets_en

[39] European Commission (2019), Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU

[40] Niskanen J. (2018), Mainstreaming passive houses: a study of energy efficient residential buildings in Sweden, https://liu.diva-portal.org/smash/get/diva2:1264439/FULLTEXT01.pdf

[41] Borodinecs A. et al (2013), Handbook of Building renovation in Central Baltic region, http://projects.centralbaltic.eu/images/files/result_pdf/ENEF_result1_a.pdf

[42] Sweden's Integrated National Energy and Climate Plan (2020), https:// ec.europa.eu/energy/sites/ener/files/documents/se_final_necp_main_en.pdf

[43] Sweden's Third National Strategy for Energy Efficient Renovation (2019), https://ec.europa.eu/energy/sites/ener/files/documents/se_2020_ltrs_official_translation.pdf

[44] National Register of Buildings (data from 30.06.2013)

[45] European Commission (2019), Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU, https://ec.europa.eu/energy/sites/ener/files/documents/1.final_report.pdf

[46] Borodinecs A. et al. (2013), Handbook of Building renovation in Central Baltic region, http://projects.centralbaltic.eu/images/files/result_pdf/ENEF_result1_a.pdf

[47] Estonia's 2030 National Energy and Climate Plan, https://ec.europa.eu/energy/sites/ener/files/documents/ee_final_necp_main_en.pdf

[48] National Development Plan of the Energy Sector until 2030, https://www.mkm.ee/sites/default/files/ndpes_2030_eng.pdf

[49] H2020 project „Forward-looking socio-economic research on Energy Efficiency in EU countries" (HERON), 2015-2017

[50] Improving the Energy Efficiency of the Buildings - Energy Savings, Unit Costs and Volumes, https://energiatalgud.ee/img_auth.php/5/51/ENMAK_2030._Hoonete_energias%C3%A4%C3%A4stupotentsiaali_uuring.pdf

[51] National Government Act on Minimum Energy Performance Requirements for Buildings, 13.12.2018., (in Estonian), https://www.riigiteataja.ee/akt/122082019002

[52] National Government Act on Minimum Energy Performance Requirements for Buildings, 13.12.2018. (in Estonian), https://www.riigiteataja.ee/aktilisa/1220/8201/9002/MKM_m63_lisa2.pdf#

[53] Information report: Long-term strategy for the renovation of buildings (Latvia), https://ec.europa.eu/energy/sites/default/files/documents/lv_2020_ltrs_official_translation_en.pdf

[54] Information report: Long-term strategy for the renovation of buildings (Latvia), https://ec.europa.eu/energy/sites/default/files/documents/lv_2020_ltrs_official_translation_en.pdf

[55] Borodinecs A. et al (2013), Handbook of Building renovation in Central Baltic region, http://projects.centralbaltic.eu/images/files/result_pdf/ENEF_result1_a.pdf

[56] Borodinecs A., et al. (2021), Pētījums par dzīvojamo ēku energoefektivitāti: I daļa. Esošās situācijas analīze

[57] National Energy and Climate Plan of Latvia 2021–2030 (2018), Draft for submitting to the European Commission for evaluation, https://ec.europa.eu/energy/sites/ener/files/documents/ec_courtesy_translation_lv_necp.pdf

[58] Information report: Long-term strategy for the renovation of buildings (Latvia), https://ec.europa.eu/energy/sites/default/files/documents/lv_2020_ltrs_official_translation_en.pdf

[59] Latvian Long-term Strategy for Renovation of Buildings, https://ec.europa.eu/energy/sites/ener/files/documents/lv_building_renov_2017_lv.pdf

[60] Cabinet of Ministers Regulation Nr. 160 (15.03.2016), https://likumi.lv/ta/id/281323-darbibas-programmas-izaugsme-un-nodarbinatiba-4-2-1-specifiska-atbalsta-merka-veicinat-energoefektivitates-paaugstinasanu

[61] Ministry of Economics (2019), Statistics of renovated buildings in Latvia (in Latvian), https://www.em.gov.lv/lv/renoveto-eku-statistika

[62] Borodinecs A., et al. (2021), Pētījums par dzīvojamo ēku energoefektivitāti: I daļa. Esošās situācijas analīze

[63] Ministry of Economics, Atbalstam daudzdzīvokļu ēku renovācijai būs pieejami 166 miljoni eiro, http://www.energoefektivakaeka.lv/index.php/home/jaunumi/129-atbalstam_daudzdzivoklu_eku_renovacijai_bus_pieejami_166-miljoni-eiro

[64] ALTUM, https://www.altum.lv/en/

[65] European Commission (2019), Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU, https://op.europa.eu/en/publication-detail/-/publication/97d6a4ca-5847-11ea-8b81-01aa75ed71a1/language-en/format-PDF/source-119528141
[66] Marszał K., et al. (2020), Renovation: Landscape of climate finance in the Polish buildings sector, https://newclimate.org/wp-content/uploads/2021/01/NewClimate_WiseEuropa_I4CE_Renovation-in-Poland_Jan21.pdf
[67] European Commission (2019), Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU
[68] German Energy Agency (dena), https://effizienzhaus.zukunft-haus.info/effizienzhaeuser/informationen-effizienzhaus-datenbank
[69] City program Development of built-up areas in St. Petersburg. The list of buildings participating in the program (in Russian), https://rzt.spb.ru/about/adresny_spisok
[70] National standard of the Russian Federation R ISO 14090-2019 “Adaptation to climate change. Principles, requirements and guidelines” (in Russian), http://docs.cntd.ru/document/1200167738
[71] Non-profit organization "Fund - a regional operator of overhaul of common property in apartment buildings", http://fkr-spb.ru/node/134
[72] IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekēi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.
[73] BACC II Author Team (2015), Second Assessment of Climate Change for the Baltic Sea Basin, https://link.springer.com/content/pdf/10.1007%2F978-3-319-16006-1.pdf
[74] HELCOM (2013), Climate change in the Baltic Sea Area HELCOM thematic assessment in 2013, https://www.helcom.fi/wp-content/uploads/2019/10/BSEP137.pdf
[75] Avotniece Z., Aniskevich S., Malinovskis E. (2017), Climate change scenarios for Latvia, https://www4.meteo.lv/klimatariks/files/summary.pdf
[76] Räisänen, J. (2017). Future Climate Change in the Baltic Sea Region and. *Oxford University Press*, 36
[77] IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekēi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.
[78] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre
[79] VisAdapt, http://visadapt.info/
[80] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre
[81] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)
[82] Commission Recommendation (EU) 2019/786 of 8 May 2019 on building renovation, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019H0786&from=GA
[83] Stagrum, A. E., Andenæs, E., Kvande, T., & Lohne, J. (2020). Climate Change Adaptation Measures for Buildings—A Scoping Review. Sustainability, 12(5), 1721. MDPI AG. Retrieved from http://dx.doi.org/10.3390/su12051721
[84] https://www.echotape.com/blog/contractors-field-guide-building-envelope/
[85] Diaa El-Masry (2017), The Role of Building Envelope in Achieving High Performance Goals, https://www.linkedin.com/pulse/role-building-envelope-achieving-high-performance-diaa-1/
[86] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre
[87] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre
[88] Peep P., Kuusk K., Kalamees T. (2020), Development and Performance Assessment of Prefabricated Insulation Elements for Deep Energy Renovation of Apartment Buildings
[89] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project “Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine”, ARCEE (2015)
[90] Designing buildings Wiki (2021), Rain gutter, https://www.designingbuildings.co.uk/wiki/Rain_gutter
[91] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre
[92] Urbangreenbluegrids https://www.urbangreenbluegrids.com/measures/measures-for-separate-buildings/water-resistant-construction-methods-and-materials-dry-proof/
[93] Energy Saver, Cool roofs, https://www.energy.gov/energysaver/design/energy-efficient-home-design/cool-roofs
[94] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project “Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine”, ARCEE (2015)
[95] Natural Water Retention Measures: Green roofs, http://nwrm.eu/sites/default/files/nwrm_ressources/u1_-_green_roofs.pdf
[96] Brudermann T., Sangkakool T. (2017), Green roofs in temperate climate cities in Europe – An analysis of key decision factors, in Urban Forestry & Urban Greening, Volume 21, January 2017, Pages 224-234, https://www.sciencedirect.com/science/article/abs/pii/S1618866716304332
[97] PERFECT: Planning for environment and resource efficiency in European Cities and Towns, Interreg Europe (2020), What are the benefits of green roofs, https://www.interregeurope.eu/perfect/news/news-article/7834/what-are-the-benefits-of-green-roofs/
[98] Scandinavian Green Infrastructure Association, https://green-roof.org/the-scandinavian-green-roof-award-2018
[99] Green Hamburg (2021), Green roofs, https://www.hamburg.com/residents/green/11836394/green-roofs/

[100] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[101] TheGreenAge, https://www.thegreenage.co.uk/article/thermal-conductivity-r-values-and-u-values-simplified/
[102] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[103] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[104] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[105] Glass for Europe (2018), The smart use of glass in sustainable buildings, http://www.glassforeurope.com/wp-content/uploads/2018/04/The-smart-use-of-glass-in-sustainable-buildings.pdf
[106] Casini M. (2015), Smart windows for energy efficiency of buildings, https://www.researchgate.net/publication/280597205_Smart_windows_for_energy_efficiency_of_buildings
[107] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[108] Bajars K., Persson A. (2017), Study of glazed spaces as a renovation strategy for two typical residential multi apartment buildings from Swedish Million programme: Theoretical analysis of two reference buildings, https://www.ebd.lth.se/fileadmin/energi_byggnadsdesign/publications/exjobb/17-6-web.pdf
[109] Looman R., Climate-responsive design: a framework for an energy concept design-decision support tool for architects using principles of climate-responsive design, https://www.climateresponsivedesign.nl/tool/datasheet/solutions/index.php?id=31
[110] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre
[111] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[112] Vilches A., García-Martínez A., Sánchez-Montañés B. (2016), Life cycle assessment (LCA) of building refurbishment: A literature review, https://www.researchgate.net/publication/310602382_Life_cycle_assessment_LCA_of_building_refurbishment_A_literature_review
[113] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[114] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre
[115] Bollen M. (2011), Adapting Electricity Networks to a Sustainable Energy System – Smart metering and smart grids, https://www.ei.se/download/18.d4c49f01764cbd6062189cb/1608302879105/Adapting-Electricity-Networks-to-a-Sustainable-Energy-System-EI-R2011-03.pdf
[116] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[117] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[118] Zandeckis A. et al. (2011), Possibilities for Utilization of Solar Thermal Energy in Multi-Family Buildings in Latvia, https://www.researchgate.net/publication/258680524_Thermal_Performance_Analysis_of_Solar_Collectors_Installed_for_Combisystem_in_the_Apartment_Building
[119] Energy efficient and ecological housing in Finland, Estonia and Latvia: current experiences and future perspectives (2013), ISBN 978-9934-8238-4-8
[120] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[121] PVStream, https://www.pvstream.com/
[122] Polysun, http://www.polysunonline.com/PsoPublic/app/home/access
[123] Holzer P., Foldbjerg P. (2014), Control of Indoor Climate Systems in Active Houses, https://www.researchgate.net/publication/268741664_Control_of_Indoor_Climate_Systems_in_Active_Houses
[124] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[125] European Commission. Green Public Procurement Electricity Technical Background Report, https://ec.europa.eu/environment/gpp/pdf/tbr/electricity_tbr.pdf
[126] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[127] CE-HEAT (2016-2019), Interreg CENTRAL EUROPE Programme, https://www.waste-heat.eu/
[128] Design Buildings Wiki (2020), Heat recovery for buildings, https://www.designingbuildings.co.uk/wiki/Heat_recovery_for_buildings
[129] Gustafsson M. (2015), Energy efficient and economic renovation of residential buildings with low temperature heating and air heat recovery (Licentiate Thesis), https://www.diva-portal.org/smash/get/diva2:851312/FULLTEXT01.pdf
[130] Muratović D. (2017), Distributed generation for self-consumption: key aspects and recommendations of good practice
[131] European Commission (2015), COM(2015) 339 final; Commission staff working document: Best practices on Renewable Energy Self-consumption; Accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions; Delivering a New Deal for Energy Consumers https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_autre_document_travail_service_part1_v6.pdf
[132] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre
[133] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[134] Baltic Environmental Forum – Latvia (2014), Smart household appliances: How to account the heat consumption of an apartment?

[135] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[136] Slijepčević S., Mikulić D., Horvat K. (2019), Evaluation of the Cost-Effectiveness of the Installation of Heat-Cost Allocators in Multifamily Buildings in Croatia, https://www.researchgate.net/publication/330907339_Evaluation_of_the_Cost-Effectiveness_of_the_Installation_of_Heat-Cost_Allocators_in_Multifamily_Buildings_in_Croatia
[137] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[138] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[139] www.universalfans.com.au
[140] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[141] Zemitis J., Borodinecs A., Kalamees T. (2019), Analysis of various ventilation solutions for residential and non-residential buildings in Latvia and Estonia
[142] https://homeguides.sfgate.com/remove-moisture-central-air-vents-48753.html
[143] Armstrong L. (2020), How to Get Water Out of Air Ducts, https://restorationmasterfinder.com/restoration/how-to-get-water-out-of-air-ducts/
[144] BASREC (2015), Best Practice Sharing Municipal Energy Integration Booklet 3 - District Cooling, http://basrec.net/wp-content/uploads/2015/01/Booklet-3-District-Cooling.pdf
[145] Calderoni M, Babu Sreekumar B, Dourlens-Quaranta S, Lennard Z, Rämä M, Klobut K, Wang Z, Duan X, Zhang Y, Nilsson J, and Hargo L. Sustainable District Cooling Guidelines. IEA DHC/CHP Report, 2019.
[146] Danfoss. District cooling, https://www.danfoss.com/en/markets/district-energy/dhs/district-cooling/#tab-overview
[147] Baltic Environmental Forum – Latvia (2014), Energy efficiency of a building: How to save electricity in the staircase?
[148] https://www.c2es.org/site/assets/uploads/2018/08/resilience-strategies-power-outages.pdf
[149] Campbell R. J. (2017), Hurricanes and Electricity Infrastructure Hardening, ttps://fas.org/sgp/crs/misc/IN10781.pdf
[150] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre
[151] Rainwater harvesting, https://www.designingbuildings.co.uk/wiki/Rainwater_harvesting
[152] Syed Azizul Haq (2017), Harvesting rainwater from buildings, https://www.springerprofessional.de/harvesting-rainwater-from-buildings/11966798
[153] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[154] Grasmanis Dz., Sovetnikov D.O., Baranova D.V. Energy performance of domestic hot water systems. *Magazine of Civil Engineering*. 2017. No. 8. Pp. 140–155. doi: 10.18720/MCE.76.13.
[155] Roberts T., Writer R. (2019), Are drain water heat recovery systems worth it, https://www.buildwithrise.com/stories/are-drain-water-heat-recovery-systems-worth-it
[156] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre
[157] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[158] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[159] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[160] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, Article 8
[161] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre
[162] BREEAM, https://www.breeam.com/
[163] JosTec, what is BREEAM and Why is it Important, https://www.rjacoustics.com/what-is-breeam-and-why-is-it-important
[164] https://www.breeam.com/discover/technical-standards/refurbishment-and-fit-out/
[165] LEED rating system, https://www.usgbc.org/leed
[166] German Sustainable Building Council (DGNB), https://www.dgnb-system.de/en/system/
[167] Sweden Green Building Council, https://www.sgbc.se/certifiering/miljobyggnad/
[168] European Commission, Eco-Management and Audit Scheme, https://ec.europa.eu/environment/emas/index_en.htm
[169] European Commission. Green Public Procurement, https://ec.europa.eu/environment/gpp/index_en.htm
[170] European Commission (2016). EU GPP Criteria for Office Building Design, Construction and Management, https://ec.europa.eu/environment/gpp/pdf/swd_2016_180.pdf
[171] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[172] European Commission. About BUILD UP Skills, https://www.buildup.eu/en/skills/about-build-skills
[173] Climate Adaptation and Mitigation Synergies in Energy Efficiency Projects (CAMS Platform), http://trea.ee/cams/
[174] Raken, Construction Quality Control Checklist, https://www.rakenapp.com/construction-checklists/construction-quality-control
[175] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre
[176] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)

[177] A Study Guide to improve energy efficiency in residential buildings prepared in the frame of the project "Awareness raising campaigns for construction related stakeholders in Russia, Belarus and the Ukraine", ARCEE (2015)
[178] Buildings Performance Institute Europe (BPIE). Europe's Buildings under the—A Country-by-Country Review of the Energy Performance of Buildings; BPIE: Brussels, Belgium, 2011.
[179] D'Agostino, D.; Zangheri, P.; Castellazzi, L. Towards Nearly Zero Energy Buildings in Europe: A Focus on Retrofit in Non-Residential Buildings. Energies 2017, 10, 117. [CrossRef]
[180] Bean F., et al. (2017), Barriers that hinder deep renovation in the building sector, http://embuild.eu/site/assets/files/1316/d4_1_embuild_final_report-1.pdf
[181] Krizmane M., et al. (2016), Enabling the landscape for deep green renovations / Energy Procedia 96 (2016) 404 – 412
[182] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre
[183] Streimikiene D., Balezentis T. (2019), Innovative Policy Schemes to Promote Renovation of Multi-Flat Residential Buildings and Address the Problems of Energy Poverty of Aging Societies in Former Socialist Countries
[184] Streimikiene D., Balezentis T. (2019), Innovative Policy Schemes to Promote Renovation of Multi-Flat Residential Buildings and Address the Problems of Energy Poverty of Aging Societies in Former Socialist Countries
[185] Kirsimaa K., Org M., Kuldna P. (2020), Mapping climate adaptation options in energy efficiency projects, Task WP4.1 of the CAMS project, led by Stockholm Environment Institute Tallinn Centre