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GreenBuilding

Minimising Energy Consumption for Green Buildings repecting present uses and public needs

Output 5.2: Report on new/revised procedures for the energy building refurbishment EUMC

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List of abbreviations

EUMC: European Union Mediterranean Countries

PHPP: Passive House Planning Package

RES: Renewable Energy Sources

SPF: Seasonal Performance Factor

SEER: Seasonal Energy Efficiency Ratio

EPC: Energy Performance Certificate

NZEB: Nearly Zero Energy Building

LED: Light Emitting Diode

PV: Photovoltaic

KPI: Key Performance Indicator

ISO: International Organization of Standardization

BMS: Building Monitoring System

BIM: Building Information Modeling

BES: Building Energy Simulation

DA: Design Approaches

FCD: Frequency Converter Devices

DSF: Double Skin Facade

1 Introduction

During the last decades, the building energy refurbishment procedures have experienced an impressive improvement in terms of inventing new procedures or revised ones in the European Union (EU) and worldwide, specifically with the development of technological aspects relating to ensure the energy efficiency of a building.

In this context, and in a direct connection to the output 5.1, the output 5.2 aims to develop two reports on the new/revised procedures for the energy building refurbishment, the first is about the EU procedures while the second is around the MPC procedures, with focus on the technological use in strengthening the energy efficiency of a building.

The sole Activity 5.2.1 under this output is to identify and evaluate new and revised procedures for the building energy refurbishment, and all the PPs are called to assess their best practices in order to compare them and produce the report to guaranteeing the gained knowledge transfer.

This report covers the best practices in the European Union Mediterranean Countries (EUMC), like the energy simulation and energy efficiency tools in addition to cost-effective technological procedures that helps minimizing the energy consumption of a building.

2 Identification of new/revised procedures for energy building refurbishment

2.1 Energy simulation tools

Energy simulation tools can be used in the design phase, allowing comparison of alternatives in terms of energy performance and thermal comfort. It performs thermal simulations of building projects, in order to provide designers, engineers or architects with energy and comfort indicators allowing a project to be evaluated (e.g. heating and cooling needs, number of overheating hours). Mutual shading effects can be studied during the planning phase. In the sketch phase, energy simulation allows us to compare energy performance and comfort level of different architectural forms (compactness, glazing areas) and major choices (e.g. integration of solar collectors). In detailed design, comparing energy performance and comfort level of different technical solutions (insulation, glazing types, solar protection, equipment, energy sources) can be based upon simulation results. The main output by the use of the energy simulation tools is the energy and comfort indicators: heating and cooling needs, energy consumption, number of overheating hours, predicted percentage of dissatisfied (PPD), predicted mean vote (PMV) (AZEB partnership, 2019).

Some of these tools are the following (AZEB partnership, 2019):

- ESP (Scotland) http://www.esru.strath.ac.uk/Programs/ESP-r.htm
- IDA (Sweden) https://www.equa.se/en/ida-ice
- PHPP (Germany) https://passivehouse.com/04_phpp/04_phpp.htm
- COMFIE (France) http://www.izuba.fr

Passive House Planning Package (PHPP)

The Energy Balance Calculation Tool PHPP (Passive House Planning Package) is to be used from the preliminary design stage through to the completion of the project, allowing comparisons to monitored results. PHPP is an easy to use planning tool for energy efficient building design, for use by architects, building engineers and planning experts. PHPP is used by thousands of Passive House practitioners already and it's easy to use interface has enabled the accurate and reliable design of tens of thousands of high performance buildings. PHPP results have been validated against dynamic building simulations and confirmed by a significant number of monitoring projects. Projects designed with PHPP have shown no performance gap between accurately modelled buildings and their operational performance. PHPP is the ideal design tool for energy efficient buildings like Passive Houses, NZEBs or other efficiency projects and supports designers in making the right decisions related to building components, layouts or other efficiency measures (Passive House Institute, 2020).

The data entry into PHPP is straight-forward, a result of its Excel format (Passive House Institute, 2020): General information of the building, the envelope data, ventilation properties, location and climate, distribution losses, renewable Energy Systems (RES), electricity, heating and cooling, contribution margins of heat generation or cooling concepts.

All relevant energy efficiency performance results of the building (Passive House Institute, 2020):

• Annual heating demand [kWh/(m²a)] and maximal heating load [W/m²]

• Annual cooling demand [kWh/(m²a)] and maximal cooling load [W/m²]

• Comfort in summer through passive cooling: Frequency of overheating [%]

• Primary Energy Renewable and Primary Energy demands for all building energy services [kWh/(m²a)]

• Estimation of annual renewable energy gains [kWh/(m²a)] by PV or solar thermal systems

• The verification of the Passive House or EnerPhit standard

PHPP offers an easy and straight-forward data entry system that requires moderate effort. Projects calculated with PHP show very reliable results, the basis for the successful completion of any energy efficiency project. The accuracy of the efficiency results is also the basis for any cost optimization process, as otherwise specific energy efficiency concepts or measures couldn´t be reliably optimised in terms of energy or cost efficiency. PHPP is, therefore, the ideal calculation and design tool to find simple and cost efficient solutions to achieve affordable and highly energy efficient buildings. PHPP is applicable in any country or climatic zone, and can include and evaluate almost any efficiency measures, which makes its application highly flexible to any design task worldwide. Furthermore, the possibility to enter multiple energy efficiency options allows the careful evaluation and optimisation of component qualities and an economic comparison to find the most cost optimal design solution (Passive House Institute, 2020).

2.2 Building's energy efficiency tools

2.2.1 Commissioning tool

Careful commissioning of the ventilation system is a major prerequisite for efficient operation. Adjustment of the air flow levels and checking the functionality of the system are thus important measures, which simultaneously influence the energy consumption and the cost efficiency of the entire building. Calculation of the necessary volume flows for ventilation of the various rooms takes place during the planning process. An optimum design process allows for the adjustment of the planned values where necessary and it is required that these values be available in a suitable form. The Commissioning Tool guides the adjustment of the ventilation air flow values and uses the important technical details of the ventilation system. In brief, this tool allows all of the components of the ventilation systems to be checked in relation to their energy efficient operation. The measurement data will be retained and well documented (AZEB partnership, 2019).

Input for the tool:

- Air quantities and volume flows to all rooms for the different operational modes
- Filter type and specification
- Frost protection method and specification
- Information pertaining to maintenance and filter replacement

The output of the commissioning tool is the documentation of the planned and adjusted air flow values of the ventilation system. It allows for superior communication between the planning phase and the operational phase and for improved ventilation system operation. The tool will specifically address the following (AZEB partnership, 2019):

- Avoiding an inadequate adjustment of the ventilation system upon commissioning.
- The adjustment of suitable air flows leading to good indoor air quality, high thermal comfort and low energy demand.
- Improved ventilation system commissioning processes and communication
- Improved documentation of both the planned and adjusted values, aiding the optimisation of the system during its operational life time.

2.2.2 Cooling system tool

The tool for the calculation of cooling systems is intended to be used at that point of the planning process when cooling systems are selected. It can be helpful for the decision of which type of system should be used and for detailing the required system's properties. There are three viable and cost-efficient options for cooling Passive Houses (AZEB partnership, 2019):

- Recirculation room air, e.g. by mini split / multi split systems or fan-coils
- Cooling the supply air that is provided by the ventilation system for good indoor air quality
- Chilled ceilings or other surfaces, e.g. concrete core activation, ceiling panels, or chilled beams.

The air-based systems usually provide some dehumidification, albeit uncontrolled. Chilled ceilings only provide sensible cooling. An additional dehumidifier may, therefore, be required for any of these systems, particularly in mildly warm but humid climates. To make Passive Houses affordable, it is important to accurately determine the cooling and dehumidification capacity of each of the systems or of their combinations. This avoids unnecessary investment costs for systems that are oversized or not required at all. A realistic assessment of the seasonal energy efficiency ratio also contributes to reductions in costs because it is an essential input to any life cycle cost analysis. Concurrently, the calculation procedure must be simple to use and must provide results, even with limited data, in order to keep planning costs low. The PHP software already contains an algorithm that determines the dehumidification contributed by any of the above cooling systems, Passive House Institute (2020). Building on this method, a standalone tool was developed within AZEB with regard to the above-mentioned requirements (AZEB partnership, 2019). The input for this tool is for a particular month:

- Ambient and indoor conditions, cooling demand and treated floor area of the building.
- Properties of the ventilation system.
- Properties of the respective cooling/dehumidification system, such as airflow rate, on/off or inverter operation, cooling capacity and energy efficiency ratio.

Tool's output is the sensible and latent cooling demand, contribution of each system, and resulting total electricity consumption. Moreover, the determination of whether the selected system is able to cover both the cooling and dehumidification demand is calculated.

2.2.3 Performance Data Generation Tool for air-to-air Heat Pumps

To evaluate a heat pump with sufficient precision its performance under different outside temperatures must be known. This type of data is not commonly available from manufacturers. However, manufacturers commonly provide so-called Seasonal Performance Factor (SPF) for heating or Seasonal Energy Efficiency Ratio (SEER) in the case of cooling. Those values are calculated by two separate standards. In this report two standards, one European (EN 14 825, 2012) and one American (AHRI 210/240, 2008), were used for the investigation. The concept behind these values, as their name suggests, is to evaluate heat pumps over the whole year period.

The intentions of their creators were most likely to provide customers an estimate about a unit's performance. There are, however, arguments why these metrics do not provide the necessary information to consumers. To calculate SPF/SEER values, just one example building and one example climate were selected for use with the applicable standards. The unit will, however, work differently in different climates and different buildings. Additionally, the energetic performance of the reference building in both standards corresponds to an average building, rather than a highly performing building. In highly performing buildings, the same unit will most probably work at a lower capacity (lower part-load operation) in comparison to an inefficient building. This will influence the performance and depends on the part-load and whether it is negative or positive. The team suggests an evaluation of the unit for each particular case- for particular building and particular climate(AZEB partnership, 2019).The output of this tool is the performance data (COP for heating, EER for cooling) and available power of an air-to-air heat pump for different outside temperatures are returned as results.

2.2.4 Energy monitoring and smart Metering systems

Oak Ridge National Laboratory developed new wireless sensors that can improve the energy efficiency of the building. This is attained by having automated control systems for the:

- Cooling units
- Heating Units
- Lighting Systems
- Other temperature access 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 Procedures of the building energy refurbishment

2.3.1 Method for public buildings renovation

A recent study focused on incorporating renewable energy sources and energy efficiency measures for proposing sustainable plans to reduce energy consumption and adverse environmental impacts in the building sector, using KPIs that optimise buildings energy performance and respect present uses and public needs. The proposed method encourages use of renewable energy sources (RES) and energy efficiency measures in public buildings, a natural competitive advantage in Mediterranean (MED) area (Kouta and Stephanides, 2020).

The method integrates planning and implementing public building renovations in 12 phases:

Phase 1 – *Preliminary data phase* includes the initial description of the building. The first records of the building include: photos of the building, architectural plans, building use, building age, technical details about main building envelope elements (walls, roof, floor, windows), and technical details about systems for heating, cooling, ventilation, domestic hot water and lighting.

Phase 2 – *Energy Performance Certificate (EPC)* includes issuing the energy performance certificate of the building. EPCs should be issued according to national legislation of building area and to Energy Performance of Buildings Directives (EPBDs). Thus, EPCs should consider at least minimum requirements of Dir. 2002/91/EC.

Phase 3 – *KPIs base-line* includes potential KPIs for additional certification of energy performance and comfort of a building in its current state (without retrofit). In Table 1, KPI3 (energy in kWh/m2/yr and kWh/yr) includes per year: final energy consumption for space heating, space cooling, domestic hot water, lighting;

electricity consumption; consumption of fossil fuel, e.g. natural gas; total primary energy consumption. Building users' comfort preference in real conditions could help define best retrofit strategies (Irulegi, Ruiz-Pardo, Serra, Salmerón and Vega, 2017). That study sought optimal retrofits by questionnaire analysis along ISO 7730, ASHRAE 55:2010 and Fanger Method, a comparison between subjective and objective comfort, definition of comfort range based on real users' preferences, and simulation.

Phase 4 – *Energy behavior* includes the reporting of energy behavior of building users. This is critical since users significantly influence final energy consumption. Meijer, Itard and Sunikka-Blank (2009) indicate that occupant behaviour is not addressed in current policies on energy renovation. A unified protocol for recording the habits of building users should be developed to estimate the type of users (high energy, medium energy, low energy consumers) and to adapt the educate-and-train phase to their needs.

Phase 5 – *Energy upgrades scenarios* includes definition of renovation type (minor, medium, major, NZEB), and scenarios to be examined for public buildings. Major renovation aims to reduce annual total primary energy consumption towards levels that correspond to minimum energy performance requirements of national legislation. Selected solutions to be examined for public buildings:

- **Lighting**: Although Mediterranean (MED) areas have much daylight during the year, they often do not seek energy savings by photosensors. Doulos, Kontadakis, Madias, Sinou and Tsangrassoulis (2019) focused on minimizing energy consumption by artificial lighting in a typical Hellenic public classroom aiming to near Zero Energy Building using LED DC luminaires and daylight harvesting; the dimming curves of DC LEDs were measured along with installed power of photosensors. From the results, the 90.5 kWhp/m^2 annual lighting primary energy consumption can be reduced to 0.55 kWhp/m^2.
- **Photovoltaics (PVs)**: Since MED areas are privileged with daylight, PVs should be a main retrofit for public buildings. Usually there is enough roof space, and public authorities may own land for PVs installation. Thus, there is no interruption in services housed in the building.
- **Heat pump**: A heat pump is installed on the roof to replace cooling and heating. This reduces oil consumption of the building, and the electricity needed by the pump is produced by PVs.
- **Roof waterproofing and isolation**: Targeted areas of the roofs of the buildings could be waterproofed using polyurea material and then insulated using polyurethane foam.

- **Shading of frames**: External aluminum shading could reduce building cooling requirements.
- **Building management system (BMS)**: The BMS could be upgraded by KNX to minimize energy waste. Stimoniaris et.al. (2015) gave a cooperative scheme (KNX/microgrid control) for enhanced demand-side energy efficiency supported by metering devices of energy use.

Phase 6 – *Simulation* includes description of methods/tools (e.g EnergyPlus, TRNSYS, TAS (EDSL), IES-ApacheSIM, eQUEST) and simulation of current building state and of energy upgrade scenarios.

Phase 7 – *KPIs scenarios* phase includes the measurement of the KPIs of Phase 3 for all energy upgrade scenarios, based on the simulation results.

Phase 8 – *Final Decision* phase includes reporting on the parameters, KPIs, simulation results, economic capacity used for deciding which renovation scenario is appropriate for the public building.

Phase 9 – *Implementation* phase includes the actual renovation works. In this phase, the final decision of the energy upgrade of the public building will take place.

Phase 10 – *Monitor* includes monitoring of refurbishment effectiveness by energy measuring devices that measure KPIs energy efficiency after renovation. Time scheduling of monitoring (time interval of KPIs recording and storing) is to be decided soon after the renovation.

Phase 11 – *Educate and Train*. Public building users, employees, and citizens get engaged in minimizing energy consumption. Phase 4 inputs energy behavior records to adapt training material to user needs. Provide savings instructions to building users (e.g. turn off lights upon leaving, spread word that natural lighting can replace artificial one, use room sensors to detect need, use energy saving mode).

Phase 12 – ***Evaluate*** includes overall evaluation of the decision on energy renovation of the public building and its users' consciousness change, based on goals established prior to energy upgrade. From the results, new policies could be proposed for energy renovation of public buildings in MED.

2.3.2 Nearly zero energy buildings (art. 9 of EPBD)

The concept of nearly zero energy building (NZEB) was introduced in the EPBD recast. It establishes that new buildings occupied by public authorities have to be NZEBs by 31stDecember 2018, while all new buildings by 31stDecember 2020. An NZEB is defined as a building of very high energy performance, where the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources produced on-site or nearby. The concept of NZEBs can be summarized in the diagram of Figure 1. According to the EPBD, Member States were requested to report NZEB definitions, reflecting on national, regional or local conditions. Their reports had to include quantified information on the meaning of ‘‘very high energy performance” and ‘‘very significant extent by energy from renewable sources” as well as a primary energy indicator (expressed in kWh/m^2) (Economidou et al., 2020).

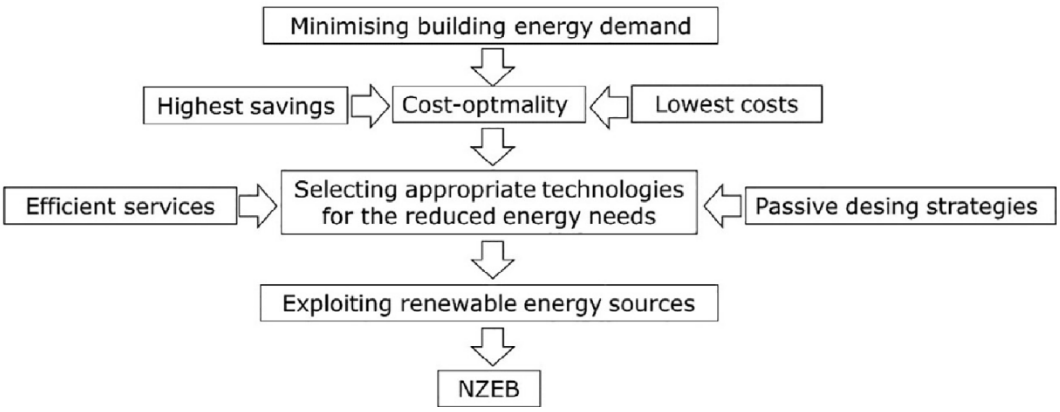


Figure 1:Concept of a NZEB (D'Agostino, & Mazzarella, 2019).

Currently, feasible construction practices are not enough to reach zero energy buildings, therefore, European Union (EU) legislation states that new buildings and renovations should be designed as “nearly zero energy buildings (nZEB)”; however, design alternatives need to be carefully considered and selected before implementation. A recent study aimed to investigate the effect of building façade elements and energy-efficient building systems on reaching nZEB with two different design approaches (DAs).These approaches are investigated through the case of a selected office building's façade retrofit options in terms of energy efficiency and thermal comfort (Çıldır, Köktürk Tokuç, 2020).

In the first day, different design variables of a double skin façade (DSF) are investigated and optimized in order to decrease the total amount of consumed energy, and the best parameters are used in the design of the south façade. In the second DA, the building retrofit aims to meet nZEB criteria by redesigning the south building façade via genetic algorithm optimization, while providing thermal comfort in all months and reducing the number of discomfort hours. In DA2, the recommendations given in the French code are applied before optimization (Çıldır, Köktürk Tokuç, 2020). The changes are as follows:

- External wall: 20 cm glass wool insulation was used instead of 6 cm stone wool insulation. The 20 cm brick was increased to 25 cm. A 15 cm gap is left between the brick wall and the insulation layer.

- Roof: 24 cm of glass wool insulation was used instead of 5 cm of stone wool insulation.
- Floor: 12 cm of glass wool insulation has been added.
- Windows: 6/12/4 low-e triple glass with 3/13 argon filling is used instead of double glazing with argon filling.
- Lighting: LEDs with linear lighting control are used instead of the existing embedded fluorescent lights (Çıldır, Köktürk Tokuç, 2020).

The results from different variable combinations are optimized through a genetic algorithm. The investigation is carried out via building energy simulation (BES) of a selected office building, validated by indoor and outdoor measurements. The results show that the parameters of the building façade can play a significant role in decreasing the energy consumption of the building, and both DAs decrease total energy consumption while utilizing currently feasible and common building technologies. Yet, in the second DA not only is the energy consumption lower but, it also significantly decreases discomfort hours.It is possible to decrease the energy consumption of indoor heating, ventilating, cooling, and lighting systems by utilizing appropriate building elements during the building design. However, it is not enough to use de facto rules to achieve nZEB, and the utilization of integrated BES models is necessary.Both approaches are evaluated in terms of energy consumption (heating, cooling, lighting, water heating, and room electricity) and thermal comfort. The results show that reaching an nZEB office is not feasible with the evaluated passive design strategies for one wall element; therefore, attaching auxiliary systems, such as lighting control, onsite energy generation, or changing other building elements are necessary to reach nZEB. Yet changing the design of even one building element can play a significant role in decreasing the energy consumption of the building even if the DAs differ. The use of genetic algorithms for optimization of BES is very useful, especially in designing the building for specific goals, such as decreasing discomfort hours (Çıldır, Köktürk Tokuç, 2020).

2.3.3 Affordable Zero Energy Buildings (AZEB)

The AZEB is a project under Horizon 2020 Programme and it has created the AZEB methodology for developing cost effective NZEB. Also, AZEB Learn has been launched to help professional clients, investors, project managers and other building professionals to apply the AZEB methodology and achieve affordable nearly Zero Energy Buildings step-by-step. Finally, AZEB trainer manuals have been created and AZEB train-the-trainer courses are being developed to facilitate educators in applying AZEB material in their own educational programs.Eight partners from Italy, Spain, Bulgaria, Germany, France and The Netherlands worked together until May 2020 to develop the integrated methodology for cost reduction of nearly zero energy buildings (AZEB partnership, 2020).

<u>The three keys to success for creating affordable nZEBs</u>

The AZEB roadmap contains 17 steps to guide the project team in developing affordable nZEBs. Affordability is about clients being able to "afford" nZEBs, compared to conventional buildings. This is a combination of the actual lifecycle costs associated with the nZEB, as well as being able to obtain the necessary financing. In the current market situation in Europe better affordability for ZEBs can be achieved in one of three ways, or a combination of these (AZEB partnership, 2020):

- reducing nZEB lifecycle costs
- guaranteeing performance at building level to pave the way for investments schemes based on lifecycle costs (and thus, if needed, enabling higher investment costs)
- increasing the nZEB's environmental, social and economic performance in relation to investment or lifecycle costs

Obviously creating an nZEB demands proper technical knowledge on how to design, build and maintain an nZEB. Technical knowledge however is not enough to create affordability. The AZEB methodology offers the additional knowledge and skills to do this by providing three general types of solutions (AZEB partnership, 2020):

- **Key 1: Quality assurance**

Steps in the AZEB Roadmap for using Key 1: Quality Assurance

  - Initiative phase: Step 2: Set balanced requirements, Step 3: Standardize costing practices, and Step 4: Install a quality assurance process.
  - Construction phase: Step 12: Commission the building services and Step 13: Create a building dossier.
  - Use and maintenance phase: Step 14: Monitor and optimize performance.
  - Extend your impact: Step 16: Evaluate and apply lessons learnt.

- **Key 2: Procurement**

Procurement practices, like tendering, contracting and choice of reimbursement methods greatly influence the collaborative conditions in a building project. As should be clear by now, in the case of nZEBs this multi-disciplinary collaboration is critical to achieve affordability. Examples of modern procurement methods are best value procurement, qualification based selection (QBS), DBFM contracts (design-build-finance-maintain-operate), multi-party agreements (MPA) and open-book compensation structures (AZEB partnership, 2020).

Steps in the AZEB Roadmap for using Key 2: Procurement

- Initiative phase: Step 6: Define practices for procurement and guarantees.

- **Key 3: Integrated project delivery.**

Integrated project delivery can be defined as a collaborative alliance of people, systems, business structures and practices into a process that harnesses the talents and insights of all participants to optimize project results, increase value to the owner,reduce waste, and maximize efficiency through all phases of design, fabrication, and construction. A combination of the right processes,tooling and attitudes is required to achieve this. When costs of any building project, also the nZEB projects, are analyzed along their lifecycle, it can be concluded that most costs incur in the construction phase and in the use and maintenance phase (AZEB partnership, 2020).

In the construction phase, improving affordability through integrated project delivery revolves around efficient and effective collaboration between the client, project manager, various (sub-contractors, trades people on-site, suppliers, commissioning authority and building operator). Their intensive collaboration can prevent waste of time, energy, materials, and prevent rework and costs due to failure. Involving and motivating the entire team applying methods such as project start-ups, lean planner, daily scrum sessions, on-site training and building information modeling creates the incentives, knowledge and skills for all participants to achieve and maybe even increase the value of the nZEB for the client (AZEB partnership, 2020).

Steps in the AZEB Roadmap for using Key 3: Integrated project delivery

- Initiative phase: Step 1: Identify relevant contextual aspects and Step 5: Conceive & select alternatives.
- Design phase: Step 7: Involve a multi-disciplinary team and Step 8: Design an optimized building.
- Construction phase: Step 9: Set up collaborative construction practices, Step 10: Teach on-site team practical nZEB skills and Step 11: Involve on-site team in time, quality and cost control.
- Use and maintenance phase: Step 15: Guide user behavior.
- Extend your impact: Step 17: Integrate the value chain.

2.4 Technologies of energy building refurbishment

2.4.1 New upcoming technologies of building energy refurbishment

Next Generation Insulation

This is a type of foam insulation developed by Industrial Science and technology for the windows. These insulations are made of environmentally friendly and advanced series of composite materials. These help to restrict the heat escape from the walls, attic areas, and other spaces during colder climates.

Cogeneration

Cogeneration is a combined method of producing both electricity and heat for energy efficient buildings. This method reduces the cost, increases efficiency and is environmentally friendly.

Advanced Window Control System

This energy efficient system makes use of microprocessors and sensors along with insulated windows. This helps to automatically adjust the shading based on the sunlight and the time of the day. This provides proper comfort, lighting, saves energy and money.

2.4.2 Thermal Performance Optimization of Envelope

Based on the life cycle cost analysis, a thermal performance optimization model of building envelope was developed for the energy-saving renovation of existing residential buildings. The calculation formulas of the economic insulation layer thickness of the roof, external wall and floor over the basement were obtained simultaneously, and the optimal relationship of thermal performance among building envelope units was proposed; that is, the equivalent U-value of each opaque building envelope unit should be equal. Moreover, the calculation methods of ultimate and optimum energy saving ratio were put forward. This model was tested in a case study existing residential building in Beijing, compared to the energy-saving renovation scenarios determined by the limit value method (LVM), the saving ratio of insulation material of those determined by the optimization model ranges from 0.53% to 73.59%; and the saving ratio of insulation investment ranges from 0.21% to 64.93% when the building envelope energy saving ratio been taken the same value and changing from 0.65 to 0.85. The limit U-value of envelopes prescribed by Design Standard for Energy Efficiency of Residential Buildings in Beijing (DB11/891–2012) cannot meet the optimal relationship. Therefore, the energy-saving renovation scenario determined by LVM cannot obtain the best economic benefit. The ultimate and optimum energy saving ratio achieved are inversely proportional to the U-value of windows. However, improving the performance of windows cannot necessarily achieve the best economic benefit. It is necessary to consider the technical advancement and economic rationality to choose the windows (Huang, Wang, Teng and Feng, 2021).

The methodology included (Huang, Wang, Teng and Feng, 2021):

- The calculation method for annual heat losses through building envelopes was established.
- The thermal performance optimization model of building envelope units was built based on life-cycle cost analysis.
- The economic thickness of the insulation layer, the optimal relationship of thermal performance among building envelope units and the ultimate and optimum energy saving ratio for the energy-saving renovation of existing residential buildings were investigated by solving the optimization model.

2.4.3 Building Envelope Technologies

New technologies are developed to increase the efficiency of the building envelope. Mainly windows of the building structures are improved by the following methods:

a. The properties of the windows can be changed according to the temperature and light-level conditions i.e. during day and night by providing chromogenic glazing.
b. Optimisation of solar gains and the shading effects can be done by using spectrally selective glasses for the windows.
c. Photovoltaic panels can be used to generate electricity by absorbing the solar radiation. This also helps to reduce the heat moving through the building envelope.

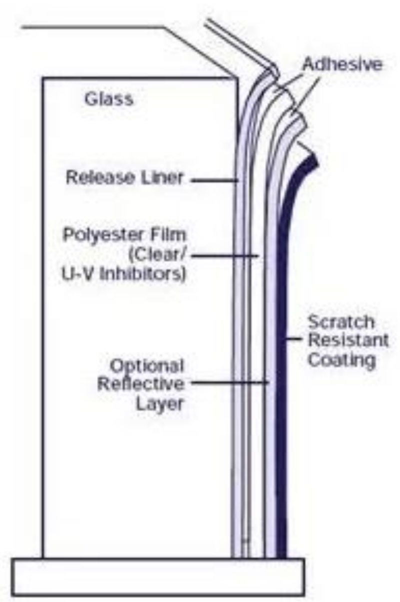


Figure 2: Windows Films

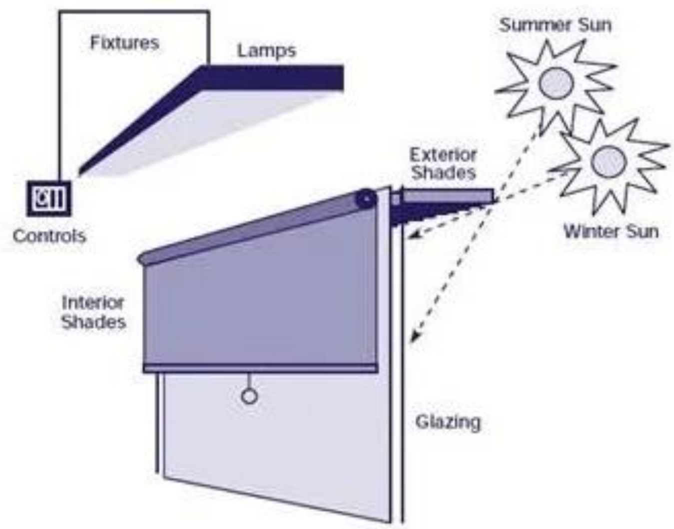


Figure 3: Shading Technologies

a) Insulation of building envelope, air tightness, 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, air tightness, 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 CO2 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 insolation 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 the following Figure.

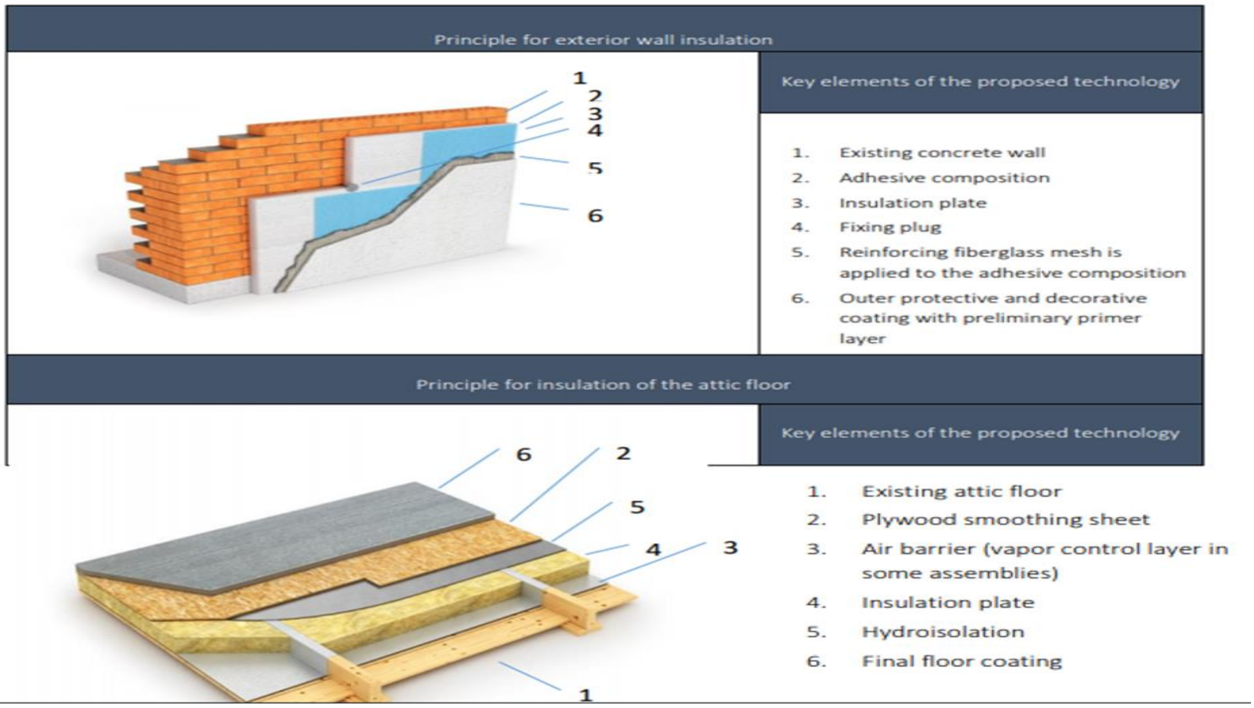


Figure 4: Technical solutions for insulation

There is a wide range of thermal insulation materials used in buildings in the UNECE (United Nations Economic Commission for Europe); some are shown in the next figure.

	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 5: Insulation materials applied in the UNECE region

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-paneled 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 the next figure.

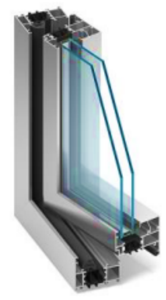
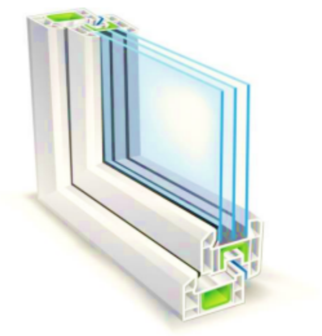
Wooden profile	Aluminium profile	PVC profile
		
Wooden windows made usually of oak, pine, ash tree or larch. **Advantages:** • Attractiveness • Good thermal insulation and frost resistance • Sound insulation • Possibility of changing colour either outside or inside **Disadvantages:** • Combustibility 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 6: 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.

2.4.4 Heating and 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 (United Nations Economic Commission for Europe), 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 renewable
- 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 *centralized* and *decentralized* heat supply systems.

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).

<u>Installation of the boiler equipment</u>

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 Eco design 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 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 7: 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 2.1). The typical solar collectors generate temperatures of 60-100°C.

Table 1: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 climates 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 2.7). A passive solar system is installed as one complete rooftop unit consisting 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 8: Examples of solar heating systems

<u>Heat pumps</u>

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 the 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 also be 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 vertical soil heat exchangers 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 the next figure.

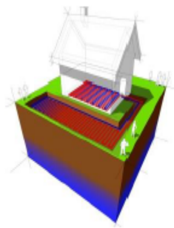
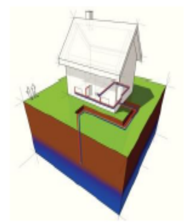
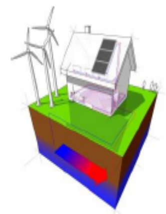
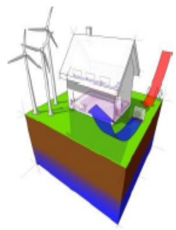
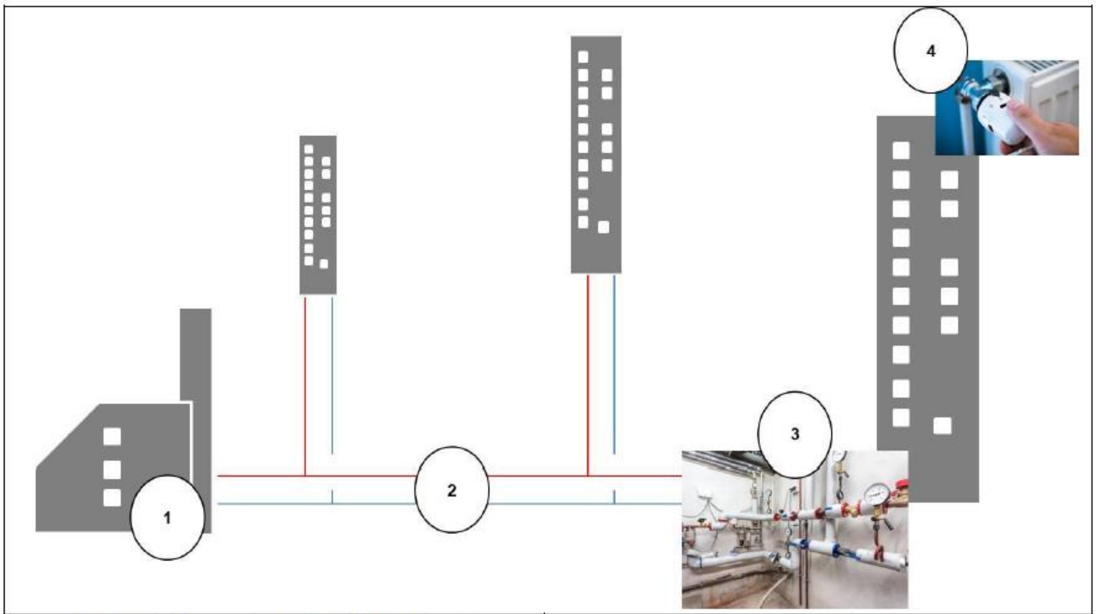
TYPE	SOIL – WATER		WATER – WATER		AIR - WATER
	Horizontal	Vertical	Horizontal	Vertical	
VIEW			 Principal diagram of heat pump with vertical collectors		
DESIGN	The collector is placed in the form of rings or twisting inside horizontal trenches lower than the depth of frost penetration into the soil (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 9: Types of heat pumps

b) Improvement of centralized heating supply systems

Centralized district heating supply systems consist 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 the following figure.



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 10: 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 CO2 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 11: 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 the previous figure), 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.

c) System performance optimization measures

<u>Insulation of pipes and equipment</u>

The following figure 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 12: 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 it has been 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

Control of temperature in individual rooms is 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 is applied. Thermostatic regulators consist of two parts: a valve and a thermostatic element, as shown in the next figure.

Figure 13: 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 overheating 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 associated with the replacement of outdated heating devices with higher energy efficient systems (higher thermal performance).

<u>Installation of balancing valves</u>

Balancing valves are part of the relief 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 carried out to take into account the actual operating conditions of the building which vary dynamically, stabilizing the dynamic regimes of its work. They can be seen in the next figure.

Figure 14: 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 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 limiting the maximum heat transfer 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. It is recommended to install them 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.

2.4.5 Ventilation, Air Conditioning and Cooling (VAC)

a) 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, and 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 the following figure) 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 CO2 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 15: Frequency converters

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, through which the two volumes of air are not allowed to mix, as seen in the next figure.

Figure 16: Heat recovery unit for mechanical inlet and outlet ventilation

b) 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.

3 Evaluation of the new/revised procedures for energy building refurbishment

3.1 Energy Simulation Tools Evaluation

3.1.1 Strengths

The links with an aeraulic model, lighting calculations, a life cycle assessment tool and a user friendly interface allows a more global assessment; using default values and possible import from BIM allows for use at early design stage, particularly by architects. The model has been validated by software comparison and experimental validation. A model reduction technique decreases the computation time, allowing thousands of simulations to be performed in an optimisation process, without reducing the precision related to detail modelling.

3.1.2 Challenges

Importing a BIM requires a precise format of this BIM (including rooms).

3.2 Passive House Planning Package (PHPP) Evaluation

3.2.1 Strengths

The accuracy of the energy demand or load calculated with PHPP when compared with measured consumption or heating load in monitored projects from various countries is very good. PHPP can, therefore, be used reliably for the design of highly energy efficient projects. PHPP also has a number of features that enable the rapid and optimized design of highly energy efficient buildings. Other strengths include (Passive House Institute, 2020):

- Due to its data entry methodology and calculation methods, international climate datasets and certification criteria, it is applicable for projects not only across Europe, but also worldwide.

- With the PER system for renewable primary energy, PHPP contains one of the only efficiency evaluation methods to evaluate a building's energy efficiency in a completely renewable energy supply environment, as anticipated for2050 or later, depending on policy progress.

- PHPP allows the input and calculation of design variants, allowing various design options to be evaluated, components optimised, solutions compared. This concept allows the comparison of the cost-efficiency of certain efficiency measures for entire design concepts.

- Data entry of energy efficiency parameters is self-explanatory for many engineers and designers new to the topic. PHPP, therefore, contains systematic input assistance and error messages, to support inexperienced users with the task of evaluating a project´s efficiency.

• The Microsoft Excel format allows for flexible data entry and even permits additional formulas or side calculations. PHPP is based on a monthly calculation and the entry detail level and effort is moderate when compared to dynamic simulations, and therefore allows an economically justifiable investment for the design of highly energy efficient projects.

• Additionally, a visual and 3D data entry method using designPH is possible for users of the popular Sketch UP CAD program. Furthermore, PHPP offers connectivity to various BIM tools or other efficiency evaluation tools for the efficient import of project data

3.2.2 Challenges

Data entry into PHPP must be accurate, otherwise the results cannot be considered reliable. This requires more effort for the data entry process when compared to less reliable energy efficiency evaluation methods and in many cases inexperienced users require support to identify the correct parameters to enter. In addition, the Microsoft Excel format is perceived as out-dated by some users(Passive House Institute, 2020).

3.3 Commissioning Tool Evaluation

3.3.1 Strengths

At the present many ventilation systems are not adjusted appropriately during their initial commissioning phase. Their operation is unbalanced or the volume flows are not correct for the boundary conditions. The Commissioning tool will serve planners and ventilation system installers in how to communicate the correct operational data and how to adequately adjust a ventilation system (AZEB partnership, 2019).

3.3.2 Challenges

The tool requires the input of a number of different parties in the planning and commissioning phase (AZEB partnership, 2019).

3.4 Cooling System Tool Evaluation

In addition to the existing methodology of the PHPP 9 software, which was used as the basis for development, the "Cooling Systems Tool" has the following features (AZEB partnership, 2019):

• Contemporary split units usually use so-called inverter technology, a compressor that can vary its capacity between 100% and, depending on the system, 10 to 60%. Below this limit the units are operating in on/off mode. The tool accounts for this behaviour.

- The sensible capacity of supply air cooling can be enhanced by recirculating additional indoor air over the cooling coil. Alternatively, if required, an internal heat exchanger (e.g. a wrap-around heat pipe) can reduce the sensible heat ratio to provide sufficient dehumidification. Such systems are currently being developed by manufacturers and are now represented in the tool. They can result in significant cost reductions because the functions of ventilation, heating, cooling, dehumidification, and possibly hot water production are integrated in one single unit.

- A detailed calculation of the energy efficiency ratio is implemented for all cooling methods.

- Stand-alone dehumidifiers typically release their waste heat (generated from the condensation process and electricity consumption) to the room. In most cases this will lead to an increased sensible cooling demand, which in turn increases the dehumidification by the cooling system. A thorough review of the existing analytical solution showed that it provides the best possible estimate.

- Split units or fan-coils can usually operate with different ratios of airflow and cooling power. For low airflow volumes the dehumidification capacity is high, but the sensible cooling capacity is lower than rated. For high airflow volumes the full sensible cooling capacity is available, but little dehumidification is provided. In the tool the user is able to enter two different operation modes. The tool automatically chooses the most appropriate mode for providing the cooling and dehumidification required at the lowest possible energy demand.

- An important input for the analysis of supply air cooling is the airflow rate. Whilst it can be assumed to be constant for residential buildings, there will be intermittent operation in many non-residential applications. This changes the behaviour of the system, particularly the dehumidification performance. The tool takes into account how many hours per day and days per week the system is operating.

- The operating time also affects the part load ratios of the systems and possibly the contribution of each system to the total cooling demand.

3.4.1 Strengths

Different cooling configurations can quickly be entered and compared, so that an informed choice of the appropriate system combination is possible. Simplicity of use and instant display of results supports the workflow (AZEB partnership, 2019).

3.4.1 Challenges

Different cooling configurations can quickly be entered and compared, so that an informed choice of the appropriate system combination is possible. Simplicity of use and instant display of results supports the workflow (AZEB partnership, 2019).

3.5 Performance Data Generation Tool for air-to-air Heat Pumps Evaluation

The tool generates approximated performance data for air-to-air heat pumps, data not generally supplied by the manufacturer. Different tools available on the market can be used to evaluate the use of heat pumps for a concrete building in a particular location. The output values from the Heat pump tool can be used and entered in energy balanced calculation tools, for example in the Passive House Planning Package(AZEB partnership, 2019).

3.5.1 Strengths

Every single heat pump needs to be evaluated, especially for a particular case, in order to get a precise picture about its performance. This process allows for more efficient operation of a unit as installation of oversized units can be avoided. What is more, investment costs can be lowered as well, as larger units often cost more. An oversized unit will also often cycle ON and OFF, having a negative result on life expectancy of the compressor. Finally, a properly designed unit will also consume less energy over the life-time of the unit (AZEB partnership, 2019).

3.5.2 Challenges

The generated performance values are approximated. The methods behind the calculation of the SPF and SEER values, provided by standards EN 14 825 (2012) and AHRI 210/240 (2008), was reverse engineered for the developed tool (the calculation methodology was followed in reverse). This means that input data were calculated from “results” delivered when following that particular standard. The tool was however tested on a large sample of different air-to-air heat pumps (from the EU and US markets) and provided performance values with sufficient precision. Nevertheless, when the performance data from a manufacturer is available, that data should be preferred.

3.6 Current deployment of energy efficient technologies

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 analyzed 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 a previous sub chapter, across the UNECE countries. There have been results for two sections: sub regions A, B, and D (EU member states, EU enlargement, and North America), followed by sub regions C, E, and F (Eastern Europe, Caucasus, Central Asia, the Russian Federation, South East Europe, and Turkey). This report will emphasize sub regions A, B and D. Throughout this subchapter, the mix of implemented technologies is visually represented in the following figures. In these figures, each colored 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 sub region, and for either new construction or existing buildings.

3.6.1 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 sub regions 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 17 and Figure 18 display the mix of building envelope technology, for both new construction and existing buildings respectively, by country in sub region A.

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 sub region 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.

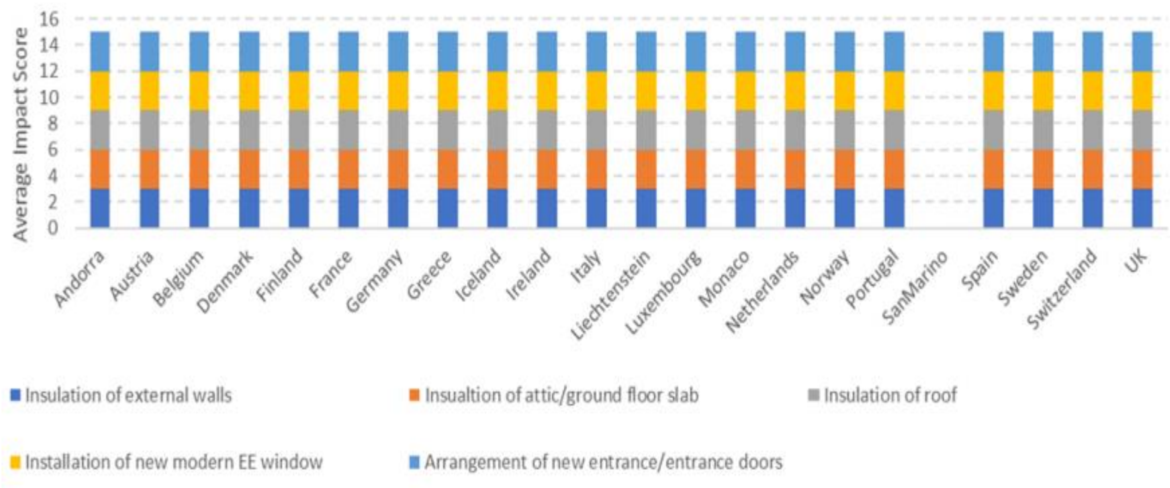


Figure 17: : New construction building envelope technology mix in subregion A

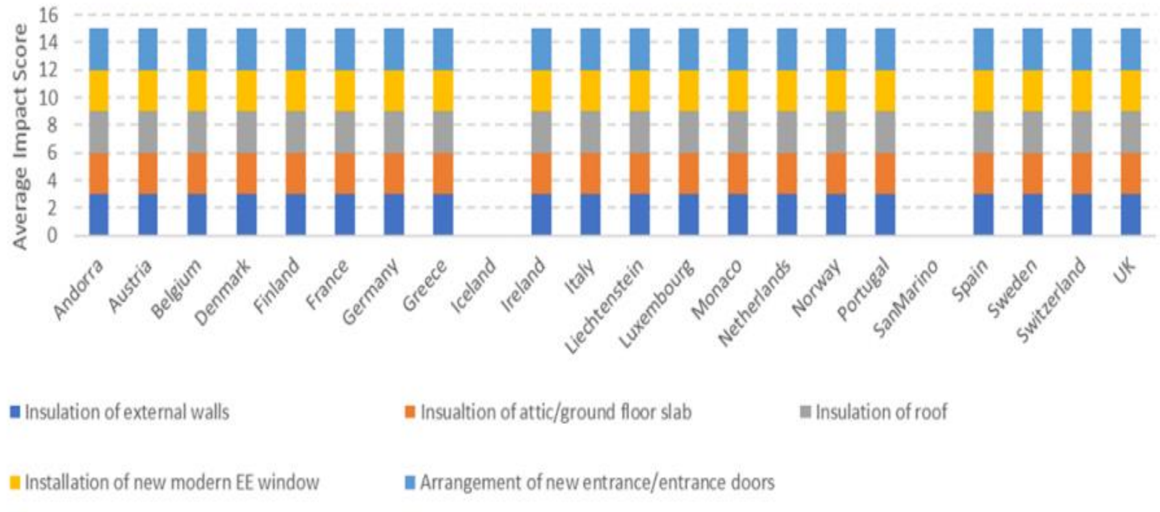


Figure 18:Retrofits building envelope technology mix in subregion A

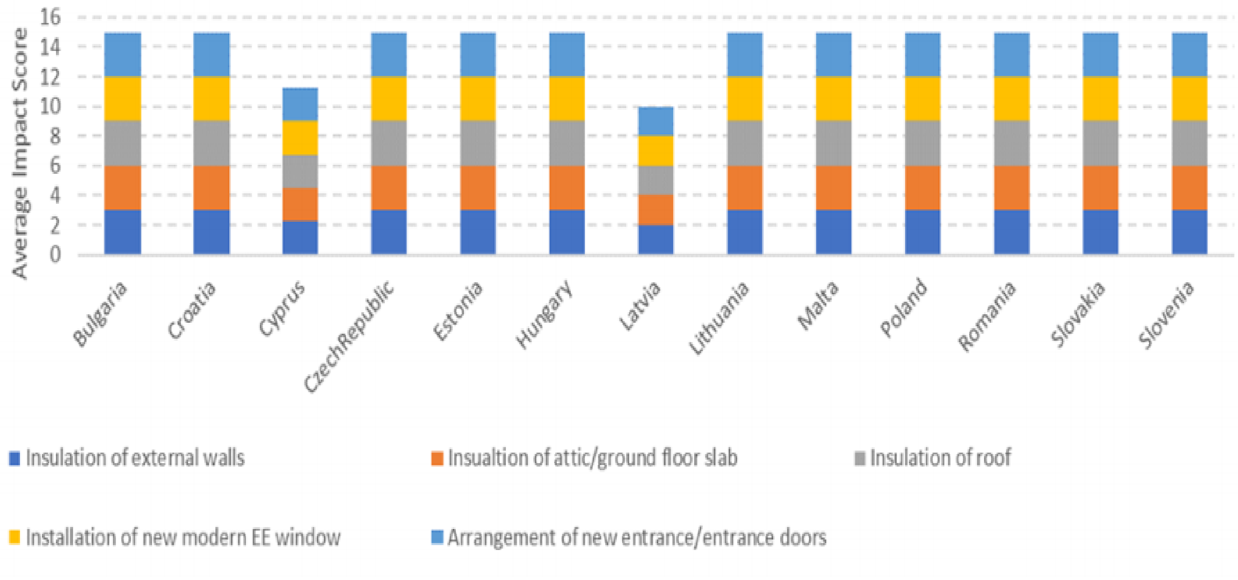


Figure 19:New construction building envelope technology mix in subregion B

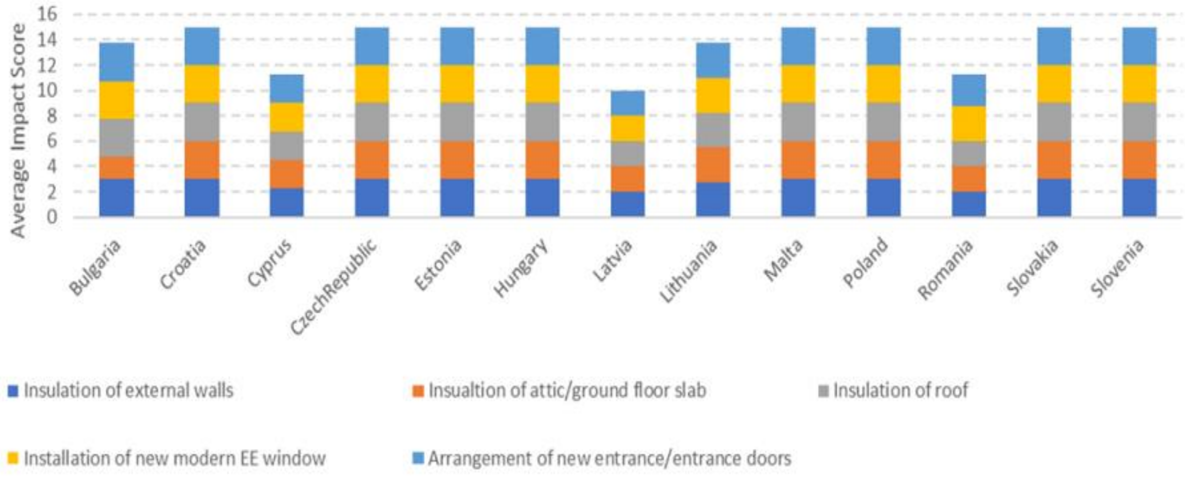


Figure 20:Retrofits building envelope technology mix in subregion B

In sub region 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 has been 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 sub region 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 sub region B is presented in Figure 19 and Figure 20.

In the North American sub region 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 CO2 emissions. In 1993, the US Green Building Council introduced the LEED8 (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 2, an excerpt from (UNECE, 2018, p.53), summarizes an assessment of the prevalence of energy efficient building envelope technologies.

Table 2:: Assessment of market saturation for building envelope materials –Source: Mapping of existing energy efficiency standards and technologies in buildings in the UNECE region (p. 53)

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

3.6.2 Space Heating, Air Conditioning, Water Heating and Cooling

Figure 21 displays a visual representation of the mix of heating solutions for new construction for all countries in sub region 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 sub region 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 sub region 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.

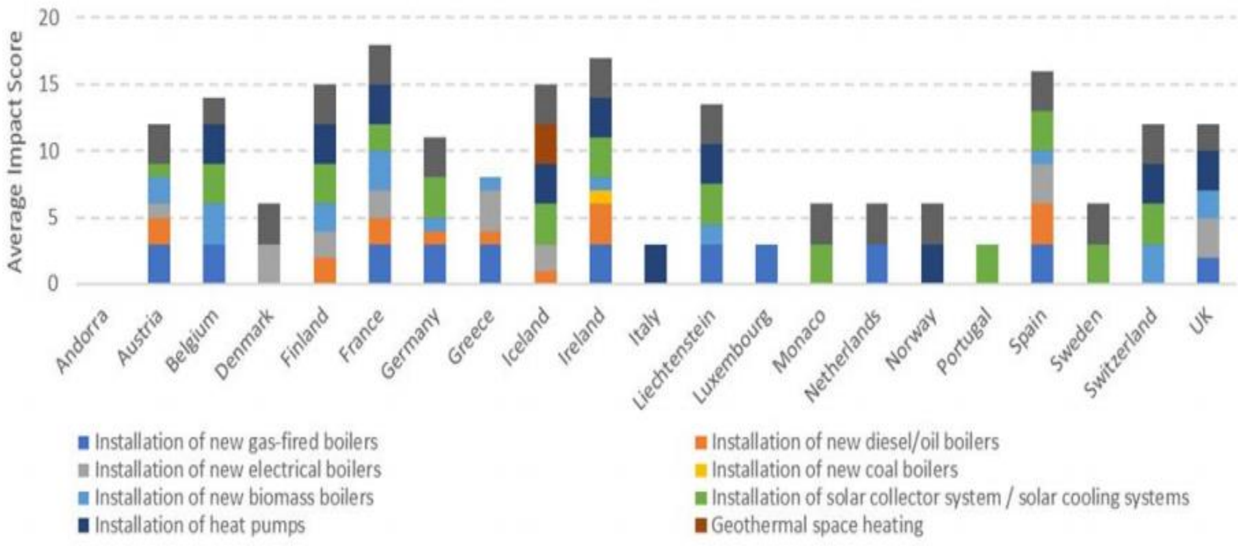


Figure 21: New construction space heating technology mix in subregion A

The stacked bar chart in Figure 22 shows, visually, the mix of new construction heating solutions in sub region 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 22 summarizes this information in visual form for sub region B.

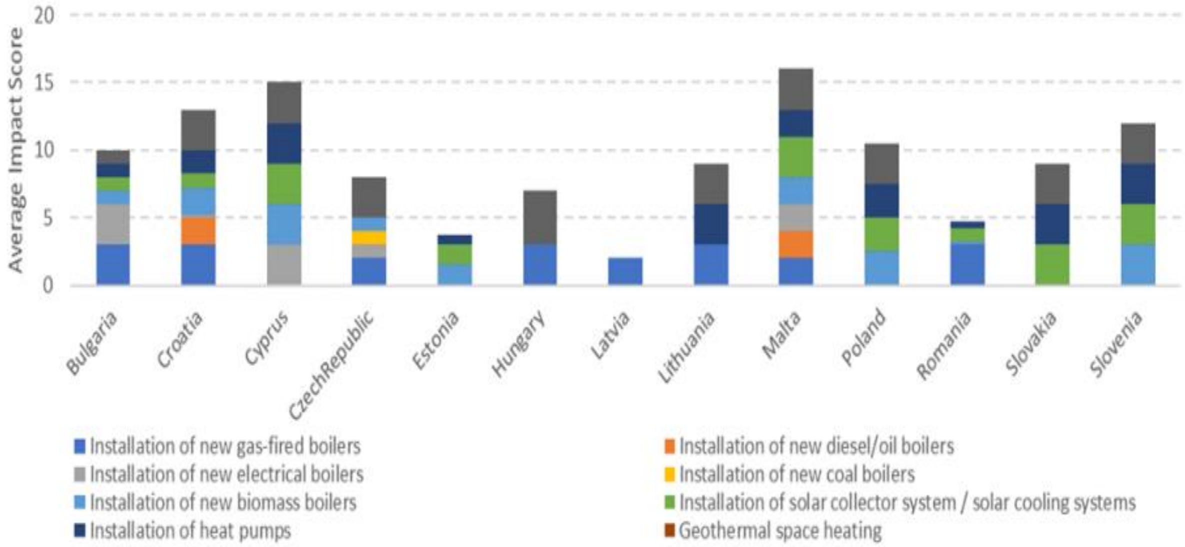


Figure 22:New construction space heating technology mix in subregion B

It is interesting to note that Canada in sub region 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.

3.6.3 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 renewable, 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 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 23 shows the mix of technology for new construction in sub regions A. There are clearly substantial differences and gaps, even among countries with similar climates.

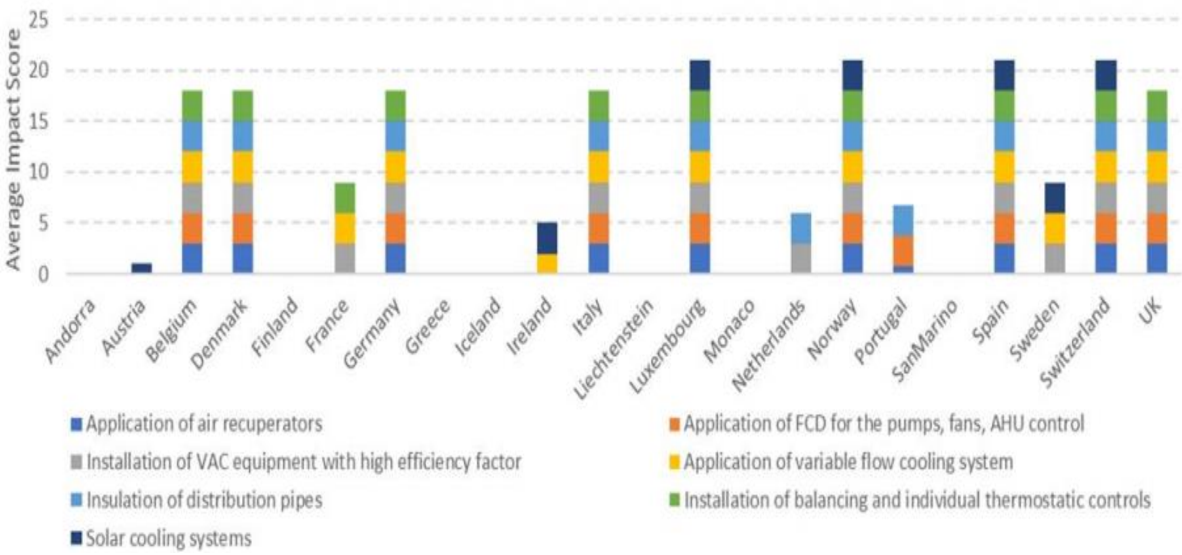


Figure 23:New construction ventilation, air conditioning, and cooling technology mix in subregion A

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 motors and cleaning burners.

One strategy used in Sweden (sub region 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 (sub region 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.

The three sub regions 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;

The three sub regions 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 3.

Table 3: Assessment of market saturation of heating, cooling, and other EE technologies - Source: Mapping of existing energy efficiency standards and technologies in buildings in the UNECE region (p.56)

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	

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 labeling, 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 Labeling Directive (2010/30/EU) and previously-mentioned Eco design 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 labeling 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 labeled products.

A second issue with labeling 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.

3.6.4 Lighting

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

- application of day lighting 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, day lighting 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 (sub region 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 sub region A. It is moderately prevalent in Austria, but only for public buildings. In sub region B, only Estonia and Cyprus make much use of day lighting, with Estonia also focusing on public and commercial buildings. In addition to reducing energy consumption, there are documented social benefits to using natural lighting.

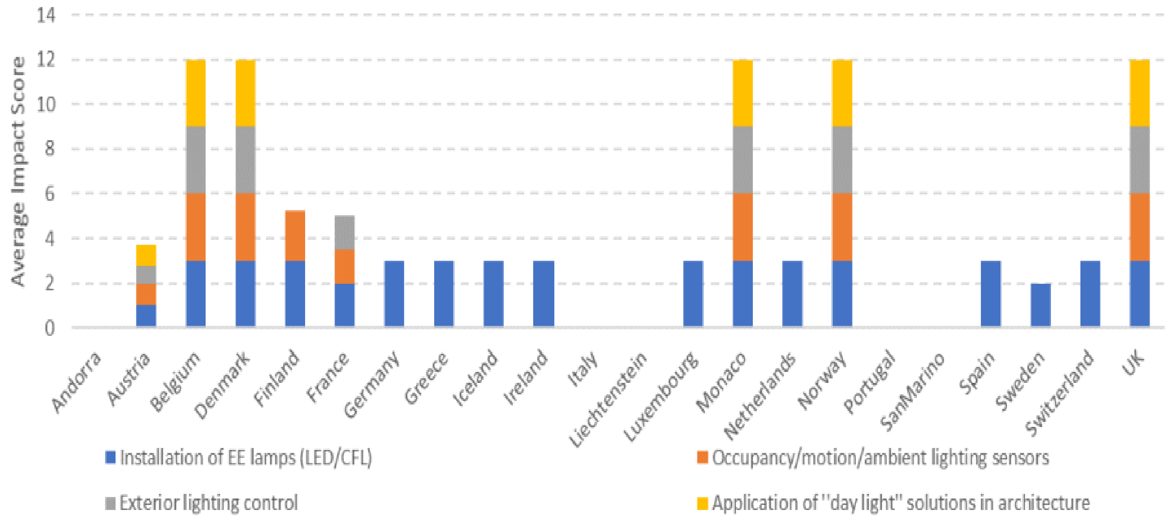


Figure 24: New construction lighting technology mix in sub region A

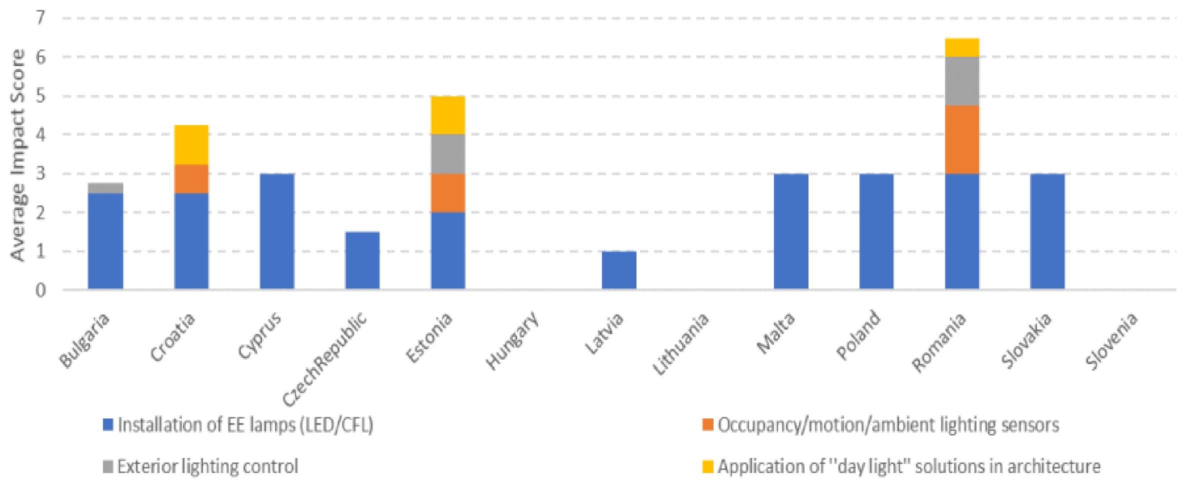


Figure 25: New construction Lighting technology mix in sub region B

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 behavior, 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 sub region B, make moderate-to-heavy use of the technology, as can be seen in Figure 26. The technology is significantly prevalent in less than half of the sub region A countries. Hence, it is clear that public policy and awareness campaigns are necessary to encourage its adoption.

The simplest, farthest 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 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 sub region 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 sub region B, Estonia is diversifying efforts for new construction, with Cyprus focusing on retrofits.

3.6.5 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 sub region A, and Estonia, Lithuania, and Malta in sub region 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.

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.

4 User needs, training and behaviour change in energy refurbishment procedures

The GreenBuilding project intends to reduce energy consumption by using renewable energy sources in public buildings, developing custom solutions for different kinds of buildings. In the framework of customizing numerous solutions and best practices for energy refurbishment procedures, user needs should be taken into account.

By considering the building occupants' needs and building use (e.g. office, administrative building, auditorium etc.) the most suitable solutions and technologies will be used, as different kinds of buildings are used by different people with various habits. Moreover, the aspects that are evaluated as the most significant by the users are the aspects that should be in priority.

For example, a survey in Bulgaria (iBROAD, 2018) found out that: (a) 83% people can reduce their household's energy consumption through renovation measures, (b) 21% of homeowners, who had not renovated, stated that the main reason was that their home is "already energy efficient", and (c) 66% are more concerned about having a warm and comfortable home than saving energy [3]. More information regarding this survey is presented in figure 26.

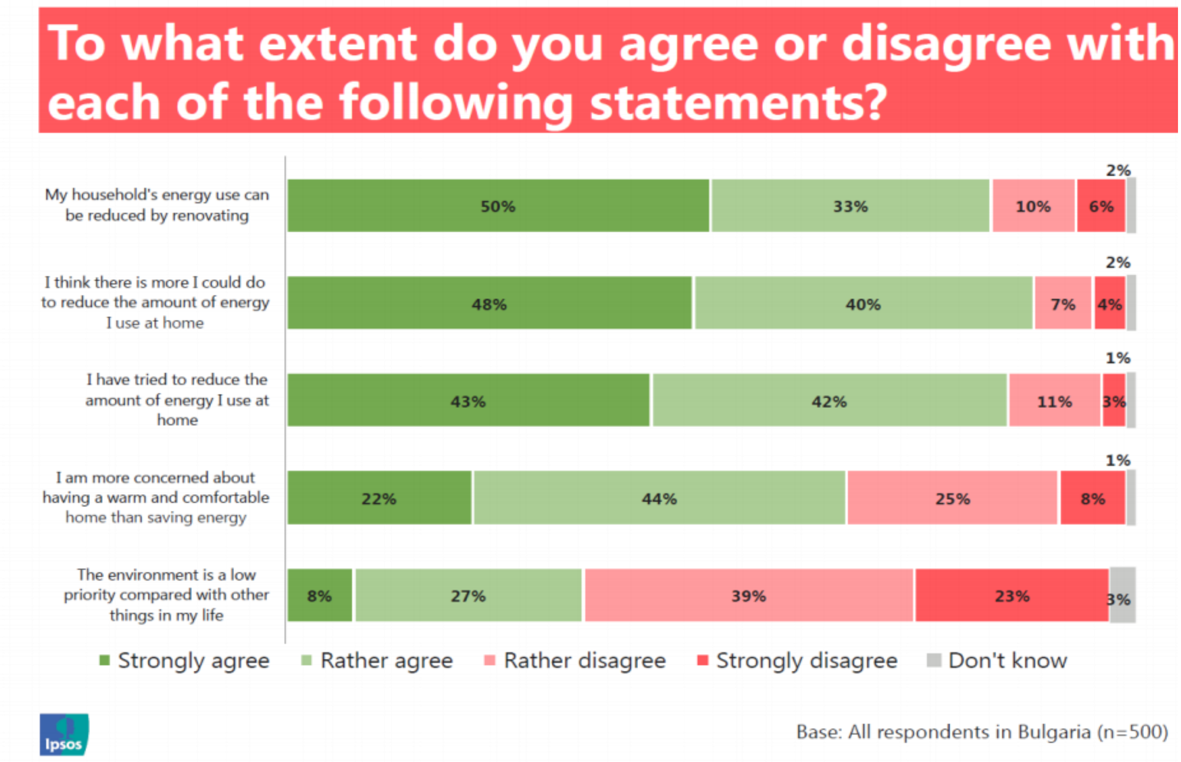


Figure 26: User needs, households in Bulgaria

Finally, all user needs, preferences and habits as well as the type of the building usage are considered when selecting best practices and solutions for reducing energy use and increasing comfort level in the building.

Usually, new solutions are accompanied by advanced technological equipment. Thus, an essential part of assuring the expected results is user training. If building users are not trained to make the best out of the offered equipment, no significant changes would be made. Training procedures should have a wide audience and be shared through innovative methods (e.g. living labs) in order to transfer knowledge, disseminate results and inspire other institutions to follow your example. There are specific procedures for training building users and mainly for helping them change behavior and habits, contributing to energy use reduction, and making the building greener.

"The Behaviour ChangeWheel"outlines a framework for designing behavioural interventions in institutional settings and brings together two models: the Capability, Opportunity and Motivation behavioural model (COM-B) and the Theoretical Domains Framework (TDF) [4]. This eight-stage process is presented in figure 27.

Figure 27:: The Behaviour Change Wheel's eight-stage process for designing behaviour change interventions

These eight stages are explained below:

1. DEFINE THE PROBLEM IN BEHAVIOURAL TERMS

What is the behaviour, where is it performed and who is doing it?

2. SELECT EXISTING BEHAVIOUR(S)

All relevant behaviours performed should be considered. If one behaviour is dependent on others, this should also be considered. Desired Behaviours characteristics: (a) changeable, and (b) measurable and significant impact.

3. SPECIFY TARGET BEHAVIOUR

What target group (**who**) should perform the behaviour? What behavioural changes need to be made by the target individuals? **When** will they do the behaviour? **Where** will they do the behaviour? **How often** will they do the behaviour? **With whom / what** will they do the behaviour?

4. IDENTIFY WHAT NEEDS TO CHANGE

Questionnaires or interviews can be used to identify what needs to change, in order to meet all Capability, Opportunity and Motivation Behavioural model criteria, as well as research regarding the problem. Considering the problems GreenBuilding project focuses, a detailed energy use per space (room) for all times for a long period could expose numerous bad habits and behaviors of users (e.g. using air condition overnight while not being at work, only to find a cool office in a hot morning of summer).

5. IDENTIFICATION OF INTERVENTION OPTIONS

Intervention functions are the means by which interventions can change behaviour. This is particularly useful for university sustainability teams and those designing behaviour change interventions. Noting all potential intervention functions, the APEASE criteria can be used to distil these to the most promising. This selects interventions that are: (a) affordable, (b) Practicable & achievable, (c) Effective and cost-effective, (d) Acceptable Or Realistic, and (e) Side effect free.

6. IDENTIFY POLICY CATEGORIES

Step six of the Behaviour Change Wheel is designed specifically for individuals in policymaking positions and may not be relevant to all situations. Once the appropriate policy categories have been identified, Michie et al. recommend using the APEASE criteria once more to determine which to select.

7. IDENTIFY BEHAVIOUR CHANGE TECHNIQUES

The specific actions required to achieve the intervention function, such as setting a goal for performing certain behaviour are examined in phase 7. The APPEASE criteria should again be used to decide between all available options. The 16 categories are as follows: (a) Goals and planning, (b) Feedback and monitoring, (c) Social support, (d) Shaping knowledge, (e) Natural consequences, (f) Comparison of behaviour, (g) Associations, (h) Repetition and substitution, (i) Comparison of outcomes – with and without making changes, with evidence from a credible source, (j) Reward and threat, (k) Regulation, (l) Antecedents – environmental changes and distraction, (m) Identity, (n) Scheduled consequences – including reward and punishment according to pre-agreed criteria, (o) Self-belief – persuasion about ability, (p) Covert learning – draw attention to positive feelings towards other staff who do actions and consider.

8. MODE OF DELIVERY

In this final phase Michie et al., concern how the behaviour change techniques are disseminated to the targets of the intervention. Authors (Michie et al. 2018) advise considering all possible modes of delivery, including face-to-face, poster, newspaper, internet, mobile phone app, phone helpline, mobile phone text and individually assessed computer programmes. The choice of mode of delivery can be made using the APEASE criteria.

The analysis of the 8 phases of the behaviour change wheel of Michie et al., is based on a collection of best practices of the "International Alliance of Research Universities" named "Behaviour Change Interventions for reduced energy use" (IARU, 2018) [5].

5 Conclusions and highlights

This report covered the technological aspects of the best practices in energy building refurbishment in the EUMC (European Union Mediterranean Countries) with the contribution of the University of Patras and the Region of Peloponnese.

The output provides an overall aspect of the literature review which highlights the identification and the evaluation of new/revised procedures for the energy building refurbishment, as well as the user needs, training and behaviour change significance in energy refurbishment procedures. More specifically, the report recorded and presented the following:

- Identification of the new/revised procedures for energy building refurbishment (energy simulation tools, building's energy efficiency tools, procedures of the building energy refurbishment and technologies of energy building refurbishment)
- Evaluation of the new/revised procedures for energy building refurbishment
- User needs, training and behaviour change in energy refurbishment procedures.

The Literature Review is essential in order to examine and compare all available methods and technologies for reducing energy consumption, by use of different renewable energy sources in public buildings in the EUMC.

The part including the user needs, training and behaviour change is essential for developing custom solutions for different kinds of buildings. For different buildings with different kinds of use (Municipality, Office etc.), different solutions are suitable, considering the occupation, the users' habits and behaviour as well as their preferences and needs. The expected results are met only by training users and changing their behaviour and habits, when needed.

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