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Mapping of Existing Technologies to Enhance Energy Efficiency in Buildings in the UNECE Region

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Acronyms and Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air – conditioning Engineers
CFL	Compact Fluorescent Lamp
DHW	Domestic Hot Water
EE	Energy Efficiency
EI	Energy Intensity
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certification
EMIS	Energy Management Information System
ENMS	Energy Management System
ESCO	Energy Service Company
EU	European Union
HVAC	Heating, ventilation, and air conditioning
INDC	Intended Nationally Determined Contributions
ISO	International Organization for Standardization
LED	Light-Emitting diode
LEED	Leadership in Energy and Environmental Design
NGO	Non-governmental organizations
NZEB	Net Zero Energy Building
SDG	Sustainable Development Goal
UNDP	United Nations Development Program
UNECE	United Nations Economic Commission for Europe

Metrics

kWh	kilowatt hour
m^2	square metre
W/mK	watts per metre Kelvin
W/m^2K	watts per square metre Kelvin
kWh/m^2yr	kilowatt hour per square metre per year
TWh	Terawatt hour
TOE	Tonne of oil equivalent

Executive Summary

One of the most important goals of public policy to stimulate the transition to a sustainable energy system is to improve energy efficiency (EE) and to accelerate progress towards sustainable development. Indeed, according to the United Nations Economic Commission for Europe (UNECE), "Improving energy efficiency is one of the most cost-effective options for meeting growing energy demand in most countries. It contributes to energy security, a better environment, improved quality of life, and economic well-being" (UNECE, 2017a, p.10). While it is generally recognized that significant progress is being made, there is still substantial potential for improving energy efficiency worldwide.

Across all countries in the United Nations Economic Commission for Europe region, the buildings sector accounts for approximately one third of energy consumption, and 40 percent of CO_2 emissions (UNECE 2018). The building sector presents a unique opportunity to improve energy efficiency substantially; both by retrofitting existing buildings and by requiring higher energy efficiencies on newly-constructed buildings. National public policy includes a variety of mechanisms which are meant to encourage increasing building energy efficiency. These include mandatory standards, cash and tax incentives, and consumer information programmes.

In 2017, the UNECE Committee on Housing and Land Management (CHLM) and the Committee on Sustainable Energy (CSE) commissioned a comparative study on building standards in the UNECE region, entitled "Mapping of Existing Energy Efficiency Standards and Technologies in Buildings in the UNECE Region". This report follows that earlier study by analysing the actual (as opposed to perceived) prevalence of specific types of energy-efficient technologies in the building stock in the UNECE region, along with the levels and types of public policy interventions supporting their deployment. The study objectives are to evaluate the adoption of these technologies in UNECE member States and appraise the gaps between the existing energy efficient technologies in buildings and their application and adoption, with assessments undertaken at national levels. The study aims to highlight the variance in the use of technologies across countries through gap analysis, and to determine if any correlation exists between the strictness and enforcement of existing standards and the levels of deployment. The data for this study was gathered through desktop research.

The UNECE member States are categorized into subregions, as set forth in Chapter 1. The analysis is based on empirical data, analysed on a 3-point scale for implementation of the building energy efficiency technologies identified in Chapter 2. The technologies were aggregated into five high-level categories - "Building Envelope and Glazing", "Heating of Domestic Hot Water Supply", "Ventilation, Air Conditioning, and Cooling", "Appliances", and "Lighting" – and were separately assessed by building type. The tabulated data and country-specific narratives are documented in the report annexes.

The data present some interesting findings for the UNECE region that can help stakeholders in a variety of roles: policy makers to understand the potential for adopting energy efficiency technologies, private sector representatives to appreciate the market potential, and governmental entities (municipal and utility providers) to comprehend the ancillary benefits of promoting building energy efficiency.

The data suggests that some aspects and types of energy efficiency technologies are consistently deployed in buildings across the UNECE member States. For example, all countries require efficient building envelope insulation (including windows), and many are phasing out incandescent bulbs in favour of more efficient lighting technology. On the other hand, there are wide disparities in the prevalence of energy efficient decentralized space heating technologies. The broad findings of this study are as follows:

1. **Energy efficiency in the building stock is improving in all regions.** Countries in Eastern Europe, Central Asia, the Russian Federation, and South-Eastern Europe – many of which traditionally have low internal energy prices – have significantly increased mandatory energy efficiency requirements, especially for newly constructed buildings.
2. **Nevertheless, energy efficiency in the building stock is improving only incrementally and in a disjointed manner.** This finding is particularly unexpected, given that recent advances in technology design have yielded remarkable advancements in efficiency and this trend is expected to continue.
3. **Three types of public policy tools are particularly successful at supporting energy efficiency improvements in buildings**. These include legal regulations (such as building standards), financial incentives (rebates, reduced-rate debt, tax deductions), and information awareness programmes for various types of energy efficient technologies. Countries with comprehensive and stringent building standards in place tend to have higher penetration rates of energy efficient technologies.
4. **Effective design and implementation of public policy is key to increasing energy efficiency.** The substantial gaps between what is available in the market and what is being used makes it clear that effective governance and use of legal and financial instruments, rather than just technical advancement, are key.
5. **Three specific technology trends can be clearly observed:**
   a. Countries in the European Union (EU) show increased adoption of high energy efficiency boilers, along with shifts to cleaner fuel sources. However, strong concerns remain regarding the use of coal for residential space heating.
   b. With the implementation of labelling and Ecodesign regulations, the adoption of energy efficient appliances is on an upward trend.
   c. Most countries in the UNECE region have banned, or are phasing out, incandescent light bulbs in favour of compact fluorescent lamp (CFL) and light-emitting diode (LED) technologies. However, lighting sensors and controls are being implemented less frequently.
6. **Energy performance certificates have accelerated retrofitting of existing buildings, but much remains to be done.**
7. **In addition to the numerous environmental benefits associated with decreased energy consumption and increased generation of renewable electricity, many of the technologies discussed in this report offer additional non-energy related social benefits.** Examples include boosting economic growth, developing local competitive markets, increasing employment, promoting implementation of lower-cost and accessible energy efficient technologies, and developing international markets.

Countries can take several priority actions to increase the deployment of technologies to enhance energy efficiency in buildings. The following recommendations cover multiple perspectives, such as educational, technical, regulatory, financial, institutional, technology adaptation, capacity development, and private sector involvement.

Recommendations

1. Policy and legislation

Recommendation A: *Governments need to provide good policy, strong institutions, and efficient public services to ensure the private sector can thrive; they should also commit to develop and sustain the institutions that implement, oversee, and regulate these policies. The private sector is critical to economic growth, but it cannot and does not act alone, the public sector should support a balanced strategy; the "Technology push and Market pull" strategy (Brocato, 2010), for example.*

Recommendation B: *Governmental research and development programmes should advance technologies which are too risky for the private sector, which will require transparent collaboration between government, industry, and energy programme administration in order to convert some innovations into marketable products.*

Recommendation C: *More specific requirements to better define cooling degree-days should be included in energy efficiency building standards, this will help to evaluate building energy performance during hot periods of the year more accurately and reasonably.*

2. Role of public and private sector; new market opportunities

Recommendation D: *Governments should undertake initiatives to raise the bar for developing building energy efficiency technologies to meet specific local needs, which can create new international markets.*

3. Connect building energy efficiency with Intended Nationally Determined Contributions (INDC) targets; reduce fossil fuel use in space heating

Recommendation E: *Governments should explicitly connect building energy efficiency measures to INDC targets to further encourage improvement.*

Recommendation F: *Governments of countries in which coal is still used for residential heating, and coal is the lowest cost fuel, should promote the use of other fuels to drive the adoption of cleaner technologies.*

4. Information awareness for multiple social benefits of energy performance certification

Recommendation G: *Local governments should publish city-level data demonstrating both decreased energy costs and higher income associated with various levels of energy performance certification to promote building energy efficiency investments.*

5. Technological adaptation through effective promotion and awareness campaigns

Recommendation H: *Governments should scale up effective promotion and awareness campaigns which are essential to encourage consumers to purchase appliances labelled with high energy efficiency ratings.*

Recommendation I: *More stringent regulations are needed to promote exterior and interior lighting in non-residential buildings and develop social pricing structures for homeowners to install smart meters. Governments should create awareness programmes reflecting upon the variety of benefits from adopting these technologies.*

6. Key focus on building retrofits

Recommendation J: *Governments should promote the creation of datasets and tools which guide analysis of, and demonstrate, the financial benefits of increasing energy efficiency through retrofitting existing buildings. Specifically, this should include the use of simulation software tools for building energy performance during the design phase of both new building construction and major building retrofits.*

Recommendation K: *Governments should develop and promote programmes to encourage complete retrofit of decrepit and condemned residences, involving private real estate investors or developers.*

7. Coordination between national and local authorities to reassess development and implementation of building codes

Recommendation L: *National and local governments need to coordinate and work together to design policies and building codes which can be adopted either nationally or locally; performance-based building codes should be preferred to prescriptive codes, as the flexibility should increase compliance.*

8. Investment and finance

Recommendation M: *Governments should develop and promote multiple financial mechanisms to increase the adoption of energy efficiency projects across the building sector: residential, public, and commercial buildings. To help overcome the complexity of investments and lack of capacity at the individual and suppliers' level, Energy Service Companies (ESCO's) should be more heavily promoted by governments.*

9. Capacity building to promote building retrofits

Recommendation N: *Standard civil engineering educational and training curricula should focus more on the largely neglected discipline of building lifecycle management; this should emphasize courses and programmes on energy efficiency and building renovation*.

Recommendation O: *Financial institutions should be empowered to understand the profitability of energy efficiency investments; this would require more effective promotion and dissemination of best practices, appropriate de-risking, and financing solutions for bankers. Clear technical and financial criteria should be defined by the financial institutions to grant loans. Additionally, a pre-approved list of eligible equipment manufacturers and suppliers, can assist in measuring and avoiding risks*.

10. Expanded use of Energy Performance Certificates (EPCs)

Recommendation P: *Governments could create tiered energy tariffs linked to EPC rating; such EPC-based tiered pricing could both encourage energy performance certification and the implementation of energy efficiency technologies.*

Recommendation Q: *Incentives for implementing energy efficiency technologies could be linked to EPC rating. For example, a C-rated building that is retrofitted such that it afterwards is rated A should receive a higher concession, higher land use tax compensation, or lower debt interest rate, as compared to an upgrade from C to B.*

Introduction

According to the report "Energy for Sustainable Development in the UNECE Region" released in 2017 by the United Nations Economic Commission for Europe (UNECE, 2017a), one of the most important goals of public policy to stimulate the transition to a sustainable energy system is to improve energy efficiency (EE) expeditiously. The report states, "Improving energy efficiency is one of the most cost-effective options for meeting growing energy demand in most countries. It contributes to energy security, a better environment, improved quality of life, and economic well-being" (UNECE, 2017a, p.10). The UN's Sustainable Development Goals target 7.3 (SDG7.3) is to "double the global rate of improvement in energy efficiency by 2030" (UNECE, 2017a, p.1). There is significant potential worldwide for improving energy efficiency, and it is widely recognized that significant progress is indeed being made. According to the Enerdata Global Energy Statistical Yearbook 2016, global energy intensity[1] improved by 1.8 percent in 2016 and 1.2 percent in 2017. However, there are still significant barriers hindering this progress.

Buildings play a pivotal role and are integral to all sectors of the economy, such as industry and manufacturing, and the services sector (tourism, financial services, schools, universities, hospitals). The building sector has the largest potential for cost-effective improvement in energy efficiency and emissions reductions (Krarti, Dubey, & Howarth, 2019). Additionally, focusing on buildings brings significant social co-benefits, such as:

- increasing energy security
- expanding entrepreneurial opportunities
- reducing energy poverty
- increasing access to energy services
- improving air quality (both indoor & outdoor), with positive impact on occupant health
- increasing comfort and living standards
- reducing in CO_2 emissions

It can be said that highly efficient buildings are the foundation of healthy, prosperous, secure, and sustainable communities.

Along with the integral impact and strong potential for increased energy efficiency in the building sector, there is a second reason to focus on energy efficiency in buildings. Buildings are already quite regulated, which facilitates dissemination of energy efficiency requirements, further driving progress. Many countries have set up official national energy efficiency laws or programmes with quantified energy efficiency targets. These programmes can have a substantial impact on the durability and effective coordination of public policy in favour of energy efficiency but require sufficient political consensus for practical implementation.

The purpose of this study is to analyse the gaps between existing energy efficiency technologies in buildings, and their application and adoption in the UNECE region. This report aims to highlight the gap between the strictness and enforcement of existing standards and the level of application of energy efficiency technologies for heating, cooling, ventilation, and lighting in the built environment.

The analysis discussed in this report (see Chapter 3) is based on empirical data, presenting some interesting findings for countries in the UNECE region, which can assist stakeholders in a variety of roles: policy makers to understand the potential for adopting energy efficiency technologies, private sector representatives to appreciate the market potential, and governmental entities (municipal and utility

[1] Energy intensity is defined as total energy consumption divided by gross world product.

providers) to comprehend the ancillary benefits of promoting building energy efficiency. The data upon which the gap analysis is based is presented in the annexes, along with country-specific narratives.

Given the importance and urgency of improving energy efficiency globally, the building sector's high potential for cost-effective improvement in energy efficiency, and many well-documented social co-benefits related to energy-efficient buildings, the existence of substantial gaps is unexpected. Indeed, multiple barriers make it difficult to transform the vast potential of energy savings in the building stock into a reality. Some of these barriers are general (that is, they apply to all energy efficiency projects in all sectors), while others are specific to buildings. General barriers to improving energy efficiency include:

- lack of technology
- limited financing
- insufficient awareness and expertise of financiers
- poorly adapted or missing regulations
- high cost of reliable information
- greater weight given to upfront costs compared to recurring costs
- lack of knowledge by building owners or design teams

It is found that governments in many countries lack a clear mandate and adequate capacity to design and implement policies in favour of building energy efficiency. One significant barrier specific to the building sector is structural complexity; a holistic systems perspective, which leads to more thorough optimization of design and operation and hence improved energy efficiency, requires more breadth and depth of expertise that what is commonly found (UNDP, 2009).

A variety of public policies designed to improve energy efficiency in the building stock have been implemented throughout the UNECE region, with differing degrees of success. In the EU countries, much attention has been given over the past decade to building energy efficiency, with the following directives:

- directive 2006/32/EC of 5 April 2006 on energy end-use efficiency and energy services
- directive 2009/28/EC of 23 April 2009 on the promotion of the use of energy from renewable sources providing for the promotion of energy efficiency
- directive 2009/125/EC of 21 October 2009 establishing framework for setting of the ecodesign requirements for energy-related products
- directive 2010/30/EU of 19 May 2010 on the indication of energy efficiency labelling and standard product information of the consumption of energy and other resources by energy-related products
- directive 2010/31/EU of 19 May 2010 on the energy performance of buildings
- directive 2012/27/EU of 25 October 2012 on energy efficiency, amending directives 2009/125/EC and 2010/30/EU and repealing directives 2004/8/EC and 2006/32/EC
- directive (EU) 2018/844 of 30 May 2018 amending directive 2010/31/EU on energy performance of buildings and directive 2012/27/EU on energy efficiency.

To help officials in EU countries implement the Energy Efficiency Directives, the European Commission has published several guidance notes; Article 5, 6, 7, 8, 9-11, 14, 15 (EU Directive 2010). Country-level implementation of these directives should induce important changes in energy efficiency in Europe, especially in the building sector. In the United States, the Energy Policy Act of 2005 (US EPA, 2018) covers almost every aspect of energy generation, distribution, and consumption, along with guidelines on energy efficiency. In 2012, 31 US states adopted either ASHRAE[2] 90.1.2007 or the ICC Energy Conservation 2000-2015[3], implementing model codes for residential and commercial buildings. Their provisions concerning

[2] ASHRAE 90.1-2007 is the primary document for establishing the BASELINE BUILDING PERFORMANCE standard for the whole building energy simulation.

[3] The International Energy Conservation Code 2015 (IECC 2015) is a model code produced by the International Code Council (ICC). This document provides the foundation for many state and city codes.

energy efficiency in buildings include: energy consumption reduction targets for public buildings, integrating energy efficient equipment in public procurement, new standards for 14 large appliances, and tax incentives for energy efficiency improvements in residential, commercial, and public buildings. However, some organizations (such as Intergovernmental Panel on Climate Change (IPCC), Global Alliance for Buildings and Construction (GABC)) have criticized these acts for making only limited progress towards energy efficiency in buildings.

In rapidly developing countries in which the built environment is largely immature, the building sector should prioritize improving energy efficiency and reducing future emissions in new construction. Policies and programmes targeting existing building stock will likely have a lower magnitude impact on overall improvement in energy efficiency. This is one aspect in which the developing economies can have a disproportionately large impact on reaching global energy efficiency targets, as the marginal cost of increasing building energy efficiency is lowest at construction time. New construction represents a significant opportunity to integrate efficient materials, new technologies, and best practices from the start. During the construction phase, the entire building system can be designed to optimize operational energy efficiency considering various factors. For example, operational energy consumption is affected by location, orientation, structure, layout, construction materials, and included equipment; all are design- and construction-time decisions. Some of these factors can be improved upon later during major renovations but are more capital intensive.

Conversely, in many countries with developed economies and extensive building infrastructure already in place, retrofitting existing buildings to improve energy efficiency and reduce CO_2 emissions should take priority over new buildings. For example, the built environment in the European Union is composed of approximately 35 percent of buildings more than 50 years old; improving their energy efficiency could reduce the region's total energy consumption by more than five percent (UNECE, 2017a, p.8).

Policies, programmes, and technologies can be considered to address energy efficiency in buildings from three perspectives: systems, structure, and service. Examples of policies and programmes which support energy efficiency in the building stock include appliance standards and labels (Energy Star, et al.), building energy codes, utility demand-side management programmes and targets, public-sector energy leadership programmes, energy pricing measures and financial incentives, education and training initiatives, targeted awareness programmes, and the promotion of energy service companies (ESCOs) (UNDP, 2009). The level of success of each of these types of policies is dependent upon many factors and may be hindered by various barriers. In addition, the best approach to improving building energy efficiency in each country may depend upon the building sector being sufficiently mature (economically) to successfully adapt to the ecological transition, as already suggested. This study links relevant national policies and technological adoption to identify the gaps between existing energy efficient technologies in buildings and their application and adoption in the UNECE region, with assessments undertaken at the national level.

The remainder of this report is structured in four major sections. Chapter 1 documents the objectives and scope of this study; the methodology used is also detailed along with perceived limitations. Chapter 2 focuses on existing energy efficiency technologies in five broad categories: "Building Envelope and Glazing", "Heating of Domestic Hot Water Supply", "Ventilation, Air Conditioning, and Cooling", "Appliances", and "Lighting". The review of the application and adaption of the relevant technologies, nation-level assessment, and gap analysis are documented in Chapter 3. This report concludes with Conclusions and Recommendations, which are based on the mapping and gap analysis, focusing on priority actions which countries in the UNECE region should take to increase the adoption of technologies to enhance energy efficiency in buildings. Recommendations include, but are not limited to, aspects of policy and legislation, investments and financial incentives, technology adaptation, and capacity development. This report ends with a set of annexes, documenting the data upon which the gap analysis was based. These annexes are organized by country alphabetically within each UNECE subregion.

Chapter 1 – Objective, Scope, Methodology, and Limitations

The objective of this study is to identify and analyse gaps between the existing energy efficient technologies in buildings and their application and adoption in the UNECE region, with assessments undertaken at the national level. As previously mentioned, this study aims to highlight the difference in the use of technologies between countries through gap analysis, and to determine if any correlation exists between the strictness and enforcement of existing standards and the level of applied technologies. This study builds upon the comparative study on building standards undertaken in 2018 entitled "Mapping of Existing Energy Efficiency Standards and Technologies in Buildings in the UNECE Region" (UNECE 2018) by the UNECE Committee on Housing and Land Management (CHLM) and the Committee on Sustainable Energy (CSE).

This study undertakes the mapping and clustering of existing technologies to enhance energy efficiency in buildings. It further identifies and analyses the gaps between existing energy efficient technologies, and their application and adoption in the UNECE region. The analysis complements the previous reports (UNECE 2017b, UNECE 2018) which were limited, respectively, to building codes and technical requirements, and various social, policy, and financial barriers. Specifically, this study extends the initial assessment of energy efficiency technologies in buildings, developed in the "Mapping of Existing Energy Efficiency Standards and Technologies in Buildings in the UNECE Region", in relation to the existing standards and current barriers.

The primary method of this study is gap analysis based on data gathered mainly through desktop research of both internet and print media, including official governmental communiques, NGO-published reports, academic publications, energy databases, and public news outlets. The data has been validated and data sources further augmented through consultations with various subject-matter experts and organizations. In line with the previous study (UNECE 2018), the UNECE member States are similarly grouped by subregions A, B, C, D, and E, with an additional subregion F[4]. Due to insufficient data, San Marino and Israel were excluded from this study. Countries are assessed on a 3-point scale (Low, Medium, High) for implementation of the building energy efficiency technologies described in Chapter 2. For tabulation and analysis, the technologies were aggregated into five high-level categories: "Building Envelope and Glazing", "Heating of Domestic Hot Water Supply", "Ventilation, Air Conditioning, and Cooling", "Appliances", and "Lighting". Where possible, relevant data was gathered separately for retrofitting existing buildings, and implementation in new construction; the data was further segregated by four types of buildings: single-family dwellings, multi-family dwellings, commercial buildings, and public buildings.

The data collected to measure and analyse the trends and patterns of application of energy efficient technologies is based on the assessment criteria listed in Table 1, by which implementation of each technology in each country was evaluated to assign an Impact Score. Several annexes conclude this report, documenting the data upon which the analysis was based. These annexes are organized by country alphabetically within UNECE subregion.

Table 1 - Impact score assessment criteria

[4] Subregion A = Andorra, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Monaco, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom.
Subregion B = Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia.
Subregion C = Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Republic of Moldova, the Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan.
Subregion D = Canada, United States of America.
Subregion E = Albania, Bosnia and Herzegovina, Montenegro, Serbia, the former Yugoslav Republic of Macedonia.
Subregion F = Turkey.

Impact Score	Assessment Criteria
3 (High)	The technology is strongly prevalent. There is governmental support and initiative to encourage adoption of the technology, and there are active measures being undertaken, which include financial support and incentives. Application of this technology is mandatory, or in a transition phase to becoming mandatory. There could be fines for non-compliance. This technology might be made affordable and economically feasible through means of incentives and being widely implemented.
2 (Medium)	National legislation (laws, building energy codes, etc.) does not require implementation of this technology. There are only some cases where implementation of this technology is supported at the regional level (e.g. in some climate zones etc., but not in the whole country). Some prescriptive recommendations may exist in legislation. This technology is frequently implemented during new construction or retrofits; despite the lack of proper regulatory framework, it may be affordable and widely used. There is a moderate trend of implementation for the technology, but there are still some existing gap areas. This could be improved with public-private partnerships, government support, push-pull marketing strategies, compliance standards, and financial incentives.
1 (Low)	Existing legislation does not require implementation of this technology. There are also no specific building energy codes that include at least prescriptive requirements. This technology is only seldom implemented in some regions (including demonstration projects, implemented by international organizations and co-financed by the various funds). The technology is likely economically inefficient. It is being implemented, but at a stage of infancy; market barriers exist which curtail adoption. Much is mentioned about it in policies, but there is not substantial applicability and efforts are required to promote the technology.
0 (Non-applicable)	Implementation of this technology is not economically feasible and not mandatory. This technology is not applicable (except possibly in some specific cases).
NI – No Information	No information, as of now, on the data point.

The analysis focuses on the following topics relevant to energy efficiency for countries in the UNECE region:

- institutional and legal policy
- building codes and standards
- existing technologies
- local capacity development
- existing availability of materials and equipment
- currently implemented financial and economic mechanisms

This report is based on the principles of the "Framework Guidelines for Energy Efficiency Standards in Buildings" (UNECE 2017c), and thus transcends the incremental, components-based approach of existing building standards analyses. It is well-known that the largest saving potential in energy use occurs when a systems perspective is used to implement energy efficiency improvements, so this basis is appropriate. This design perspective influences the gap analysis and subsequent recommendations. Furthermore, the identified gaps are analysed by highlighting the difference in the use of technologies among countries of the UNECE region.

The scope of the study is limited to evaluating the adoption of building energy efficiency technologies by UNECE member States, identifying implementation gaps and possible causal barriers, and recommending actions that consider the ecological transition at all levels of building renovations and new building programmes. The validity of the conclusions and recommendations in this report is limited by the data which was publicly available through desktop research at the time of study development. Where appropriate in the remainder of the report, specific assumptions which have been made are documented; all conclusions are likewise dependent upon these assumptions. Finally, unlike the aforementioned report (UNECE 2017b), this study is not based on data elicited via a structured survey from subject matter experts. To the extent that said experts hold relevant information that is not publicly available, the conclusions and recommendations here may be biased.

This study was reviewed, and results validated, by stakeholders from the UNECE region, relevant national authorities, and members of the UNECE Joint Task Force on Energy Efficiency Standards in Buildings. The preliminary findings of the study were validated at the Third Meeting of the Joint Task Force in Geneva, Switzerland on October 3rd, 2018, and the finalized study presented during the Ninth International Forum on Energy for Sustainable Development, on November 12th-15th, 2018 in Kyiv, Ukraine.

Chapter 2 – Energy Efficient Technologies in Buildings in the UNECE Region

Buildings consume significant amounts of energy to maintain comfortable occupancy conditions, which requires space heating and domestic hot water preparation, ventilation and air conditioning/cooling, and power supply for lighting and other household appliances. There are advanced technical solutions for buildings to reduce energy consumption, CO_2 emissions, and energy wastage, while providing maximum thermal comfort and ensuring occupant safety. In general, such technologies either reduce the energy demand or increase the efficiency with which energy is used. Recently, effective building planning at the construction stage has become increasingly important; this includes effective planning of eco-design, building orientation, effective use of green plant systems for the roof and building facade, use of shading, planning of natural lighting and natural cross section ventilation, etc.

Modern building regulations define the requirements of building engineering systems and set building envelope thermal performance limits, which also determine the most optimal energy consumption, in terms of technical and economic conditions.

Building codes provide guidelines for new construction and for retrofitting the existing building stock to create high-performance buildings by applying an integrated, holistic design process, which increases building life-span, reduces energy consumption, and contributes to a better, healthier, more comfortable environment for people to live and work. Several technological options exist which, along with providing energy efficient solutions, also: support sustainability measures, reduce operating costs and environmental impacts, and increase building adaptability, durability, and resilience. This chapter focuses on how and where energy is consumed in a building during its operational life, and on relevant existing energy efficient technologies, which have been divided into the following five broad categories:

- building envelope and structure; insulation, glazing, airtightness and reduced thermal bridging
- space and water heating
- central air conditioning/cooling
- appliances and equipment
- lighting

The following are some examples of energy efficient measures (the list of technologies is not prescriptive, and the adequacy of each technology depends on the specific region, its climate conditions, and other factors) which can be adopted to make buildings efficient and productive:

- **thermal protection for enhancing the building envelope and structure:**
    - thermal insulation of the building envelope
    - replacement of obsolete windows and doors with modern energy-efficient ones
    - increasing the airtightness of buildings (adequate ventilation of premises must be arranged along with increased of air tightness)
    - improving design details to reduce thermal bridging in the building envelope
- **decrease heat losses in buildings:**
    - restoration and sealing of inter-panel joints of the walls and ceilings, in case of panel building[5] construction
    - installation of additional entrance groups (halls, wind porches) with double doors
    - installation of automatic door closers

[5] Panel building is a building constructed of large, prefabricated concrete slabs/panels.

    - installation of heat recovery units to limit heat loss by the ventilation system and supply fresh and clean air

- **improvement and optimization of internal heat-supply systems, to decrease energy consumption:**
    - thermal insulation of heating system pipelines, hot water risers, and heating system distribution networks
    - installation of automatic individual heat points for the heat supply system
    - installation of thermostats for heating system radiators
    - installation of balancing valves on heating system risers
    - installation of heat- and water-heating boilers with weather-compensating controls
    - use of circulating pumps for heating systems and hot water supply with built-in or external frequency converter drives
    - installation of reflective insulation behind radiators
    - hydro-pneumatic or chemical cleaning of heat supply systems, including basic equipment

- **reduction and optimization of electricity consumption:**
    - replacement of lamps and bulbs in internal and external lighting systems
    - use of scheduling/occupant or daylight sensors for lighting controls
    - use of high-efficiency electric heating/cooling equipment (heat pump)
    - optimization of energy consumption by elevators with installation of frequency converter drives
    - use of frequency converters in the engineering building systems to optimize the operation of fans, pumps, and other relevant equipment
    - installation of energy-efficient household appliances
    - installation of photovoltaic heating and power-generating systems (solar panels)

Some of the basic energy efficiency measures are described in the remainder of this chapter, highlighting their impacts on energy consumption and applicability in the UNECE subregions.

2.1. Building Envelope: Insulation and Glazing

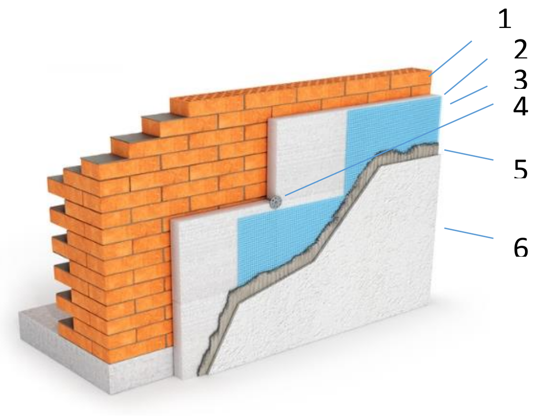
2.1.a Insulation of building envelope, airtightness, thermal bridging

The building envelope has the greatest impact on building energy performance; it is a prime focus area to consider when energy efficiency measures are planned for both existing and new buildings. Considering the functions of the building envelope (i.e. security, comfort, shelter, privacy, aesthetics, ventilation, etc.), it is imperative to optimize the design of the building envelope to meet the occupants' requirements while reducing energy consumption and heat loss.

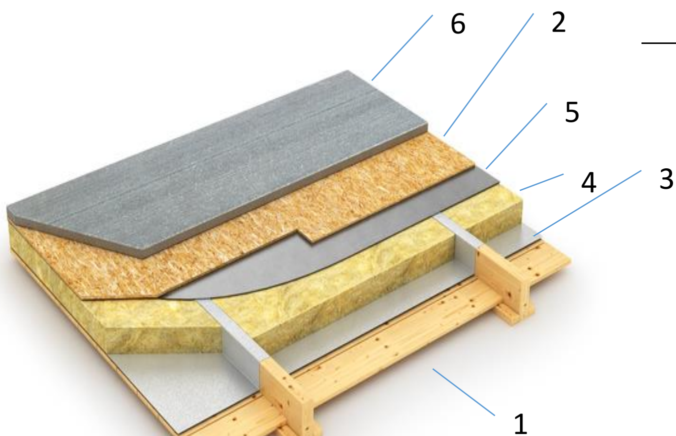
The importance of thermal insulation, airtightness, and reducing thermal bridging in buildings is equally relevant for countries in both hot and cold climates. Heat loss through leakage during cold months leads to increased use of heating energy, this is analogous to losing cool air from central air conditioning due to high heat gain in the premises during the summer months (both situations resulting in increased consumption and higher CO_2 emissions). Most building heat loss occurs through the walls, roofs, floors, and glazing, sealing joints, thermal bridges etc.

Adequate levels of insulation as well as the reduction of thermal bridging are critical measures for improving thermal performance and comfort, but also to ensure long-term building durability. Proper insulation can reduce heat loss in cold climates and heat gain in hot climates. The type and amount of insulation varies according to climate, building type, and usage. There are many available energy efficient technologies which address the building envelope that are predominantly applied to new buildings. Some may also be implemented during retrofit upgrades, as applicable.

Selection of insulation layer thickness is based on the requirements of the construction and regulatory criteria, climate conditions, current thermal, and other necessary parameters. All of which should be considered during the architectural design stage. The principles of some technical solutions for insulation of external walls and for attic/ground floor or basement slab (included, but not limited to) are illustrated in Figure 1.

Principle for exterior wall insulation	
	**Key elements of the proposed technology** 1. Existing concrete wall 2. Adhesive composition 3. Insulation plate 4. Fixing plug 5. Reinforcing fiberglass mesh is applied to the adhesive composition 6. Outer protective and decorative coating with preliminary primer layer

Principle for insulation of the attic floor	
	Key elements of the proposed technology



	1. Existing attic floor 2. Plywood smoothing sheet 3. Air barrier (vapor control layer in some assemblies) 4. Insulation plate 5. Hydroisolation 6. Final floor coating

Figure 1 - Technical solutions for insulation

There is a wide range of thermal insulation materials used in buildings in the UNECE; some are shown in Figure 2.

	Fiberglass	Rock wool	Slag wool	Expanded polystyrene (Frothed non-pressed)	Extruded polystyrene
VIEW					
CHARACTERISTIC	Initial raw materials for production of fiberglass are: sand, soda, limestone, drill (or etibor), cullet. Heat conductivity - 0.038-0.046 W/mK. Max operational temperature - 450 °C. Min. operational temperature -60 °C.	The main raw materials for production of stone (basalt) cotton wool are rocks. Heat conductivity – 0.035 — 0.042 W/mK. Max operational temperature – up to 1000 °C (only in case of lack of deformation).	Initial material for production of slag cotton wool are domain slags. Heat conductivity – 0.04 – 0.07 W/mK. Max operational temperature - 300 °C.	Expanded polystyrene (or polyfoam) stands for the foam plastic which consists for 98 percent air. Heat conductivity – 0.036 – 0.050 W/mK Max operational temperature - +70 °C. Min operational temperature - 50 °C.	Extruded expanded polystyrene consists of granules of polystyrene formed by an extrusion method. Heat conductivity - 0.028 -0.034W/mK Max operational temperature - +75 °C. Min operational temperature - 50 °C.
ADVANTAGES	• Lightness • Elasticity • Good sound-proofing properties; • Non-flammable • High compression for easy transport	• Non-flammable • High elasticity • Immunity to mould and fungus • Resistance to short-term influence of moisture – can be mounted during rain • Fibres are not caustic	• Low water absorption – is ideal for work under the open sky in any weather	• Low price • Excellent flexibility • High durability on compression at the low density • Simplicity of installation	• High durability on compression at the low density • Low water absorption • Low vapor permeability • Low coefficient of heat conductivity
DISADVANTAGES	• High fragility of fibres • High water absorption	• Low compression of material; inconvenient for transport • High cost	• High fragility of fibres • Low indicators of heat conductivity	• Flammability • High water absorption • Repeated transition of temperature through 0ºC leads to destruction	• Combustible material[6] • High cost
RESTRICTIONS	It is necessary to use the coveralls made of a dense material, gloves, respirator, and safety glasses during installation.	Requires careful transport and protection against mechanical influences.	Not recommended to use together with metallic facade elements.	Prohibited to use without covering – requires cement and sand or plaster protection from the open environment.	Prohibited to use without covering – requires cement and sand or plaster protection from the open environment.

Figure 2 - Insulation materials applied in the UNECE region

[6] One of the types of expanded polystyrene is extruded polystyrene foam. It has a more ordered structure of small closed pores. This production technology increases the moisture resistance of the material, but does not reduce fire hazard, which remains high. Ignition of expanded polystyrenes occurs within a temperature range of 220°-380°C, and self-ignition occurs in a temperature range of 460-480°C. Burning polystyrene foam produces large amount of heat and toxic by-products.

2.1.b Installation of modern windows with higher thermal characteristics

Replacing outdated windows with the latest window technology insulation is much more efficient than repairing them. Building standards in several countries require the installation of energy efficient windows with high thermal characteristics. These windows are made using multi-chamber glazing profiles, which is a more complicated design than traditional wooden-panelled windows. The design of double-glazed or triple-glazed window units (for the regions where it applies) consists of sheets of glass divided by a spacer which is hermetically sealed on each end. The glass panes are separated by air, or filled with insulating gas, to reduce heat transfer.

As well as having advanced thermal characteristics, multi-chamber windows are stronger, resist deformation, and are more durable. Windows made of a broad range of materials are available; the comparison of main technologies is shown in Figure 3.

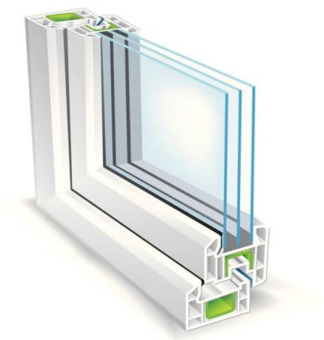
Wooden profile	Aluminium profile	PVC profile
		
Wooden windows made usually of oak, pine, ash tree or larch. Advantages: • Attractiveness • Good thermal insulation and frost resistance • Sound insulation • Possibility of changing colour either outside or inside Disadvantages: • Combustibility and hygroscopicity • Ongoing maintenance or finishing required	Aluminium windows are divided into two types: light and warm aluminium. Windows made of **light aluminium** are suitable for buildings which do not require significant sound and heat isolation. **Warm aluminium windows** consist of two parts: external – cold, and internal – warm, which are produced separately and later merged directly on the building. Advantages: • Lightness • Durability • Resistance to weather conditions • Possibility to customize the configuration and complexity of the window Disadvantages: • Susceptibility to electrochemical corrosion • High thermal conductivity of the aluminium – requires thermally broken frames to achieve high performance	These windows are made of polyvinylchloride (PVC). Advantages: • Good thermal insulation • Excellent sound insulation • Resistance to various atmospheric actions • Simple operation and maintenance Disadvantages: • Mechanical damages of a plastic window cannot be corrected

Figure 3 - Energy efficient window profiles

Depending on the thermal and technical requirements, window profiles can be specified in accordance with building regulations or requirements; acoustic insulation could be included, for instance. In many countries, windows have energy saving glazing, incorporating a glass panel coated with a thin layer of silver, which can significantly decrease the glazing emissivity. This type of single-chamber double-glazed window is warmer than the simple double-chamber ones. At the same time, it weighs about 30 percent less, which contributes to a longer lifespan. Moreover, due to the silver coating, this type of double-glazed window exhibits the mirror effect. The enhanced reflectivity allows the windows to help a room stay cooler during the summer, and warmer in the winter.

The importance of proper window installation by highly qualified specialists, in order to reduce thermal bridging and ensure proper air tightness of the window, should be highlighted.

2.2. Heating, Domestic Hot Water Supply

Different approaches to the design of building heat supply systems depend largely on the availability of energy resources, fuel prices, infrastructure, technological development, and relevant energy policy. Heat supply system technology is in a transition phase in the UNECE region, and there are significant technological advancements being made to include renewable energy as a source of heat supply. The following governmental support measures are important for the implementation of renewable energy solutions:

- development of a proper legal framework and related policies
- establishment of targets for promoting renewable energy sources for use in electricity or heating
- provision of financial/fiscal incentives for investment in renewables
- adoption of medium-term feed-in tariffs for the purchase of renewable energy
- imposition of an obligation on power companies to secure a certain percentage of their supplies from renewable sources

The implementation of renewable energy solutions can be applied to both centralized and decentralized heat supply systems.

2.2.a Improvement of decentralized heating supply systems

The principle of decentralized heat supply is based on independently-produced heat energy for internal needs. Decentralized heating systems can rely on both non-renewable fuel (e.g. installation of boiler equipment) and renewable energy (installation of roof-top solar collector systems and heat pumps[7]).

Installation of the boiler equipment

One of the most widespread measures for modernizing decentralized heat supply systems is the replacement of outdated boilers with more efficient ones (for the regions where it applies). The efficiency of new boiler equipment can be determined by the efficiency in energy generation from fuel combusted. The coefficient that defines the efficiency of boilers is called the efficiency coefficient. A higher efficiency coefficient means the input of fuel required by a boiler is less for the heat generation or for hot water supply. Compared to the traditional boilers, more modern boiler equipment has a higher efficiency coefficient from combusting similar amounts of the same fuel type. Moreover, there is also technology that allows the boiler to switch to a different fuel type with higher calorific value, along with an additional feature - automatic heat regulation systems coupled with weather compensated control.

There are different types of boiler equipment which operate using various fuels, including: natural gas, diesel, coal, electric, and biomass (see Figure 4). One of the most efficient boiler technologies is condensing boilers, which are more efficient than traditional boilers. These extract additional heat from the condensation of water vapor, formed as a result of the hydrocarbon combustion process; the condensing boiler is currently considered as the most innovative boiler technology.

EU Directive 2009/125/EC (establishing a framework for setting Ecodesign requirements for energy-related products) forbids the sale of non-condensing gas-fired boilers in the entire EU region, barring a few exceptions. The higher efficiency and environmental-friendliness of condensing boilers make them

[7] A heat pump can be truly renewable only when the electricity used to drive the pump comes from a non-fossil fuel source. Additionally, according to the EU Directive 2009/28/EC, point 31: "Heat pumps enabling the use of aerothermal, geothermal or hydrothermal heat at a useful temperature level need electricity or other auxiliary energy to function. The energy used to drive heat pumps should therefore be deducted from the total usable heat. Only heat pumps with an output that significantly exceeds the primary energy needed to drive it should be taken into account."

superior to traditional gas-fired boilers. Currently, all European manufacturers are obliged to produce only condensing gas-heating equipment for sale in the EU countries.

Figure 4 - Examples of modern gas-fired boilers

Solar collector solutions

Solar heating is one of the most widely-used technical solutions using renewable energy in the building sector. Heat from solar radiation can be used for domestic hot water and internal heating in residential or public buildings. There are two types of solar collectors: flat and vacuum tube collectors (see Table 2). The typical solar collectors generate temperatures of 60-100°C.

Table 2 - Types of solar collectors

Flat solar collectors	Vacuum tube collectors
Advantages	
• Low cost solution • Easy to install and maintain • Simple to operate and generally no other equipment required (such as pumps) • Proven technology with significant lifetime (more than 25 years) • Ideal for intermittent loads (e.g. houses, restaurants, and small businesses) • Transparent insulation can be equipped for flat collectors to achieve a higher efficiency. It can be used to reach the higher target temperatures or applicable in cold climate to protect the collector against the freeze. This variant also has overheating prevention at the collector level.	• Higher efficiency compared to flat collectors • Ideal for high and constant loads (hotels, spas, swimming pools, and gyms) • Ideal for solar cooling and heating; temperatures can range from 50°C in winter to 120°C in summer • Cover winter load, except in extreme conditions • Not prone to damage from heavy snow or hail
Disadvantages	
• Lower efficiency compared to vacuum tube collectors • Temperature range not ideal for solar cooling; during extended winter periods, cannot accommodate the DHW (domestic hot water) load • Sensitive to damage from extreme snowfall or hail	• Relatively expensive solution • Not ideal for small DHW loads (such as houses) • Hot summer conditions may cause glycol pyrolysis if there is no constant consumption or water circulation (temperatures may rise above 130°C) • Prone to damage if used for intermittent loads • Low electricity consumption due to the need for forced recirculation, especially during summer

Solar systems can be divided into two key categories: passive and active (see Figure 5). A passive solar system is installed as one complete rooftop unit comprised of a solar collector and water tank. This system is relatively less expensive but at the same time it is inappropriate for cold climates.

Active solar water heating and heat supply systems include a wide range of engineering equipment: solar collectors, controllers, circulation pump, broad tank, main storage container, and connecting pipes. Active systems are more expensive, but give more benefits and can be used during the winter season. Electric heating provides for the necessary water temperature, especially during cloudy weather with lower levels of radiation. In general, these systems consume less electricity annually. Active systems can be used not only for water heating, but also for heat supply systems. Further, it is possible to adjust the capacity of active solar systems (within specified limits) by means of adding more solar collectors. For example, in case it is necessary to heat more water or to increase the heating area.

	
Passive solar system with flat collectors	Active solar system with vacuum-tube collectors

Figure 5 - Examples of solar heating systems

Heat pumps

A heat pump operates on the principle of vapor-compression cooling. Heat power is carried by means of condensation and evaporation of a coolant (generally, freon circulating within closed contours). Heat pumps consume electricity to operate the coolant compressor and secondary circuit circulation pumps. There are several benefits of installing heat pumps in buildings:

1. Installation of heat pumps systems is most economically feasible at the time of construction, as it is easier to plan for the needed space. During a building retrofit, it may be possible to integrate a heat pump into existing heat supply system along with a heat collector.
2. In cold climates and warm seasons, heat pumps using a water source can work more effectively than air-based heat pumps, or other air conditioning systems. Heat pumps are much more efficient than other electric heating systems and, depending on fuel prices, they can be also more affordable than other heating systems.
3. Heat pumps demonstrate outstanding efficiency when daytime temperatures fluctuate drastically.
4. Heat pumps are economically feasible in countries where natural gas is unavailable or relatively expensive compared to electricity. Heat pump systems have lower energy costs, when the electricity price (for kW) is 3.5 times higher than the price of traditional fuel (per production of 1 kW).
5. In areas where drilling is relatively cheaper, geothermal systems with a vertical soil heat exchanger are the most attractive. However, flat geothermal systems (low depth, wide area) can also work well if there are large areas on the property which can be used for this purpose.

Heat pumps may be classified according to the source of low-potential thermal power, as shown in Figure 6.

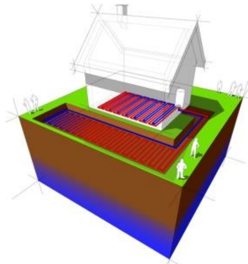
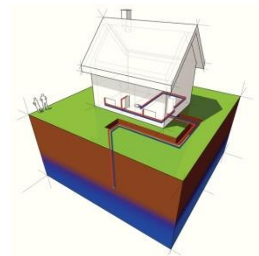
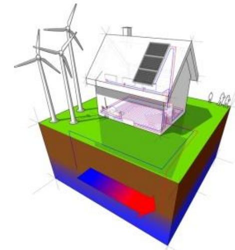
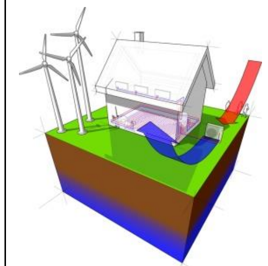
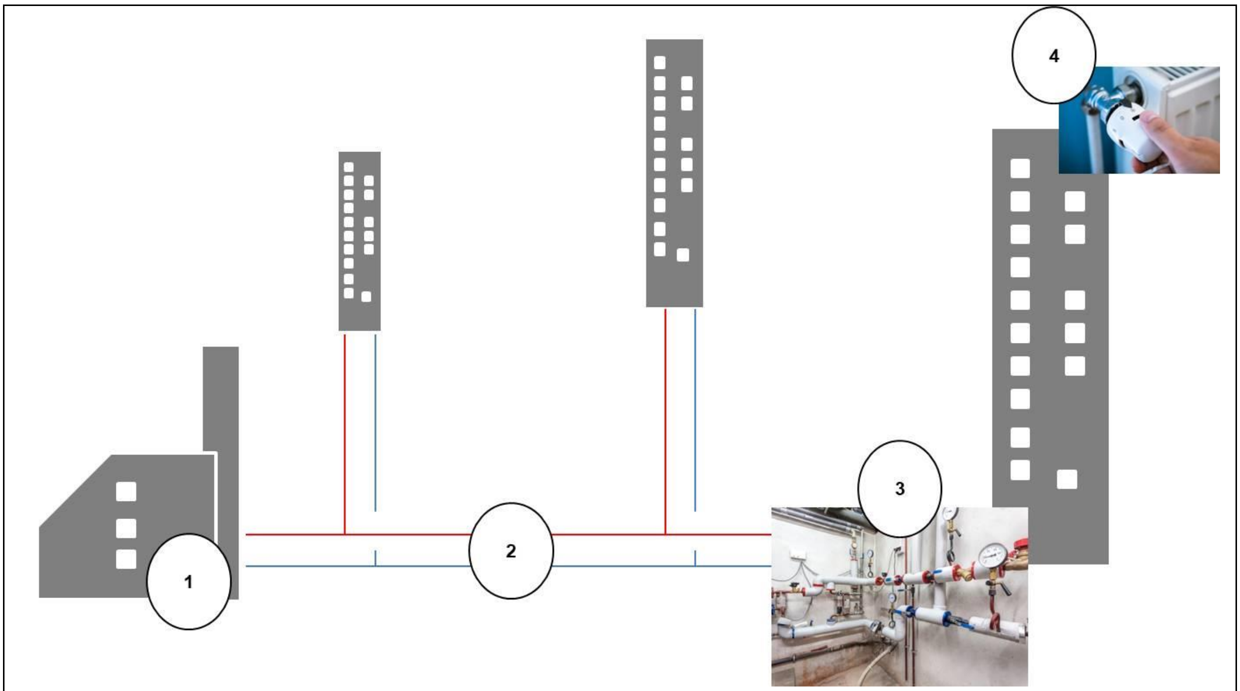
TYPE	SOIL – WATER		WATER – WATER		AIR - WATER
	Horizontal	Vertical	Horizontal	Vertical	
VIEW			 Principal diagram of heat pump with vertical collectors		
DESIGN	The collector is placed in the form of rings or twisting inside horizontal trenches lower than the depth of frost penetration into the soil (usually at least 1.2m).	The collector is placed vertically in a well up to 200m in depth.	The collector is placed in the form of rings or twisting in a water reservoir (lake, pond, river) lower than the frost penetration depth.	The collector is placed vertically in a well, and the second well is located in downstream water in an underground layer of 15-20m.	The units consist either of two blocks, which are placed outside and inside the building, or of a monoblock connected with the external space by a flexible air duct.
APPLICATION	This method is the most economically feasible for residential buildings, in case if land area is available to place a horizontal collector.	This solution is applied when the land area does not allow to place the contour horizontally, or there is the threat of landscape damage.	This is the most cost-effective solution, but it requires a water reservoir.	This solution is applied where there is sufficient ground water and site size, which allows the placement of two wells.	This variant is applicable and inexpensive. Although the capacity of these units is reduced, they are sustainable and operate at temperatures as low as -15°C. Below that it is necessary to connect another heat energy source.

Figure 6 - Types of heat pumps

2.2.b Improvement of centralized heating supply system

Centralized district heating supply systems consists of a heat energy source, distribution heating network, and individual heat points (which connect the network to the internal heating systems of a building). Each of these components holds an important role in reliable and quality heat supply; please see Figure 7.



View of principal diagram of centralized district heating	Main elements	
	1	Central heating plant/central boiler
	2	District heating network
	3	Heat individual point
	4	Internal heating system of building

Figure 7 - Diagram of centralized district heating system

Multi-family residential, public, and commercial buildings are usually equipped with engineering systems which include heating, ventilation, and air conditioning (HVAC), and hot water supply. Regardless of the building purpose and size, all engineering systems should provide safety and comfort for the occupants and reliability of supply whilst saving energy and reducing CO_2 emissions. The centralized heating system is a complex operating system; for instance, the load of heating and ventilation systems depends on the outdoor air temperature and heat release in the premises, as well as the operations of the domestic hot water supply system.

Implementation of district heating systems requires a complex automation system within the buildings' heat supply systems, covering the heat points and heat consuming systems. In many countries, the centralized heat power supply system uses an automated control system, which is an obligatory measure in new buildings and for retrofits.

Figure 8 - Individual automatic heat point with weather compensation control

The most significant energy savings from heat consumption systems can be achieved with the application of automatic heating individual points (see Figure 8), which have the following basic functions:

- adjustment of the temperature of hot water supplied into the heating system, depending on the outdoor air temperature (weather compensation control)
- adjustment of the temperature of the hot water which returns from the building's internal heating system to the district heating network, in line with the outdoor air temperature as per the set temperature schedule
- accelerated warming-up of the building after energy saving mode (reduced heat consumption)
- correction of the heat consumption according to the indoor air temperature in the premises
- constraining hot water temperature in the heating supply system pipelines
- adjustment of the heat load in the hot water supply system
- adjustment of the heat load by the ventilation units with the freezing protective function
- adjustment of the heat consumption reduction within set periods, in accordance with the outdoor air temperature
- adjustment of heat consumption, considering the orientation of the building and its ability to act as a heat sink

Hands-on practical experience in modernizing the heat points has proven the effectiveness of this measure in many countries.

2.2.c System performance optimization measures

Insulation of pipes and equipment

Figure 9 shows the insulation of supply system pipelines, which is a necessary measure in new constructions and building retrofits. Insulating pipelines by wrapping with insulation materials not only reduces the heat losses in the pipelines, but also maintains the estimated heat carrier temperature at a consistent level. Insulated pipelines maintain their temperatures better, leading to substantial energy savings.

Figure 9 - Pipe insulation and insulated distribution pipes of HVAC systems

There are several types of materials available on the market for pipeline thermal insulation. The application of thermal insulation for cold and heat power supply systems is an obligatory measure for new constructions and retrofits in many countries. In case of retrofits, pipeline should only be insulated after the pipelines are repaired and pressure-tested, which usually include the following activities:

- dismantling of any existing thermal insulation
- cleaning of the pipeline surface
- replacement of pipeline sections as necessary
- installation of the thermal insulation

Installation of thermostatic regulators on radiators

Control of temperature in individual rooms is a fundamental for rational use of energy. In the common case of radiator heating, significant heat savings can be achieved by installing thermostatic control valves on radiators. For other types of heat emission systems, such as floor heating or fan-coils in offices, the same logic applies. Thermostatic regulators consist of two parts: a valve and a thermostatic element, as shown in Figure 10.

Figure 10 - Thermostatic radiator control elements

Thermostatic valves are usually installed in the heating system before the radiator. These thermostats can be adjusted by the building occupants according to the desired indoor temperature. The key working component of a thermostat is the thermostatic element, which has a temperature-sensing element inside which controls, together with the valve, the water flow into the radiator.

By avoiding excessive heat supply when the ambient temperature corresponds to occupants' preferences, the thermostat prevents over-heating of the premises and maintains ambient comfort. By means of automated regulation of the air temperature, radiator thermostats allow, depending on users' behaviour, reduced energy consumption by the heating system of the building. Without a thermostat, temperatures can overshoot, and occupants may vent excess heat by opening the windows. This is clearly an inefficient use of energy resources.

Installation of thermostats on radiators in existing buildings is typically coupled with the replacement of outdated heating devices with higher energy efficient systems (higher thermal performance).

Installation of balancing valves

Balancing valves are part of clearance pipe fittings, intended for the circulation of hydraulic balancing rings (risers, branches) of the cold and heat power supply systems. Optimization of system performance should be done for account for dynamically varying real-life building operation conditions, providing stabilization of the dynamic regimes of its work. They can be seen in Figure 11.

Figure 11 - Balancing valves for HVAC systems

The application of dynamic balancing valves, using differential pressure control, provides the following benefits for systems of cold and heat power supply:

- ensuring hydraulic stability and optimal operational conditions of the system elements: emitters and their controls, pipe distribution systems, heat/cooling generators
- ensuring that the right amount of energy, at the right time and the right place, is available across the entire building; this is known as the dynamic balancing principle
- reduction of the noise level of the different elements operation, for instance radiator thermostats for the heat supply system or regulating valves for the fan coils in the cold supply systems, by means of automatically maintained reduced pressure at the same level
- reduction of the noise level in pipelines and other elements by means of restricting the maximum heat carrier flow
- stabilization of the heat, cold supply, and ventilation systems during periods of extended continuous operation by means of compensation, increasing the resistance of hydraulic elements to corrosion and scum
- simplification of the installation and maintenance of the systems by means of combining functions with overlapping parts, including the descent of the heat carrier and air, which gives the possibility of computer diagnosis of the heating and ventilation systems
- possibility to divide the heat or cooling system of the building into temperature zones, i.e. into floor- or apartment-specific systems (one of the causes of energy savings)

- reduction of energy consumption by circulating pumps
- additional economic and health benefit by preventing diversion of the heat carrier in the heating and ventilation systems

Dynamic balancing is provided by automated balancing valves for risers or for each heat emitter. They are recommended to be installed with the default values; where solutions for risers are chosen, they should be installed on each riser of the heating systems and should only have their settings tuned afterwards. Implementation of this measure should be done after the development of the design documentation, and after the heating system is flushed. During repair of heat and cold supply systems, it is reasonable to install balancing valves together with other measures. During installation of balancing valves, it is necessary to consider the commissioning work which should be performed by specialized organizations.

Energy Monitoring and Smart Metering Systems

Energy monitoring and smart metering systems consist of hardware and software components. The overall structure of the technical portion can be represented as a three-level system. The lower (first) level of the system combines smart meters with digital telemetry and pulse outputs, pulse counting devices, interface converters, transceivers, as well as all components of the infrastructure related to the construction of information communication channels with the next (second) level. Energy monitoring and smart metering systems include three levels of hardware components:

- Measuring components (smart meters) - control and measuring system which measures the parameters of resources consumption, forms and provides primary data (measurement results) on the quantity and quality of resources consumed, provides intermediate storage of all received (unmodified) information for each automation object (measurement, diagnosis, scheduling, and other results), in accordance with the required periods of storage
- Linking components - devices intended for the reception of measuring data and signals of faulty measuring components, and transferring them to processing by the computing components
- Computing components – a unified computer centre for data processing, analysis, storage, and distribution of information resources. At this level, the resulting data is generated based on the information obtained from measuring the components

2.3 Ventilation, Air Conditioning, and Cooling (VAC)

2.3a Application of frequency converter drives for electric motors

Modern building engineering systems have a variable operating mode (ability to change parameters or characteristics during the operation of the system), allowing for the reduction of designed parameters of fresh-air, heating, cooling, hot or cold water. These parameters must be optimally set to maintain proper ambient climate conditions, and to ensure efficient energy consumption. These changes are influenced by the fact that all modern engineering systems have a dynamic mode of operation, which adjusts to constant changes of factors (outdoor climate conditions which influence the building, indoor heat gain from solar radiation, equipment or people, occupancy changes, changes of the current level of energy, hot or cold-water consumption, etc.).

The use of frequency converter drives (FCD, shown in Figure 12) for electric motors of pumps and fans of all engineering systems in buildings helps to optimize and adopt these systems' operational parameters. As part of varying the basic parameters of engineering systems, FCDs reduce the spinning rate of electric motors, and hence reduce power consumption. This change is typically controlled by pressure, temperature, flow, and CO_2 sensors. FCDs are highly efficient and extensively applied in many countries. As an example, the application of FCDs for the fans of outdoor condenser units of a central cooling system can:

- reduce power consumed by compressors
- significantly reduce energy consumption by fan electrical motors
- increase fan resources
- reduce noise
- support the floating condensing pressure function

Figure 12 - Frequency converters

2.3.b Application of heat recovery for centralized mechanical ventilation systems

Heat recovery is a process of extracting heat from air which is expelled from a building via outlet ventilation, and then injecting that heat back into the supply air coming in through inlet ventilation. This reduces energy consumption for space heating, due to the additional (intermediate) heating of air in the recuperator. A recuperator is a heat transfer device in which cold air is heated by warmer exhaust. The heat transfer occurs across the plates of a heat exchanger, across which the two volumes of air are not allowed to mix; see Figure 13.

Figure 13 - Heat recovery unit for mechanical inlet and outlet ventilation

2.3.c Application of variable flow cooling systems

Modern cooling systems with variable coolant consumption (ability of the cooling system to change the cooling demand during its operation) are widely applied in public buildings, where the centralized air conditioning system includes typical air handling units as well as fan coils and other appliances. The hydraulic structure of a building cooling system is divided into the primary and secondary contour. The chiller (the cold energy source) is connected to the primary contour, while the fan coils and air conditioning units are attached to the secondary contour. A group of circulation pumps and shut off and balancing valves are also part of the hydraulic system. The traditional approach in design and operation of cooling systems is based on systems with a constant consumption of coolant. It means that the coolant is continuously supplied from the chiller through pipelines, which distribute it to the consuming devices. This traditional approach is not energy efficient because it requires constant consumption of electricity. The application of new systems with variable coolant consumption allows the implementation of technical solutions aimed at reducing the amount of cooling water consumption, depending on the occupants' needs. Therefore, the operational costs of coolant pumping are significantly reduced in the cold-water supply system, with the subsequent possibility of changing the cold energy produced by the chiller. The use of circulation pumps with variable consumption in a secondary hydraulic contour can also decrease the energy consumed by pump groups.

2.4 Energy Efficient Appliances (EE labelling)

Application of energy efficient appliance labelling is an invaluable measure for reducing direct internal electrical consumption by consumers. Every type of building includes many pieces of household or office equipment such as copiers, printers, intercoms, kettles, refrigerators, freezers, washing machines, dishwashers, electric stoves etc. Home appliances consume a significant proportion of household electricity.

The use of household appliances with an A class of energy efficiency is an efficient way to reduce energy consumption, as well as contribute to the ecological footprint of buildings. In this regard, electrical appliances can be certified according to the ISO 9001 and ISO 14001 standards, which indicate that no hazardous substances harming nature have been used. The majority of large household appliances must be certified and properly labelled in accordance with the European energy efficiency class (from G to A+++). The class of energy efficiency should be reflected on a special label applied on the electrical appliance, such as that shown in Figure 14.

Home appliances of energy efficiency A class and higher can significantly reduce energy consumption. Labels typically include the following information:

- Title, model, producer;
- Class of energy efficiency: colour code with alphabetic reference (from A to G), which reflects the level of energy consumption;
- Level of annual energy consumption;
- Additional information regarding the type of appliance, e.g. the internal volume of the refrigerator in litres, the maximum speed of rotation for washing machines etc.; and
- Noise level expressed in Decibels.

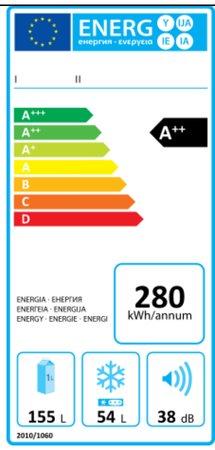


Figure 14 - Energy efficiency labelling

2.5 Modernization of Existing Building Lighting Systems

Modernization of the existing lighting system in residential buildings is aimed at replacing incandescent lamps with energy efficient lamps or modules. Multifamily residential and municipal public buildings usually use either filament or fluorescent lamps, and in some cases, light-emitting diodes (see Figure 15). However, there are different opportunities to optimize the lighting systems for example, in the public areas (such as staircases, common laundries, cellars, attics, etc.) of buildings, e.g.:

- replacement of outdated inefficient lamps
- installation of sensor-based lighting management systems
- accompanying actions

Energy saving lamps can be characterized by their lower energy consumption and longer service life; additionally, these lamps do not require any extra operational cost or maintenance. Bulb replacement can be implemented both individually (installation of the energy saving lighting appliances by inhabitants in their houses), and by building owners (installation of energy saving lamps and modules in public areas, such as stairs, entrance tambours, outdoor lighting systems).

There are many types of internal building lighting appliances with various ingress protection classes. The most efficient, simple, and affordable solution is the replacement of existing outdated lamps with energy efficient ones. Presently, the most widespread LED or CFL lighting appliances are also equipped with motion sensors. There are also different types of lighting appliances with built-in devices providing emergency lighting in case of a power outage.

Motion- and thermo-sensitive devices can detect the absence/presence of people and turn off/on the lights as appropriate. Ambient light sensors can do the same, toggling lights in the presence or absence of sufficient ambient light. These kinds of controls can include automatic dimming as well as switch scheduling. The economic attractiveness of sensor-based lighting controls is building specific, depending on factors such as operational hours, occupant behaviour, electricity prices, etc. In order to enhance the energy efficiency benefit in buildings, it is reasonable to implement a lighting management system, which is preferably automated, or includes the installation of dimmers (to reduce luminescence).

In addition to providing better illumination, the following measures can also be implemented to improve the efficiency of energy consumption for building lighting:

- maintain the cleanliness of plafonds
- do not cover or otherwise block the front windows
- use pale wall colours (which better reflects the light)
- install lighting modules on the ceiling only, but not on the walls, as this leads to reduced lighting capacity

Figure 15 - LED lighting fixtures

Chapter 3 – Current Deployment of Energy Efficient Technologies - Data Analysis and Review

Much progress has been made globally towards improving energy efficiency in buildings, helped along primarily by three types of public policy tools: legal requirements (such as building standards), financial incentives (rebates, reduced-rate debt, tax deductions), and information awareness programmes. In the European Union, the EU directives have played a vital role in promoting energy efficiency in the building stock; in fact, “Energy efficiency first" is a key element of the EU directives. However, despite these efforts, energy efficiency in the building sector is improving only incrementally and in disjoint fragments.

In search of the gaps between what technologies are available in the market and what is used by countries, data obtained from UNECE member States has been analysed to identify instructive differences, lessons learned, and best practices in the building sector. The ultimate goal of this study is to understand and elucidate the current building energy efficiency trends and patterns in the UNECE region. This chapter documents the data analysis for the major classifications of energy efficiency technologies detailed in Chapter 2, across the UNECE countries. Results are presented in two sections: subregions A, B, and D (EU member states, EU enlargement, and North America), followed by subregions C, E, and F (Eastern Europe, Caucasus, Central Asia, the Russian Federation, South East Europe, and Turkey).

Throughout this chapter, the mix of implemented technologies is visually represented in Figures 16 - 30. In these figures, each coloured bar in each stack represents the average impact score for the specified technology, across all building types, for the specified country. Each bar chart displays the data for a specified subregion, and for either new construction or existing buildings

Subregions A, B, and D

Building Envelope: Insulation and Glazing

Strict adherence to the EU directive 2018/844 of 30 May 2018, amending directives 2010/31/EU on energy performance of buildings and 2012/27/EU on promoting implementation of energy efficiency in buildings has significantly increased adoption of energy efficiency technologies in the building sector. These directives have had far-reaching consequences, one of which is that most countries in subregions A and B are aggressively installing building insulation and windows with high energy efficiency ratings. In addition, energy performance certificates are generating real economic value for building owners. One study (CCC, 2016) found that residences in the Netherlands with A, B, or C ratings generated a nearly four percent premium. In Ireland, A- and B-rated homes showed premiums of nine and five percent over D-rated homes, respectively; the market assigned a discount of over 10 percent to homes with F and G ratings. Building owners are hence able to earn a profit on energy efficiency investments from both reduced energy consumption and increased economic rents. Figure 16 and Figure 17 display the mix of building envelope technology, for both new construction and existing buildings respectively, by country in subregion A.

The Passivhaus concept is being further extended by the Powerhouse Consortium in Norway, who is developing the Powerhouse design concept, in which a building is designed to be net positive for energy over its entire lifecycle – including construction and demolition.

The final major impact throughout the European Union is the requirement for new buildings to meet the nearly zero-energy building (NZEB) standard. NZEB are designed to be highly efficient and use renewable sources to generate the low amounts of energy they consume. In subregion A, Belgium and

Germany have taken the NZEB standard one step further and are implementing the Passivhaus standard for both new and existing buildings. This standard has more stringent requirements for space heating/cooling energy consumption, air tightness, and energy generation.

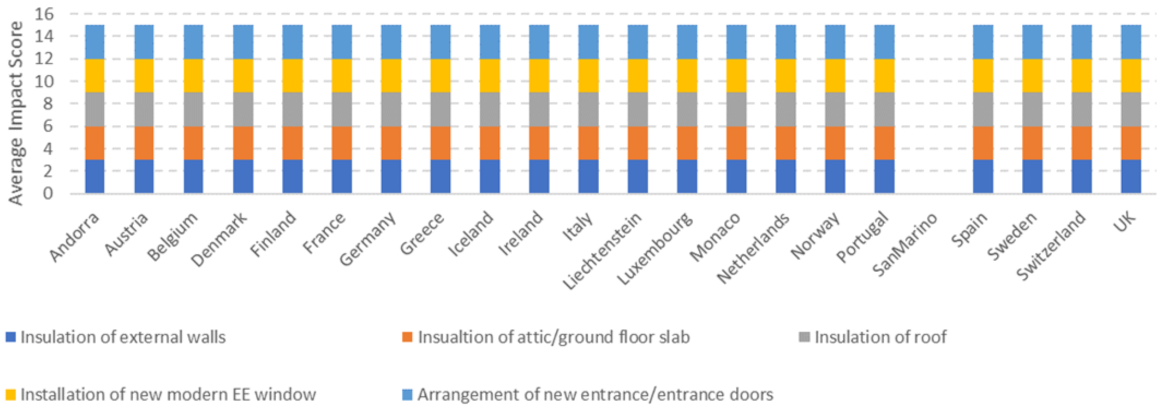


Figure 16 - New construction building envelope technology mix in subregion A

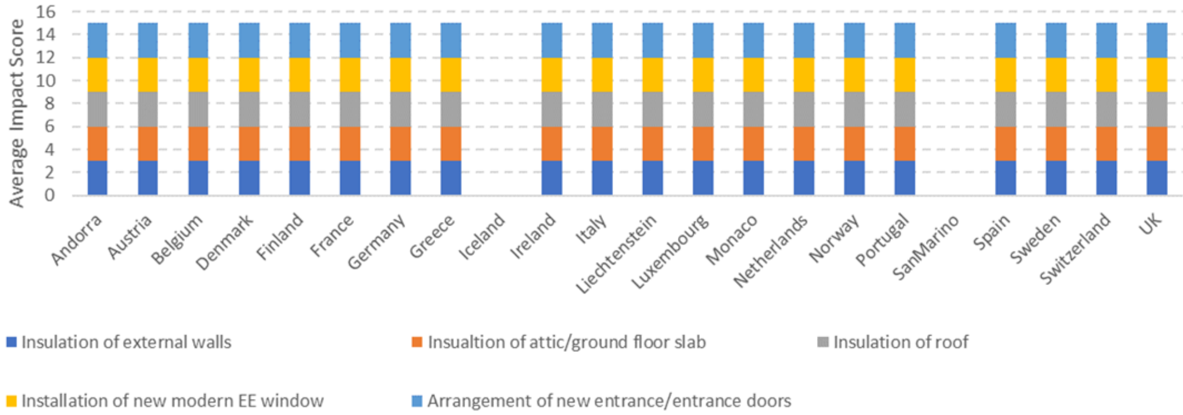


Figure 17 - Retrofits building envelope technology mix in subregion A

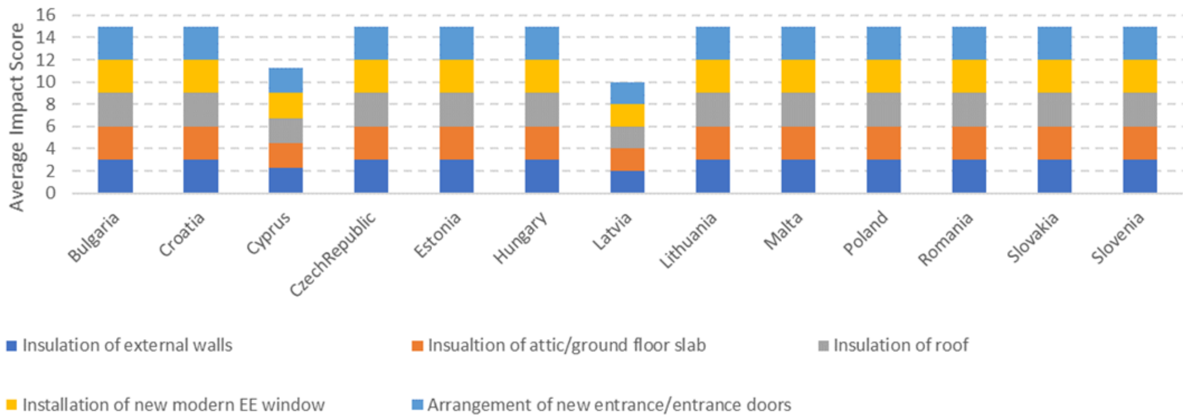


Figure 18 - New construction building envelope technology mix in subregion B

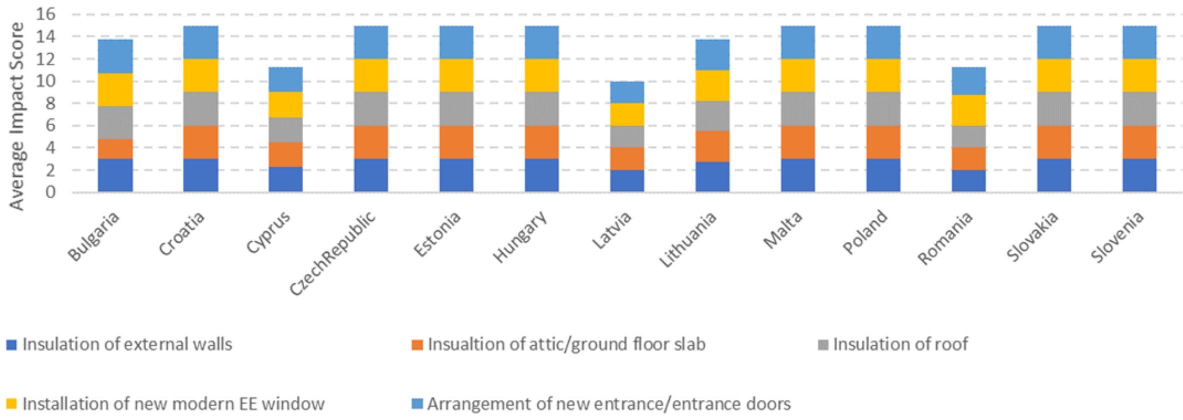


Figure 19 - Retrofits building envelope technology mix in subregion B

In subregion B, almost all countries have made substantial progress in implementing effective building envelope systems for both retrofits and new construction, with the sole exception of Latvia. Some countries, such as Romania, have implemented strong support measures by way of grants and tax incentives. Since 2010, thermal rehabilitation of residential buildings was financed through bank loans that were guaranteed by the Romanian government (financing from state and local government and owners); this includes the building envelope and replacement of heating systems for low income households, along with effective audit practices. Still, renovation in existing buildings is lagging, apart from commercial buildings. Similarly, the data on Bulgaria and Cyprus show less implementation of building envelope energy efficiency technologies for commercial and public buildings; Lithuania is relatively behind in implementing retrofitting measures for single-family residences. Other countries in subregion B, such as Croatia, Cyprus, Czech Republic, Estonia, Hungary, Malta, Poland, Romania, Slovakia, and Slovenia, have achieved a remarkably fast and strong penetration of NZEB within the existing national building stock. The data for subregion B is presented in Figure 18 and Figure 19.

In the North American subregion D, both the United States and Canada have extensive building standards – at the federal, state, and local levels – which set minimum energy efficiency requirements for the building envelope. Many US states have codes regulating building renovations as well. An analysis of relevant building standards (PNNL, 2016) in the US by Pacific Northwest National Laboratory suggested that residences and commercial buildings would save over $125 billion between 2012 and 2040, corresponding to 841 million tons of avoided CO_2 emissions. In 1993, the US Green Building Council introduced the LEED[8] (Leadership in Energy and Environmental Design) building rating certification programme, which is similar in many ways to the NZEB standard in the European Union. LEED is now the most widely used green building rating system in the rest of the world; a LEED certification demonstrates that a building meets stringent energy consumption requirements.

The data analysis confirms the prior analysis of the deployment of building envelope technologies for subregions A, B, and D. Specifically, the data support the idea that the most progress in technological implementation has been made in building insulation technologies. There is a strong correlation between implementation and adherence to building codes. Table 3, an excerpt from (UNECE, 2018, p.53), summarizes an assessment of the prevalence of energy efficient building envelope technologies.

Table 3 - Assessment of market saturation for building envelope materials

[8] https://new.usgbc.org/leed

Countries	Double-glazed low-e glass	Window films	Window attachments (e.g. shutters, shades, storm panel)	Highly insulating window (e.g. triple-glazed)	Typical insulation	Exterior insulation	Air sealing
Sub-region A - European Union (EU15), Norway and Switzerland	Mature market	Established market	Mature market	Established market	Mature market	Mature market	Mature market
Sub-region B - European Union enlargement (EU13)	Mature market	Established market	Mature market	Established market	Mature market	Mature market	Established market
Sub-region D - North America	Mature market	Established market	Established market	Initial market	Mature market	Mature market	Established market

Source: Mapping of existing energy efficiency standards and technologies in buildings in the UNECE region (p. 53)

Space Heating, Air Conditioning, Water Heating and Cooling

Figure 20 displays a visual representation of the mix of heating solutions for new construction for all countries in subregion A. For each country, the impact score has been averaged across all four building types (multi-family home, single-family home, commercial, public) for each type of technology. France has the most diverse mix of heating solutions in subregion A, followed by Spain and Ireland. Ireland is the only country in the region using coal in both new and existing buildings. With the exceptions of Greece, Italy, Luxembourg, and Portugal, all other countries in subregion A have shown improvements in developing centralized space heating solutions. Belgium, Finland, France, Ireland, Spain, and Switzerland have adopted various types of renewable energy for space heating (biomass, solar, and heat pumps). The UK, Norway, Italy, and Iceland have a higher market share in heat pumps and biomass-fired boilers. The data shows Germany uses solar energy for space heating. No evidence of substantial implementation of these technologies was identified in Andorra.

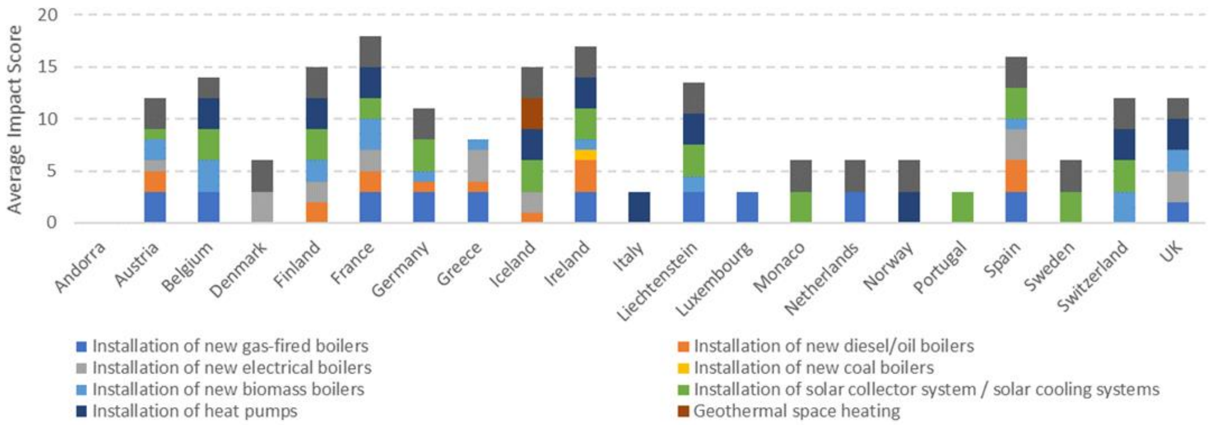


Figure 20 - New construction space heating technology mix in subregion A

The stacked bar chart in Figure 21 shows, visually, the mix of new construction heating solutions in subregion B. Slovenia is leading the adaptation of most energy efficient technologies in space heating, using biomass-fired boilers, solar, and heat pumps in its technology mix for new and existing buildings – as are Cyprus, Malta, Poland, and Slovakia. Latvia and Hungary both have a large share of gas-fired boilers, though Hungary additionally supports the adoption of heat pumps for space heating.

Croatia and Malta have a diverse mix of space heating technologies and use diesel and oil boilers in new and existing buildings. The Czech Republic is the only country in the region to still have coal-fired boilers in new and existing buildings. Country data on Romania, Latvia, and Estonia show no market penetration of central heating systems in the building stock. Figure 21 summarizes this information in visual form for subregion B.

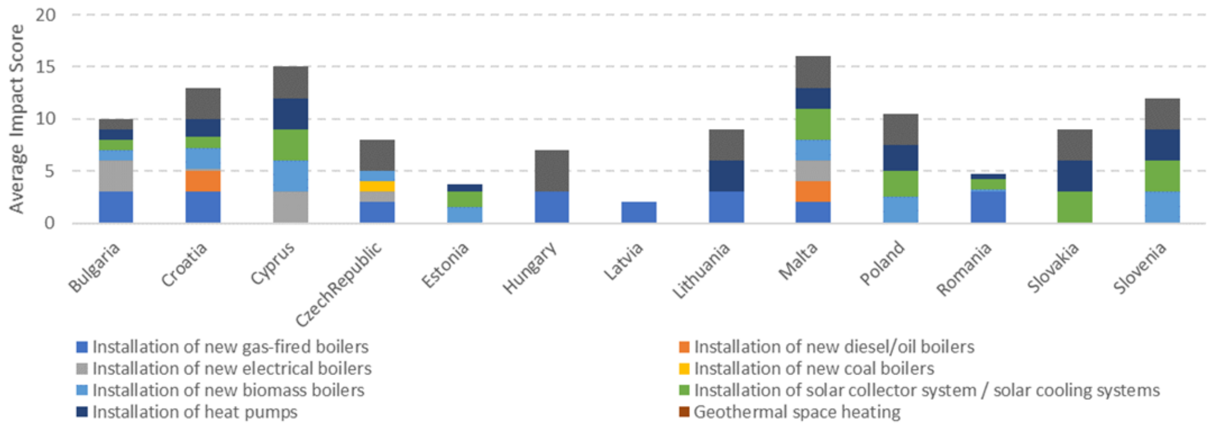


Figure 21 - New construction space heating technology mix in subregion B

It is interesting to note that Canada in subregion D has the most diverse technologies used for space heating, including coal, with the lone exception that geo-thermal power is not used. This can be seen clearly on the Canada sheet in the annex. Indeed, only Iceland in the UNECE region uses geo-thermal power for heating. The United States, on the other hand, tends to rely mostly on decentralized heating, and exhibits low adaptation of central heating systems.

Ventilation, Air Conditioning, and Cooling

After the building envelope, the second most productive area for improving energy efficiency in buildings is the subsystems responsible for ventilation, space heating/cooling, and water heating/cooling. In 2016, the European Commission, acting to curb this energy demand, boost renewables, reduce energy costs, and decrease harmful CO_2 emissions, published its first plan (EC, 2016) to tackle the massive amount of energy used for heating and cooling in the building sector. A major strategy of the plan is to improve integration of the power grid with district heating and cooling systems, so utility-scale renewable power could replace fossil fuel generation for district heating/cooling. Figure 22 and Figure 23 show the mix of technology for new construction in subregions A and B. There are clearly substantial differences and gaps, even among countries with similar climates.

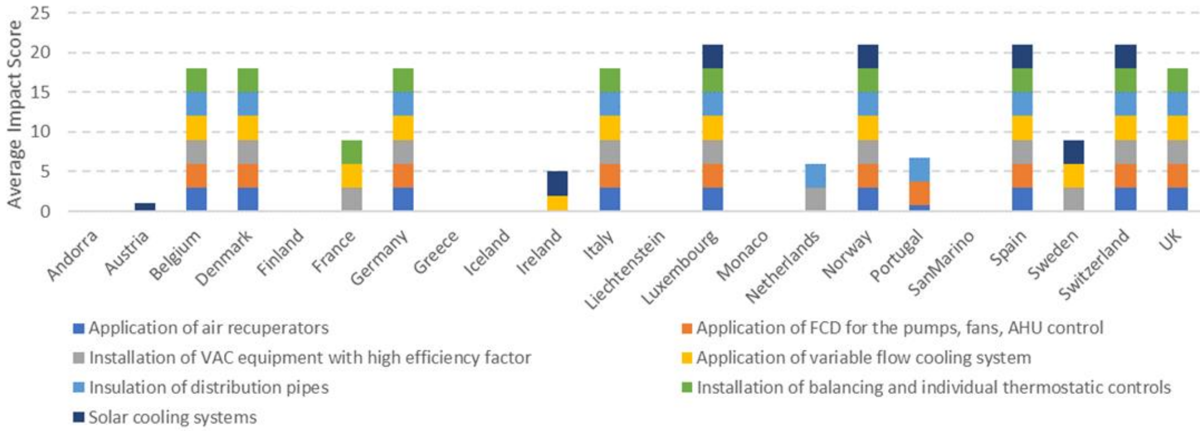


Figure 22 - New construction ventilation, air conditioning, and cooling technology mix in subregion A

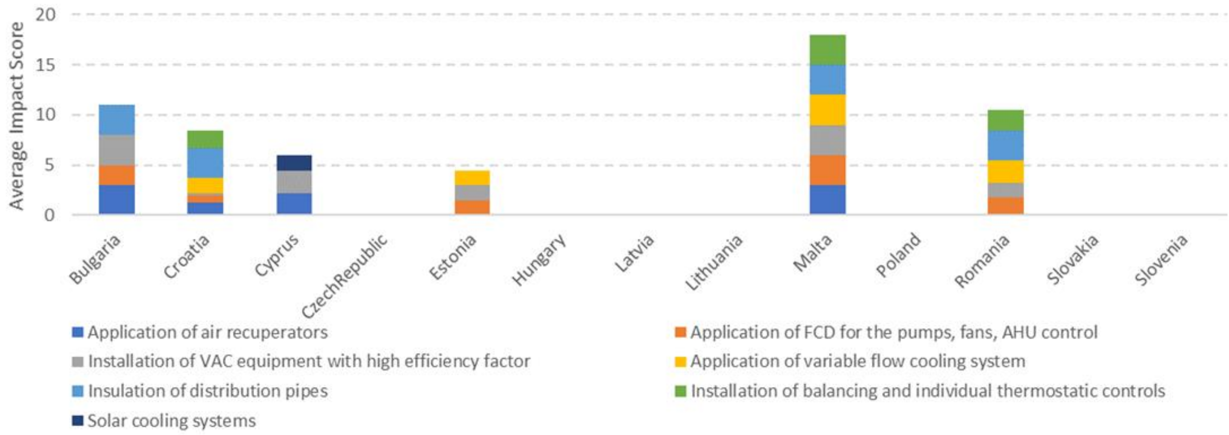


Figure 23 - New construction ventilation, air conditioning, and cooling technology mix in subregion B

There have been significant advances in the efficiency of space-conditioning equipment in recent years. While a variety of fuels and technologies are used to heat residential buildings in the UNECE region, natural gas is mainly used. However, impressive gains in energy efficiency technologies in boilers, along with design improvements in vent dampers and HVAC systems, are leading to development of technological solutions which can significantly contribute towards energy savings for residential and commercial buildings. Distribution systems and controls are frequently overlooked opportunities for improving the efficiency of space conditioning systems. For example, leaky air distribution ducts can result in significant energy losses, suggesting that greater attention to such simple parts is warranted. Existing building retrofits improve the efficiency of space heating systems already in place, and are usually limited to simple maintenance, such as replacing filters, oiling

One strategy used in Sweden (subregion A) to improve the efficiency of space conditioning is to link district heating systems with industries. In some parts of Sweden (SSB, 2011), a significant proportion (up to 90 percent) of multi-family residential buildings rely upon district heating that uses waste heat from nearby industrial plants and waste incinerators. Not only does this reduce energy consumption for space heating, but it also reduces industrial waste heat. Finland (subregion A) is another useful example. It is one of the leading countries in the world in the utilization of combined heat-and-power generation. More than 30 percent of the country's electricity is generated in connection with the production of district heat. Almost half of the population lives in residences warmed by district heating.

motors, and cleaning burners.

The three subregions A, B, and D have significantly progressed in deploying energy efficiency technologies for heating and cooling, with market and policy makers pushing the adoption of technology in the building sector; this is demonstrated in

Table 4.

Table 4 - Assessment of market saturation of heating, cooling, and other EE technologies

Countries	Condensing boilers	Biomass boilers (wood chip and pellet)	Pellet stoves	Heat pumps	Solar thermal systems	PV systems	Other
Sub-region A - European Union (EU15), Norway and Switzerland							
France	X	X	X	X	X	X	
Germany	X	X	X	X	X	X	
Italy	X	X	X	X	X	X	
Portugal	X	X	X	X	X	X	Cogeneration, trigeneration, district heating and cooling
Switzerland	X	X	X	X	X	X	
Spain	X	X	X	X	X	X	
United Kingdom	X	X	X	X	X	X	
Sub-region B - European Union enlargement (EU13)							
Bulgaria	X	X	X	X	X	X	
Croatia	X	X	X	X	X	X	
Czech Republic	X	X	X	X	X	X	Forced ventilati with heat recovery, heat recovery
Slovakia	X	X	X	X	X	X	Combined Heat and Power
Sub-region D - North America							
Canada	X	X	X	X	X	X	
United States of America	X	X	X	X	X	X	

Source: Mapping of existing energy efficiency standards and technologies in buildings in the UNECE region (p.56).

Appliances

Throughout the lifetime of a building, equipment such as appliances, lighting, and electronics is replaced and upgraded. Each occurrence represents an opportunity to maximize efficiency improvements. Such upgrade opportunities are much more frequent than major retrofits — appliances are replaced several times over the life of a building; electronics and lighting even more often. Each replacement decision has less energy impact than a retrofit, but the aggregate impact is of nearly comparable importance. The primary tool used by policymakers to encourage the adoption of energy efficiency in both household and office appliances has been through labelling, though some governments have implemented cash rebate programmes.

In the USA, the American Recovery and Reinvestment Act (DOE, 2015) has resulted in an unprecedented number of household appliances being replaced with energy efficient upgrades. Other countries with similar programmes include Canada, Denmark, and Germany. EU member States are bound by the 2010 EU Energy Labelling Directive (2010/30/EU) and previously-mentioned Ecodesign Directive. These directives require many household appliances to meet minimum energy efficiency standards and to carry energy labels, categorizing the expected energy consumption (similar to the voluntary Energy Star programme introduced by the US Environmental Protection Agency). However, obtaining the maximal impact of appliance labelling programmes requires promotion on the part of EU member State governments; the case of Latvia is instructive of this point. Latvia, for example, has failed to realize the expected increased energy efficiency in appliances, as there has been insufficient promotion of labelled products.

Overall, the low-hanging fruit of improved energy efficiency in appliances has probably already been picked; large appliances - such as refrigerators, freezers, and washers - are substantially more efficient than their 1990's counterparts.

A second issue with labelling is the stringency of the efficiency requirements – specifically when minimum requirements are equal, or very close, to the market averages. More stringent regulations that drive technological innovation are needed to induce market changes and improve energy efficiency.

Lighting

The energy efficiency of building lighting can be improved by the application of three main types of technological solutions:

- application of daylighting architectural solutions
- installation of interior & exterior lighting sensors and controls
- installation of newer light bulbs (CF & LED)

Policymakers predominantly use legal constraints, such as building codes and technological standards, and information awareness programmes to drive improvements in lighting energy efficiency. Many countries have phased out inefficient lighting technologies by tightening efficiency standards. Building codes also place requirements on lighting fixtures and control systems to encourage efficiency. While enhanced standards have a big effect, they mostly impact new construction (and buildings undergoing deep retrofits, to a lesser degree). For example, daylighting architectural solutions, which involve designing a building to make maximal use of sunlight for internal lighting, can obviously mostly be applied to new construction. Policymakers from Finland, Denmark, Monaco, and Norway (subregion A) have been effective in encouraging the use of this technology in both new and existing buildings. Figure 24 presents the data on lighting technologies in new construction for subregion A. It is moderately prevalent in Austria, but only for public buildings. In subregion B, only Estonia and Cyprus make much use of daylighting, with Estonia also focusing on public and commercial buildings. In addition to reducing energy consumption, there are documented social benefits to using natural lighting.

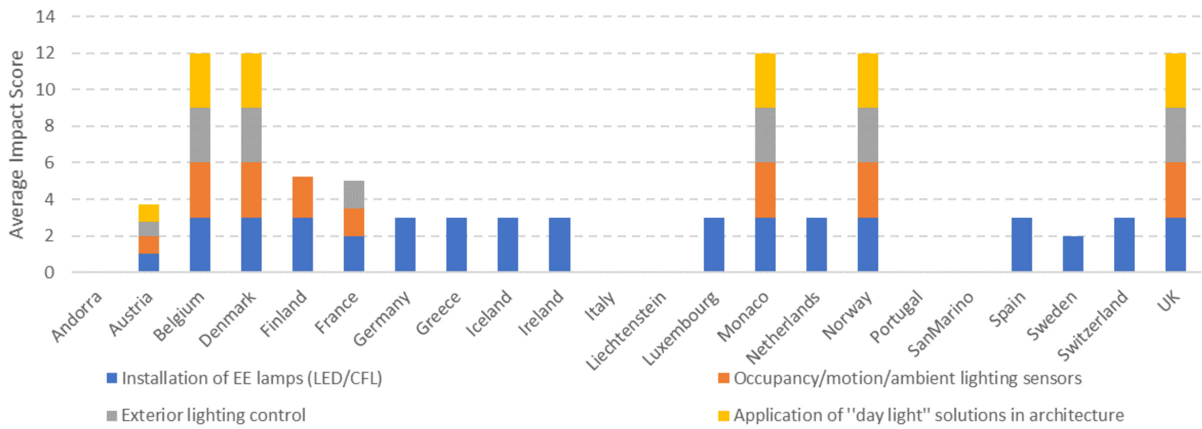


Figure 24 - New construction Lighting technology mix in subregion A

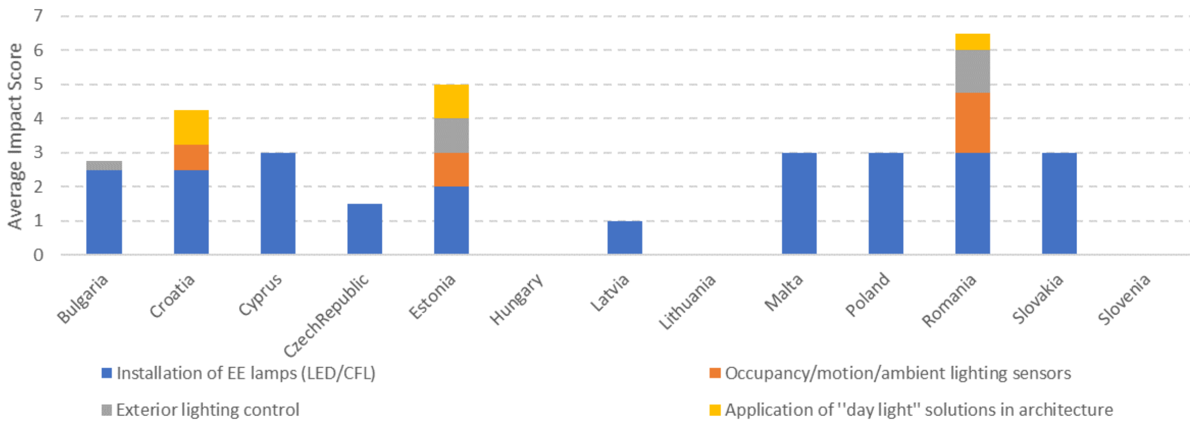


Figure 25 - New construction Lighting technology mix in subregion B

An energy saving initiative undertaken in 2013 in France, required all non-residential buildings in France to turn off the lights at night to reduce both light pollution and energy consumption. Indoor lighting which can be seen from outside must be switched off at 1 AM or one hour after closing time (whichever is earlier) and can only be switched-on after 7 AM or one hour before opening (whichever is earlier). Outdoor lighting of building facades (shops, monuments, schools, city halls, etc.) can only be on between sunset and 1 AM. Sensor-based control systems have the potential to support and enable initiatives such as this.

Lighting sensors and controls are technologies that can have a tremendous impact on energy consumption for lighting – both interior and exterior – by ensuring that lights are only used when required. The economic attractiveness of sensor-based lighting controls is building specific, depending on factors such as operational hours, occupant behaviour, electricity prices, etc. It is nearly inconceivable that the appropriate application of lighting sensors and control technology could not reduce energy consumption and pay for itself. Despite the disproportionately large impact on reducing building energy consumption, sensor-based lighting controls are not widely used. Only Cyprus and Estonia, in subregion B, make moderate-to-heavy use of the technology, as can be seen in Figure 25. The technology is significantly prevalent in less than half of the subregion A countries. Hence, it is clear that public policy and awareness campaigns are necessary to encourage its adoption.

The simplest, furthest reaching, and most prevalent technology for decreasing lighting energy consumption is energy efficient light bulbs. Compact fluorescent (CF) bulbs and light-emitting diodes (LED) are far superior to both incandescent and halogen bulbs. New energy efficient light bulbs can be used in both new and existing buildings, residences, public buildings, and commercial buildings.

The United States began phasing out incandescent bulbs in 2007, and the Canadian government began banning them in 2014. The European Union voted in 2009 to ban them, with the ban taking full effect in September of 2018. In the EU, the incandescent ban is expected to reduce annual energy consumption by 9.4 TWh - equivalent to Portugal's electricity consumption over five years. These savings correspond to a reduction of 3.4 million tonnes of CO_2 emissions every year, as well as a significant reduction in waste. However, simply banning incandescent bulbs is not enough, as has been seen by some of the earliest adopters.

The UN member States which implemented relevant policy earliest – such as Denmark and the United Kingdom – have seen sharp reductions in sales of incandescent bulbs, as expected. However, much of this market share has inadvertently been shifted to halogen bulbs. Halogen bulbs are only slightly more efficient, so the full potential for energy savings that could be achieved through switching to CF bulbs or LEDs has not been realized; there is little sign of LEDs having significantly penetrated the domestic lighting markets yet. One reason for this could simply be higher cost.

In subregion A, most countries are relying solely on energy-efficient lamp replacements to drive reductions in energy consumption for lighting – such as Germany, Spain, and Switzerland. A few countries are much more diversified, investing in efforts to use all three types of technological solutions. Denmark, Monaco, and Norway exemplify this strategy of diversification. In subregion B, Estonia is diversifying efforts for new construction, with Cyprus focusing on retrofits.

Energy Monitoring and Smart Metering Systems

There are several types of energy efficient technologies that have the potential to impact multiple building subsystems. A good example of technology that enables increased energy efficiency in several different building subsystems is smart metering and smart building systems. In fact, one of the primary objectives of EU energy efficiency directives is to encourage the use of information and communication technology and smart technologies to ensure buildings operate efficiently. The governments of Denmark, Italy, Switzerland, and the United Kingdom in subregion A, and Estonia, Lithuania, and Malta in subregion B have implemented energy efficiency policies promoting the application of such smart systems. In fact, nearly all buildings in Finland, Italy, and Sweden are already equipped with smart meters.

> The UK Government is committed to ensure that every home and small business in the country is offered a smart meter by the end of 2020. Their Smart Metering Programme (DBEIS, 2018) aims to roll-out over 50 million smart meters (gas and electricity) to all domestic properties and smart/advanced meters to smaller non-domestic sites in Great Britain - impacting approximately 30 million premises. The Smart Metering Programme is currently in the main installation phase, and there are now over 11 million smart and advanced meters operating across British homes and businesses.

In the United States, cloud-based energy management and control systems are extensively used as they obviate the need for on-site staff with expertise in maintaining the building energy systems. Using a third-party firm to monitor the building, for instance checking HVAC equipment or setting lighting schedules, can be a cost-effective way to reduce energy consumption. However, for a multi-tenant office building, split incentives may discourage a building owner from purchasing a cloud-based control system when tenants are responsible for their energy consumption. However, for office buildings in which the owner is responsible for paying the energy bill and maintaining the building's primary energy consuming systems, there is more economic incentive to invest in such technology. This suggests that the highest barrier in implementing smart metering and control systems technologies in buildings is the requisite capital expenditure - which most countries believe is the key issue.

Subregions C, E, and F

Building Envelope: Insulation and Glazing

Countries of subregions C and partly E have similar post-Soviet types of building construction. Most of the existing residential and public buildings were designed and constructed between 50 and 30 years ago. Policies and norms of the 1970's and 1980's was stricter in terms of construction materials quality and envelope safety levels, but with less emphasis on energy efficiency requirements such as insulation and glazing. However, extensive requirements for retrofit programmes to improve insulation and glazing for existing building have been recently created.

Most of the countries in subregions C, E, and F had updated their building codes for insulation and glazing in both new construction and retrofits by 2018, mandating insulation and glazing right from the design stage. Requirements for retrofits are different, and in most cases, necessitate additional external financing and modification of procurement procedures for public and multi-family residential buildings. The technology mix of the existing building envelope in subregions C, E, and F is presented in Figure 26 below.

> Countries of subregions E and F (Serbia, Albania, Montenegro, less in Turkey) are working towards decreasing imports of fuel for domestic energy consumption, by investing in renewable energy sources and bioenergy, in order to become more sustainable and self-sufficient. In 2018, a pilot implementation of these projects was undertaken, predominantly in countries of subregion E, with the operations subsidised by the government or international donors.

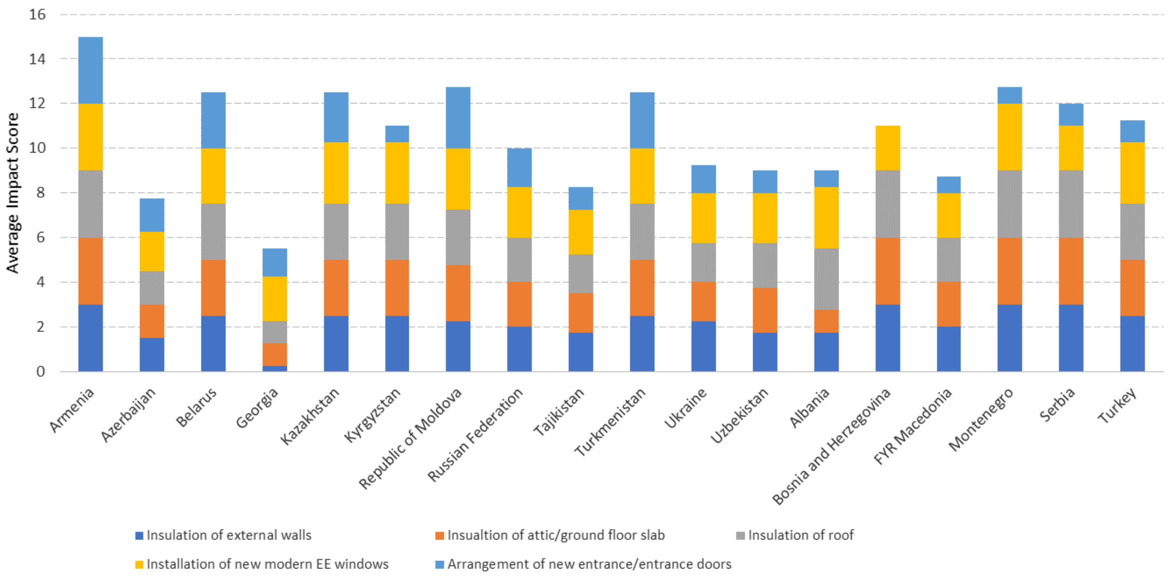


Figure 26 - Technology mix of existing buildings envelope modernisation in subregion C, E, and F

There is a common approach in almost all countries of subregion C to include typical energy efficient measures, like modern insulation and glazing, for retrofits and new construction for multi-family residential and public buildings. These requirements are reflected in country-specific laws on energy efficiency (or equivalent). In most cases, proper insulation and glazing are considered to be a measure with a long-term payback period, especially considering lower energy prices, such as exist in subregion C. However, most countries do understand the importance of insulation and glazing for the sustainable development of buildings.

> Armenia is a leader among all countries of subregions C, E, and F in scaling up energy efficient technologies in buildings. In 2018, the country transposed the EU Directive on building energy performance and harmonized it with local construction and design standards. This resulted in enforcement of mandatory energy efficiency requirements for all building types, and improved technology penetration with an important role of local manufacturers of insulation materials.

There are different support mechanisms made available for various building types. For multi-family residential and public buildings, there are incentive mechanisms provided by the government to eliminate the financial gap (subsidized loans, tax incentives, specialized energy efficiency funds, where insulation and glazing are priority measures). Public buildings are usually financed by the state; regional or municipal budgets have a special internal policy which includes mandatory implementation of energy efficient insulation and glazing for both new construction and retrofits. In Kazakhstan, Armenia, Ukraine, the Russian Federation, and some other countries in subregion C, E, and F, there is a requirement to perform a specified number of annual insulation and glazing projects for public and multi-family residential buildings, which are included in the budget of relevant departments (or municipalities).

Commercial buildings have fewer specified mandatory requirements for insulation and glazing in various regulations across all countries of subregions C, E, and F. In most cases it is a market driven process supported by business owners. Analysis of the insulation technology mix for existing buildings shows a good level of insulation and glazing technologies implementation, except for the arrangement of new entrance doors in all countries besides Armenia, Moldova, Kazakhstan, and Turkmenistan. This issue is being handled by improving local legislation and public procurement requirements, in order to cut energy and financial losses. This is especially relevant for countries of subregion E with higher energy prices, and countries of subregions C and F with cold climates.

Single-family residences still have lower levels of energy efficient insulation and glazing implementation. By 2018, as a result of numerous awareness raising campaigns supported by local governments and international organizations across all the countries of subregions C, E, and F, there was an obvious shift in individual homeowners' understanding of the potential for savings[9]. For example, special micro-finance tools were developed and implemented in 2012 by the Asian Credit Fund in Kazakhstan and Kyrgyzstan to support citizens of rural areas to improve the quality of their houses. In Uzbekistan there are programmes for construction of new standardized energy efficient individual houses supported by the government. These programmes offer subsidized pricing and mortgage schemes. A similar approach is implemented in Armenia.

Space Heating, Air Conditioning, Water Heating and Cooling

Modern technologies in space heating, and domestic hot and cold water supply show various levels of fuel mix used across countries of subregions C, E, and F for each technology. Some coal mining countries of subregion C, like Kazakhstan, still actively use coal for electrical and heat energy generation, from large combined heat and power plants to small-scale boilers, and this trend appears

[9] http://www.eurasia.undp.org/content/rbec/en/home/presscenter.html

likely to continue while coal is in cheap supply. In this case it is better to concentrate on the promotion of eco-friendly coal burning technologies, rather than to completely ban the use of coal.

Improvement of Decentralized Heating Source

The technology mix for the improvement of decentralized heating sources of existing buildings in subregions C, E, and F is presented in Figure 27 below. Subregion C includes several coal mining and consuming countries, where decentralised heating and power generation are mainly based on coal. Modern energy efficient coal-burning technologies have medium or low levels of use. By 2018, some coal consuming countries of subregion C demonstrated interest in investing in new energy efficient technologies for using coal. Pilot implementations of high efficiency boilers and pyrolysis-type back-pressure steam turbine energy generators in the Russian Federation and Kazakhstan show substantial technical and financial potential for cleaner energy generation from fossil fuels or municipal waste[10].

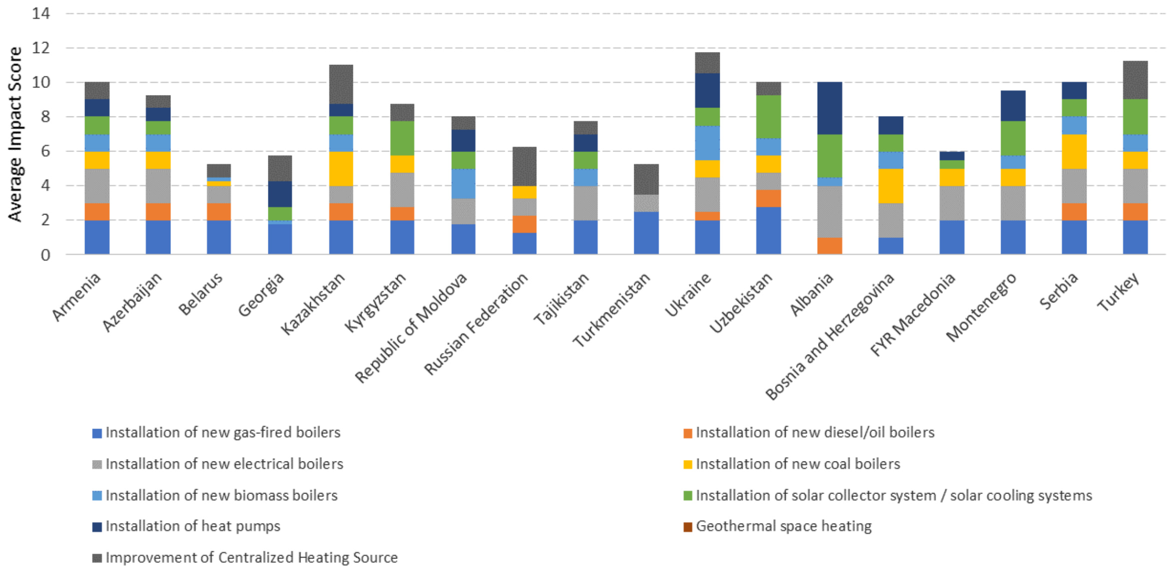


Figure 27 - Technology mix of improvements of decentralized heating sources for existing buildings in subregions C, E, and F

Implementation of biomass-fired boilers is still in a development stage for most of these countries, with slightly better implementation in Ukraine and Moldova from subregion C, and Serbia and Bosnia and Herzegovina in subregion E.

Installations of new energy efficient gas-fired boilers are mandatory in Turkmenistan and Uzbekistan for all building categories. Other countries show better implementation levels for building retrofits and new construction of multi-family and public buildings, with lower levels of implementation for other building types. Based on the analysis of collected data, it is fair to conclude that modern gas-fired heat and energy generators produced by both global companies and local manufacturers, are highly available across countries of subregions C, E, and F. Most of the countries of Central Asia in subregion C with low population density have low stock availability of spare parts in case repairs are needed; this means that sometimes there are limited options for selecting a technology in the local market (municipal level) without reference to energy efficiency factors. Another barrier against higher penetration of these technologies is limited to the level of professionalism and competence of local maintenance specialists.

[10] http://rpn.gov.ru/sites/all/files/users/rpnglavred/filebrowser/docs/doklad_po_tbo.pdf

The owners of commercial buildings in most of the countries of subregions C, E, and F have clear understanding of the benefits of modern energy efficient generation equipment used in commercial buildings such as shopping malls, hotels, and office, because it helps reduce energy bills. Unfortunately, gaps in accessibility of easy and inexpensive financial resources remain, especially for countries with low internal energy prices. These gaps present an implementation barrier that is difficult to surmount

Some countries in subregions C, E, and F have adopted advanced mandatory requirements for implementation of heat pumps (Albania and Ukraine), and solar collector hot water systems (Uzbekistan and Kyrgyzstan). Both national agencies and international donor organizations have launched a series of renewables-focused projects in the building sector in order to stimulate the dissemination of these technologies.

More than half of the countries use electrical boilers across various building types of subregions C, E, and F because there is a lack of other fuel sources available for heating and domestic hot water preparation. In such cases, it is required to have a deep focus on installation of new efficient electrical energy generation units, with properly-adjusted waste heat recovery schemes, in order to increase total electricity generation efficiency. Nevertheless, no countries were identified with governmentally supported mandatory requirements for the installation of energy efficient electrical boilers. This is a serious gap that should be eliminated in the near future. In most cases, this gap is primarily due to the absence of a reasonable rapid alternative fuel.

Common Measures and Improvement of Centralized Heating Systems

Subregions C and E have a long history of implementing centralised heat supply systems. Equipment that is currently in operation in countries of subregion C was principally designed and installed in the 1960’s and 1970’s, and already became the object of a large-scale renovation campaign powered by several national policies, as well as region-specific incentives and relevant financial tools. Improvement of centralized heating systems is a critical issue for most of the big cities in countries of subregions C and E.

Figure 28 presents the technology mix in subregions C, E, and F for common measures and improvement of centralized heating systems in new construction.

The chart shows that the most popular technical solution used in each country of subregions C, E, and F is the installation of individual heat points with weather compensation control.

There are some countries, such as the Russian Federation, Kazakhstan, Turkey, and Ukraine, with mandatory requirements for implementation of this measure for both retrofits and new construction of all types of buildings except single-family residences. Other countries with existing centralised district hot water supply systems are in the process of adopting or implementing this technology. Countries which are not focused on supporting this activity are Albania, Bosnia and Herzegovina, the former Yugoslav Republic of Macedonia, Montenegro, Belarus, and Uzbekistan.

Common measures are widely implemented across all countries of subregions C, E, and F. Insulation of pipes and other equipment solutions are mandatory in Ukraine, Moldova, Turkmenistan, and Belarus. Despite the importance of pipe insulation, several countries have very low levels of implementation: Kyrgyzstan, Armenia, Turkey, Georgia, Montenegro, and Serbia. These gaps are tracked by governmental discussions in these countries and should be resolved in the near future.

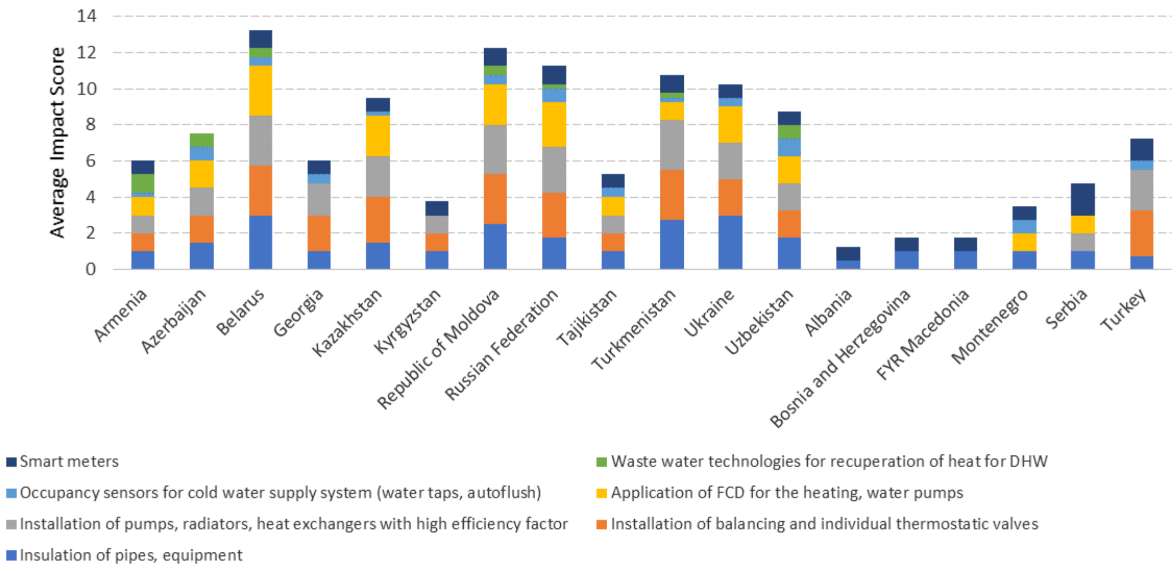


Figure 28 - Common measures for heating system for new construction technology mix in subregions C, E, and F

Some countries of subregions C, E, and F (the Russian Federation, Turkey, Moldova, Ukraine, Turkmenistan, Belarus) have already added installation of balancing valves, thermostats, efficient pumps, heat exchangers, and other relevant engineering equipment into the mandatory country policies and design norms.

Insulation of distribution pipes for cooling networks is widely implemented in almost half of the subregion C and F countries (Turkey, Uzbekistan, the Russian Federation, Azerbaijan, Moldova, Ukraine, and Belarus). Governmental support and other investments into this measure increased during the last 5-6 years and resulted in the cooling equipment market growth, with an active presence of modern efficient equipment suppliers. In order to ensure the proper functioning of the new equipment, detailed attention was focused on increased quality of insulation.

Other technologies from the list of common measures, e.g. energy efficient water pumps, water supply sensors, and wastewater heat recuperators, are still implemented at low or medium levels for most of the multi/single family residential and public buildings in countries of subregions C, E, and F. Some pilot projects on heat recuperation and recovery for the building stock have been implemented by national agencies in the Russian Federation, Belarus, Kyrgyzstan, Uzbekistan, and Turkey with the support of international organizations. Local financial institutions should focus more on raising awareness and transparent financing schemes with better support from municipal administrations. This is especially true for public buildings.

Ventilation, Air Conditioning, and Cooling

Research for this study identified a trend, showing that most of the countries are focused mainly on ventilation and air conditioning for predominantly newly constructed buildings. From the technical point of view, there are limitations to VAC equipment installation and modernisation during the retrofit of multi-family residential buildings. This is predominantly due to limited indoor space and the absence of VAC system design in the original construction. Implementation is higher, however, for both existing building retrofits and new construction of other building types.

Installation of air recuperation units and modern frequency converter drives for fans and pumps is common to the construction of new commercial and public buildings. This trend can be seen in Ukraine, Moldova, and the Russian Federation, where these technologies are mandatory and show high implementation levels. Figure 29 presents existing gaps in the implementation of ventilation, air conditioning and cooling technologies for existing buildings in subregions C, E, and F.

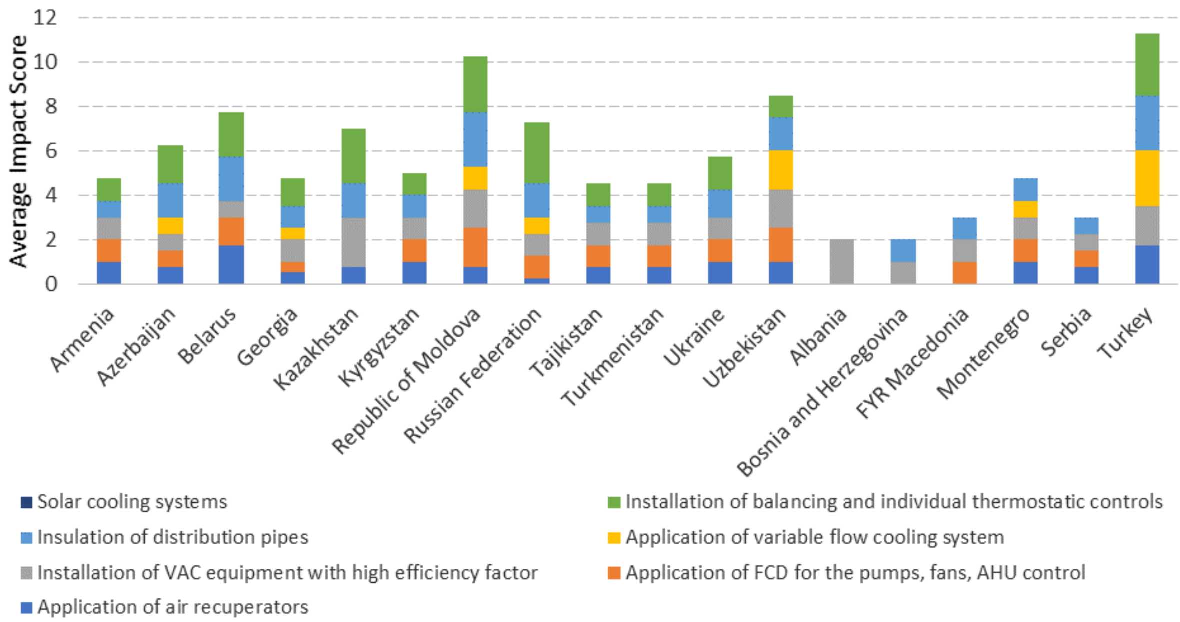


Figure 29 - Ventilation, air conditioning and cooling technologies mix for existing buildings in subregion C, E, and F

Analysis shows that the countries of subregion E and F still have certain gaps in the implementation of energy efficient technologies for VAC systems. However, these issues should soon be resolved by implementing strict mandatory requirements from EU Directives, which are currently being transposed into national laws. Turkey shows a high penetration rate of modern VAC equipment even for the retrofit of existing buildings. Climate conditions, favourable trade channels and location, and product availability, as well as strong governmental support, have resulted in a high level of technology penetration. National and international banks in Turkey are very active in promoting of various packaged “Energy efficient home” solutions[11].

Implementation of variable flow cooling systems across the countries in subregion C is a relatively new trend, which shows high potential for increasing energy efficiency in the building sector. The technology is mostly used for commercial and public buildings in Turkey, Georgia, Moldova, and Montenegro. Variable flow cooling systems are implemented less frequently in multi-family residences in all countries.

Promotion and implementation of modern absorption-type cooling units and effective individual air conditioners is supported by several international and national stakeholders operating in the countries of subregions C, E, and F. For the Russian Federation, Uzbekistan, Turkey, and Ukraine, the technology is either mandatory or currently at a high level of implementation for both retrofits and new construction of all building types, except commercial buildings.

[11] http://www.tr.undp.org/content/turkey/en/home/sustainable-development-goals/goal-7-affordable-and-clean-energy.html

Appliances

The promotion of energy efficient appliances use is a relatively new trend for the countries of subregion C. Nevertheless, building energy load profile analyses have demonstrated that the implementation of modern appliances (household and especially commercial) could bring large energy savings to the overall energy consumption pattern of a typical building. By 2018, the Russian Federation, Kazakhstan, and Turkey have promoted the implementation of energy efficient appliances with the support of international donors, conducting campaigns to raise awareness, covering both public and private sector representatives.

Across subregion C, there is a certain level of understanding of the benefits of energy efficient appliances, and there is market demand for highly efficient household appliances. Unfortunately, most appliance suppliers in these countries attempt to obtain a marketing advantage on better promotion by naming the equipment as more efficient than they are, rather than reporting accurate reduced energy consumption parameters. This mainly impacts uninformed customers, suggesting the need for governmentally supported information awareness campaigns.

For public and commercial buildings, implementation of modern efficient appliances became a common norm in the last 5-6 years, mainly because of increasing energy prices. Most of the countries of subregions C, E, and F adjusted their public procurement procedures for both new construction and retrofit processes, with strong requirements to purchase only high efficiency class equipment.

The countries of subregions E and F are following the general European approach of mandatory implementation of energy efficient appliances for all building types. Only a few countries, such as Turkmenistan (subregion C) and Bosnia and Herzegovina (subregion E), still have not made energy efficient appliances mandatory, though they are making progress in this regard. The Russian Federation, Kazakhstan, and Kyrgyzstan launched a joint information campaign in 2017, entitled "Together Brighter" to encourage installation of energy efficient appliances.[12]

> Awareness campaigns, aimed at promoting energy efficient appliances, have taken place in almost all countries of subregions C, E, and F. The Russian Federation, Kazakhstan, and Kyrgyzstan launched a joint information campaign "Together Brighter" in 2017, supported by the Ministries of Energy from each country. Implementation of energy efficient appliances and green energy living standards are also promoted during the annual "Energy Efficiency Day", which usually takes place in all three countries at the beginning of September.

Lighting

A global trend towards installation of modern energy efficient lighting systems in full scale is seen across all the countries of subregion C, E, and F. The implementation of energy efficient lighting systems has been strongly promoted. The national governments, together with various international donors, provided massive support for improving the capacity of local producers, with a focus on developing, in most cases, modern LED technologies. It is interesting to note that construction design norms and practices were significantly modified towards mandatory implementation of efficient LED and CFL lamps, with an official ban of production and distribution of incandescent lamps. Figure 30 presents the application of lighting technologies in subregions C, E, and F, for new construction.

[12] https://minenergo.gov.ru/node/6034

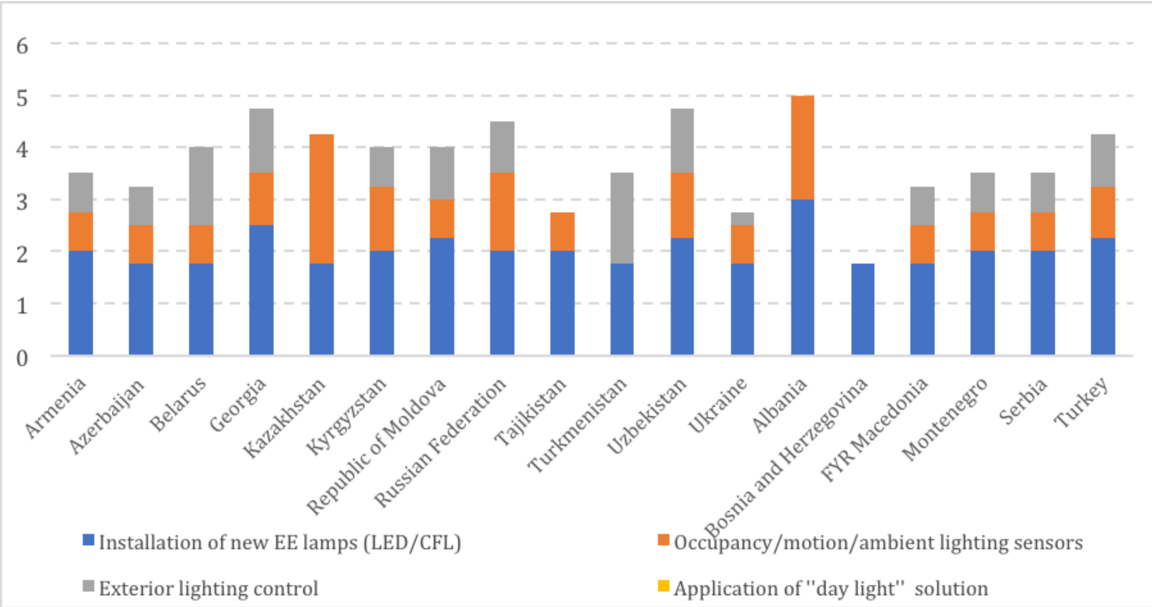


Figure 30 - Application of lighting technologies in subregions C, E, and F, for new construction

This study identified no policies of mandatory implementation of LED lamps in subregions C, E, and F; nevertheless, there is certainly a positive trend of installation in all the countries. The highest levels of penetration are in capital repairs and new construction of all building types except for single-family residences. In addition, there are some countries focused on further promotion of occupancy/daylight sensors, exterior lighting control, and daylight architectural solutions. At the moment, almost all countries still have low levels of implementation of these technologies. Nevertheless Albania, Kazakhstan, and the Russian Federation strongly support the implementation of various light sensors (occupancy, motion, ambient light) in order to reduce lighting expenses in the common premises of multi-family residential buildings (stairwells, entrance halls, etc.). Promotion and change of procurement procedures for the implementation of energy efficient lighting for residential and public buildings with governmental support has resulted in growing market interest in ESCO-financing of such projects[13].

Smart Systems and Solutions

The primary objectives of smart solution measures and metering systems are tracking and verification of energy consumption. Without an established metering system and officially approved control methodology, it is difficult to conduct a fair calculation of achieved energy efficiency or forecast estimated energy consumption profiles and future energy savings potential. One of the biggest gaps in terms of implementation of smart solutions in countries of subregions C, E, and F is the lack of legislative acts, which are focused on regulating the methodologies for the analysis of energy efficiency results and savings potential. This means that massive implementation of smart meters and data collection systems would be redundant and provide little value without simultaneous, national-level adoption of a properly-developed analytical methodology.

[13] http://www.rs.undp.org/content/serbia/en/home/ourwork/environmentandenergy/energy/removing-barriers-to-promote-and-support-energy-management-syste.html

Having a strong administrative and analytical approach to smart solutions shows good results in Serbia and Bosnia and Herzegovina, (subregion E), Ukraine, Kazakhstan, Armenia, the Russian Federation (subregion C), and Turkey (subregion F)[14]. The implementation, supported by the government, of municipal level energy management systems, in these countries resulted in high quality increases of energy action plans for municipalities, which used such an approach. This is especially true for multi-family residential and public buildings.

In 2015, Serbia started a national energy management programme of massive connection of public buildings to a centralized database used by national authorities and municipalities for budget planning and energy consumption forecasting. This experience is now being transferred across subregion E to Bosnia and Herzegovina and Albania. In subregion C, the Russian Federation and Kazakhstan are among the leaders in the implementation of energy management smart systems. Since 2012, the Russian Energy Agency has operated the State Energy Information System, which incorporates all energy consumption data from multi-family, commercial, and public buildings. Originally it was developed for manual data input, but during the last 2-3 years it significantly migrated towards digitalization and smart data collection.

In 2012, Kazakhstan became the first country in the non-European region to introduce a strict mandatory requirement for the nomination of responsible municipal energy managers in charge of implementing a relevant smart data collection system for objects consuming over 1,500 TOE annually. This approach continued until 2016, when the mandatory requirement was excluded from the law and the positions of energy managers were no longer financed by the state budget. This resulted in an immediate freeze of all energy management activities. This example confirms the benefits and efficiency of a systematic approach which could be effective – but only with the strong support of the national government. This is especially true if relevant administrative positions are created and financed as new roles, rather than increasing duties and responsibilities of the existing personnel.

[14] http://ems-undp.rs/en-US/Blog/Post?id=18

Conclusions and Recommendations

The broad findings of the study are as follows:

1. **Energy efficiency in the building stock is improving in all regions.** Countries in Eastern Europe, Central Asia, the Russian Federation, and South East Europe – which traditionally have low internal energy prices – have significantly increased mandatory energy efficiency requirements, especially for newly constructed buildings.
2. **Nevertheless, energy efficiency in the building stock is improving only incrementally and in a disjointed manner.** This finding is particularly unexpected, given that recent advances in technology design have yielded remarkable advancements in efficiency and this trend is expected to continue.
3. **Three types of public policy tools are particularly successful at supporting energy efficiency improvements in buildings**. These include legal regulations (such as building standards), financial incentives (rebates, reduced-rate debt, tax deductions), and information awareness programmes for various types of energy efficient technologies. Countries with comprehensive and stringent building standards in place tend to have higher penetration rates of energy efficient technologies.
4. **Effective design and implementation of public policy is key to increasing energy efficiency.** The substantial gaps between what is available in the market and what is being used makes it clear that effective governance and use of legal and financial instruments, rather than just technical advancement, are key.
5. **Three specific technology trends can be clearly observed:**
    a. Countries in the European Union (EU) show increased adoption of high energy efficiency boilers, along with shifts to cleaner fuel sources. However, strong concerns remain regarding the use of coal for residential space heating.
    b. With the implementation of labelling and Ecodesign regulations, the adoption of energy efficient appliances is on an upward trend.
    c. Most countries in the UNECE region have banned, or are phasing out, incandescent light bulbs in favour of compact fluorescent lamp (CFL) and light-emitting diode (LED) technologies. However, lighting sensors and controls are being implemented less frequently.
6. **Energy performance certificates have accelerated retrofitting of existing buildings, but much remains to be done.**
7. **In addition to the numerous environmental benefits associated with decreased energy consumption and increased generation of renewable electricity, many of the technologies discussed in this report offer additional non-energy related social benefits.** Examples include: boosting economic growth, developing local competitive markets, increasing employment, promoting implementation of lower-cost and accessible energy efficient technologies, and developing international markets.

Countries can take several **priority actions** to increase the deployment of technologies to enhance energy efficiency in buildings. The following **recommendations** cover multiple perspectives, such as educational, technical, regulatory, financial, institutional, technology adaptation, capacity development, and private sector involvement.

Policy and legislation

1. In buildings, space conditioning is the largest source of fuel consumption across all UNECE countries, despite differences in climate. The initiatives taken in subregions A, B, and D are causing a paradigm shift in the adoption of technologies for heating and cooling. The analysis of subregions A and B shows increased adoption of highly efficient boilers, along with shifts to cleaner fuel sources. The trend is predominantly moving towards efficient gas-fired boilers, electric boilers, solar collector systems, and heat pumps. This is likely due to the market reacting to relevant EU directives, which also target technologies in building insulation and windows. Most design and construction norms in countries of subregions C, E, and F currently have clear definitions of the implementation of heating systems, and capacity calculations, but cooling degree-days are not factored into the standards. This may have a substantial impact in countries with warm and hot climates, hindering accurate computation of building energy performance.

Recommendation A: *Governments need to provide good policy, strong institutions, and efficient public services to ensure the private sector can thrive; they should also commit to develop and sustain the institutions that implement, oversee, and regulate these policies. The private sector is critical to economic growth, but it cannot and does not act alone, the public sector should support a balanced strategy; the "Technology push and Market pull" strategy (Brocato, 2010), for example.*

Recommendation B: *Governmental research and development programmes should advance technologies which are too risky for the private sector, which will require transparent collaboration between government, industry, and energy programme administration in order to convert some innovations into marketable products.*

Recommendation C: *More specific requirements to better define cooling degree-days should be included in energy efficiency building standards, this will help to evaluate building energy performance during hot periods of the year more accurately and reasonably.*

Role of public and private sector; new market opportunities

2. Since 2000, the energy consumed by residential space heating in subregions A and B has decreased, as a percentage of total household consumption, by at least 4 percent (CCC, 2016). This development is due to initiatives undertaken by the private sector to develop efficient technologies. European companies have developed and produced more than 90 percent (CCC, 2016) of the efficient and renewable boilers used in the EU countries. In many cases, they have no competitors for their innovations, and have found international markets including China, South Korea, and the Middle East. A similar approach can be encouraged by national governments in the other subregions. There is currently strong support for development and manufacturing energy efficient technologies, encouraged by various tax incentives and procurement preferences for local companies, in a few countries in subregions C and E. However, most advanced energy efficient technologies are still imported.

Recommendation D: *Governments should undertake initiatives to raise the bar for developing building energy efficiency technologies to meet specific local needs, which can create new international markets*.

Connect building energy efficiency with Intended Nationally Determined Contributions (INDC) targets; reduce fossil fuel use in space heating

3. There are several countries in the UNECE region in which coal is still prevalent as a decentralized building heating fuel. Since coal is cheaply and easily available in these countries, modern energy efficient coal-fired boilers are being adopted in both new construction and building retrofits.

While energy efficiency is improved, strong concerns remain regarding the health risks of using coal for residential space heating. Installation of increased efficiency coal-fired boilers should be encouraged only in the short term as a stop-gap measure. Along with the health concerns are the clear global climate consequences. Increasing energy efficiency in the building stock will result in a clear reduction in CO_2 emissions from electricity generation, which is related to the Intended Nationally Determined Contributions as part of the UNFCCC negotiations. Governments can simultaneously promote energy efficiency in the building sector and progress toward climate change reduction goals by connecting building energy efficiency measures with INDC targets.

Recommendation E: *Governments should explicitly connect building energy efficiency measures to Intended Nationally Determined Contributions (INDC) targets to further encourage improvement*.

Recommendation F: *Governments of countries in which coal is still used for residential heating, and coal is the lowest cost fuel, should promote the use of other fuels to drive the adoption of cleaner technologies*.

Information awareness for multiple social benefits of energy performance certification

4. In subregions A and B, energy performance certificates are mandatory and widely implemented. Buildings throughout the European Union can be rated and certified for their efficient use of energy. In subregion D (United States), buildings may voluntarily obtain LEED certification, which shares similarity with the NZEB codes. Buildings with higher ratings tend to earn substantially higher premiums; owners are hence able to earn a profit on energy efficiency investments from both reduced energy consumption and increased economic rents. While the major benefits of energy performance certificates has been documented in multiple countries across subregions A, B and D, more information is needed to support mandatory building certification in the other subregions. Local governments can promote increased energy efficiency in buildings associated with EPCs by collecting and publishing data demonstrating both decreased energy costs and higher income from rental or sale.

Recommendation G: *Local governments should publish city-level data demonstrating both decreased energy costs and higher income associated with various levels of energy performance certification to promote building energy efficiency investments*.

Technological adaptation through effective promotion and awareness campaigns

5. With the implementation of labelling and Ecodesign regulations, the adoption of energy efficient appliances is on an upward trend. In subregions A and B, some countries have failed to realize the expected increased energy efficiency in appliances, as there has been insufficient promotion of labelled products. In addition, some appliance labelling schemes have minimum requirements which are equal, or very close, to the market averages. Most countries of subregions C, E, and F have progressed substantially due to the existence of regulations mandating installation of energy efficient appliances - for both new and retrofitted buildings. Similarly, lighting control system and smart meters are not yet widely integrated into building systems, though these technologies can have a large impact on reducing energy consumption. Only a few countries from subregions B and D have made moderate use of these technologies.

Recommendation H: *Governments should scale up effective promotion and awareness campaigns which are essential to encourage consumers to purchase appliances labelled with high energy efficiency ratings.*

Recommendation I: *More stringent regulations are needed to promote exterior and interior lighting in non-residential buildings and develop social pricing structures for homeowners to install smart meters.*

Governments should create awareness programmes reflecting upon the variety of benefits from adopting these technologies.

Key focus on building retrofits

6. Much of the efforts to increase energy efficiency in the building stock appear to be focused on new construction. The existing building stock will continue to consume energy inefficiently, leading to waste through inefficient insulation and appliance use. In addition to impacting building sector energy consumption, retrofitting the existing building stock can provide multiple types of benefits to society, such as: growing the economy by creating opportunities for other sectors, encouraging small and medium enterprises, adding job opportunities, and leading to local content R&D. In some countries of subregions A, B, C, and E, measures are being adopted to encourage building retrofit programmes with the help of technological tools. Multi-family residential buildings with shared ownership which are deemed unfit for occupancy could be demolished and rebuilt – or undergo major retrofits – without recourse to public funds. This can be done through programmes wherein private real estate investors or developers construct new sustainable buildings or retrofit existing building shells with more residential capacity. The developer guarantees unchanged ownership to current owners and a better living space, while investors profit from selling the extra residential capacity.

Recommendation J: *Governments should promote the creation of datasets and tools which guide analysis of, and demonstrate, the financial benefits of increasing energy efficiency through retrofitting existing buildings. Specifically, this should include the use of simulation software tools for building energy performance during the design phase of both new building construction and major building retrofits.*

Recommendation K: *Governments should develop and promote programmes to encourage complete retrofit of decrepit and condemned residences, involving private real estate investors or developers*.

Coordination between national and local authorities to reassess development and implementation of building codes

7. In some countries, the governance structure is such that building codes are made at a national level, while local governments choose whether to adopt the codes or not. This is found mostly in countries from subregions C, D, and E; the situation hinders the national government from driving action. Also, the codes should be updated more frequently considering the rapid pace of development in building technology. Performance-based building codes with minimum energy standards rather than prescriptive building codes would help increase adoption, as it gives building owners the flexibility to choose the best technology to reduce energy consumption.

Recommendation L: *National and local governments need to coordinate and work together to design policies and building codes which can be adopted either nationally or locally; performance-based building codes should be preferred to prescriptive codes, as the flexibility should increase compliance.*

Investment and finance

8. In most UNECE countries, substantial financial barriers to energy efficiency technology adoption in households remain for both new buildings and retrofits. Several countries are facing challenges to support incentive schemes encouraging increased building retrofits. Financing options to support the energy efficiency transition across the building sector could include: establishing national and regional public finance mechanisms (loans, grants), making reduced-rate financing available (by banks, local authorities, and private financiers) to support the adoption of energy efficiency measures by individuals, project finance options (by banks, institutional, and other

private investors) for public and commercial building owners, and carbon credits and renewable obligation certificates for utilities companies.

Recommendation M: *Governments should develop and promote multiple financial mechanisms to increase the adoption of energy efficiency projects across the building sector: residential, public, and commercial buildings. To help overcome the complexity of investments and lack of capacity at the individual and suppliers' level, Energy Service Companies (ESCO's)should be more heavily promoted by governments.*

Capacity building to promote building retrofits

9. The analysis undertaken in this study shows that much of the effort to increase energy efficiency in the building stock is focused on new construction across the UNECE region. Instead, by focusing more on renovation of existing buildings, countries can obtain varied social benefits; one of which is increased jobs in small- and medium-sized enterprises. Increased activities of international financial institutions on energy efficiency projects influence local investment markets and support the growing interest of local banks and other financial institutions in energy efficiency lending and project financing. However, there is still a gap in financial professionals' technical competence, limiting their understanding of the multiple benefits of energy efficiency investments.

Recommendation N: *Standard civil engineering educational and training curricula should focus more on the largely neglected discipline of building lifecycle management; this should emphasize courses and programmes on energy efficiency and building renovation.*

Recommendation O: *Financial institutions should be empowered to understand the profitability of energy efficiency investments; this would require more effective promotion and dissemination of best practices, appropriate de-risking, and financing solutions for bankers. Clear technical and financial criteria should be defined by the financial institutions to grant loans. Additionally, a pre-approved list of eligible equipment manufacturers and suppliers, can assist in measuring and avoiding risks.*

Expanded use of Energy Performance Certificates (EPCs)

10. Energy performance certificates are in use in many countries. They are, however, currently used predominantly only for informational purposes. EPCs could be used in additional ways to provide more value to building owners and further encourage energy efficiency investments. Consider that buildings with higher EPC ratings use energy less and/or more efficiently, and hence owners are directly compensated for the investment. This benefit could be magnified if higher-rated buildings also received lower energy tariffs, for example. Furthermore, most countries in the UNECE region implement energy performance certification and energy efficiency technology investment incentives separately. In the majority of cases, incentives are related to the implementation of a single specified technology. A more holistic programme would provide incentives proportional to the EPC rating of a building, and projected improvement (similar to performance-based building standards). There are currently only a few cases of incentives linked directly to EPC rating.

Recommendation P: *Governments could create tiered energy tariffs linked to EPC rating; such an EPC-based tiered pricing could both encourage energy performance certification and the implementation of energy efficiency technologies.*

Recommendation Q: *Incentives for implementing energy efficiency technologies could be linked to EPC rating. For example, a C-rated building that is retrofitted such that it afterwards is rated A should receive a higher concession, higher land use tax compensation, or lower debt interest rate, as compared to an upgrade from C to B.*

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