Erasmus+ Project ID: 2023-1-ES01-KA220-HED-000156652

BIM4Energy Project

Title: Basic concepts of energy efficiency in buildings

1 – Aims.

The objectives of this Basic concepts of energy efficiency in buildings tutorial are as follows:

- Understand energy efficiency principles: gain an understanding of the basic concepts of energy efficiency and their relationship to building design and operation.
- Identify key energy-saving techniques: be able to identify and describe practical methods and technologies for improving energy efficiency in buildings.
- Recognize environmental impact: develop an awareness of the environmental benefits of energy-efficient building practices.
- Energy performance assessment: get acquaint with the assessment of the energy performance of buildings.
- Promote sustainable building solutions: understand key elements that promote energy-efficient design and construction practices.

2 - Learning methodology.

The teacher will give an explanation about Basic concepts of energy efficiency in buildings for about 1 hour.

Students will read this tutorial and follow the steps shown in the tutorial, namely:

- Introduction to energy efficiency.
    - Basic definitions.
    - Importance of energy efficiency.
    - Historical context of energy efficiency.
- Energy Auditing and Benchmarking.
    - Methods to assess the energy use of buildings.
    - Ways to Establish Performance Benchmarks.
- Energy efficiency solutions for buildings.
    - Insulation and Building Envelope Design.
    - Thermal insulation systems.
    - Building airtightness.
    - Thermal bridges.
    - Requirements for normative U-values of partitions.
    - Heating, Ventilation, and Air Conditioning (HVAC) Systems.
    - Energy-efficient appliances and equipment, Energy-Efficient Lighting.
    - Renewable Energy Integration.
    - Smart Building Technologies.
    - Passive design solutions.
    - Sustainable Building Materials.
- Future trends in Energy Efficiency.
    - Smart Buildings and the Internet of Things (IoT).
    - Advances in Building Materials and Technology.

In order to evaluate the success of the application, a questionnaire will be held for the students.

3 - Tutorial duration.

The implementation of this tutorial will be carried out through the BIM4ENERGY Project website www.bim4energy.eu by self-learning.

The tutorial is structured to be delivered over:

Total duration: 4 hours.

4 – Necessary teaching recourses.

Computer room with PCs with internet access.

Required software: Microsoft Office.

5 – Contents & tutorial.

5.1 – Introduction to Energy Efficiency.

5.1.1. Basic Definitions.

Energy performance of a building (part of a building) means the calculated amount of energy required to meet the energy demand associated with the normal use of the building, including energy for heating, cooling, ventilation, hot water and lighting of the building [1]. Energy efficiency refers to using less energy to perform the same task or achieve the same output in a building, system, or process. This is accomplished by optimizing how energy is consumed and by minimizing waste [2].

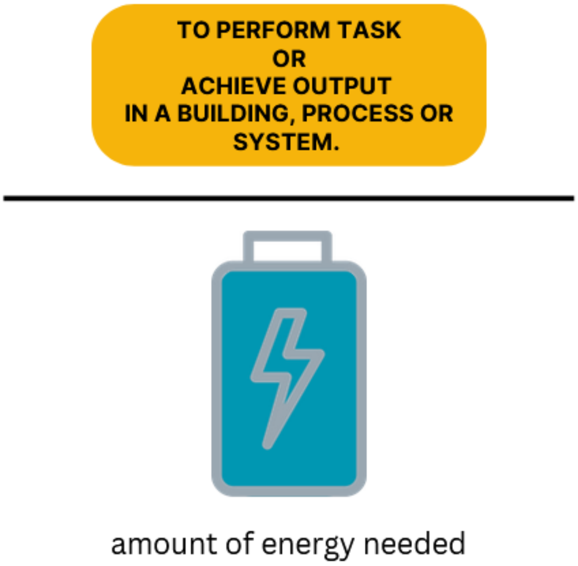


Figure 1 Efficiency.

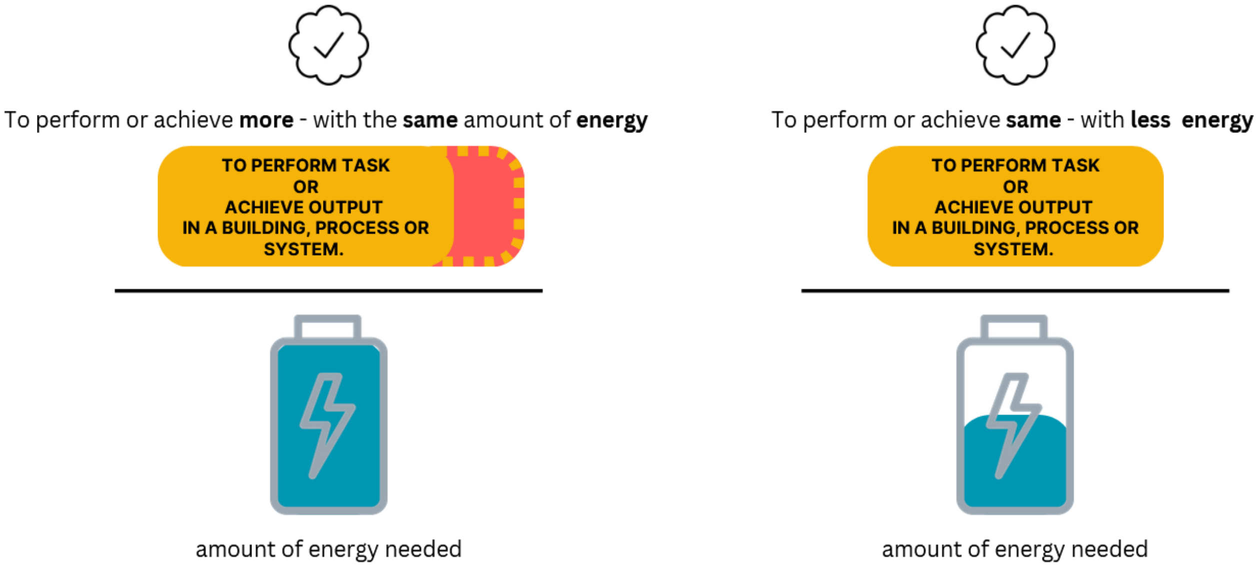
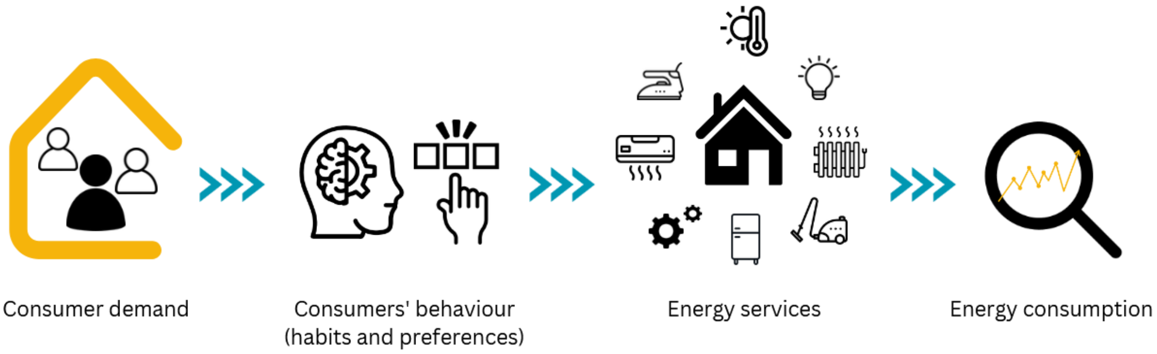


Figure 2 Efficiency improvement.

In buildings, energy efficiency typically focuses on heating, cooling, lighting, and the operation of appliances. A building with high energy efficiency uses less energy for heating, cooling, lighting, and appliances while still providing comfort and functionality for occupants. Rational use of energy resources is one of the most effective ways to reduce energy consumption while minimising environmental impact.

Consumer behaviour influences energy consumption. Each energy consumer uses energy services in ways that are common to him. Behavioural patterns shaped by our surroundings determine our energy consumption patterns and the actions we take as consumers. These actions have a direct impact on the amount of energy consumed. In order to benefit from investments in more efficient equipment, tools and systems, users must use them properly. Energy efficiency targets are achieved through a combination of efficient and energy-saving solutions and changes in consumer behaviour. However, if consumers do not change their energy-wasting habits and ignore energy reduction initiatives, the opportunities for improving energy efficiency are significantly reduced.



Energy-efficient buildings can include residential, commercial, and industrial structures that are designed or retrofitted to meet modern efficiency standards. Achieving energy efficiency often involves improving insulation, using energy-efficient appliances, and optimizing lighting systems. Another key aspect is the building's "envelope," which includes the walls, roof, floors on the ground, windows, and doors that separate the interior from the exterior environment. The design and materials used for the envelope play a crucial role in reducing energy loss. The goal is to reduce overall energy consumption while maintaining or improving building performance. It is also important to distinguish between energy efficiency and energy conservation; the latter involves reducing energy use through behavioural changes, while energy efficiency focuses on technology and system improvements.

When looking at energy efficiency, we need to keep in mind the energy consumed by a product or building throughout its entire life cycle, from production to recycling or refurbishment.

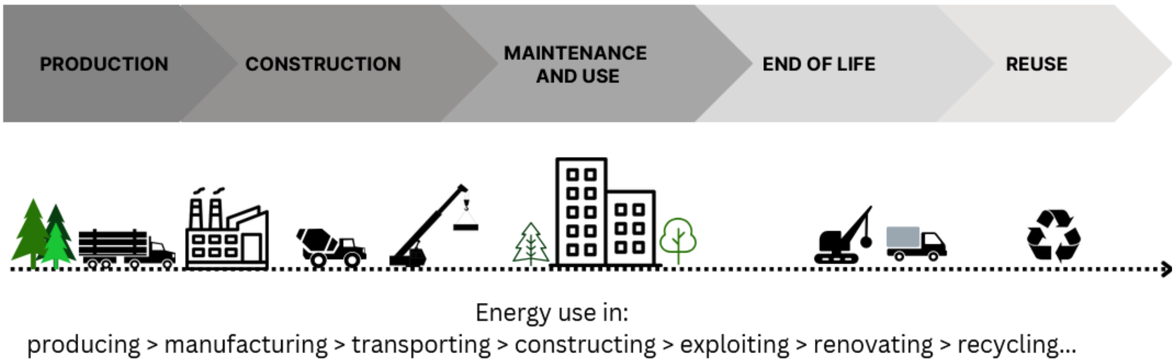


Figure 3 The life cycle and energy consumption of the product or service.

5.1.2. Importance of Energy Efficiency

The built environment has become a key area of focus for reducing carbon emissions and addressing the impacts of climate change. The buildings sector uses energy for constructing, heating, cooling and lighting homes and businesses, as well as the appliances and equipment installed in them. The energy consumption of buildings is a major contributor to global greenhouse gas emissions, with heating being one of the largest energy demands. The importance of energy efficiency in buildings cannot be overstated, as it directly affects both economic and environmental sustainability. Energy-efficient buildings reduce operational costs by lowering energy consumption for heating, cooling, and lighting. In a world facing rising energy prices, improving energy efficiency can offer significant financial savings for building owners and occupants. In particular, when on average 75% of buildings in the EU today are energy inefficient. From a global perspective, increasing energy efficiency is one of the most cost-effective ways to reduce greenhouse gas emissions. Buildings are responsible for a large portion of energy consumption worldwide – approximately 40% of global energy use and related CO2 emissions – so improving efficiency in this sector can have a profound impact [3]. Additionally, energy-efficient buildings provide improved indoor comfort for occupants by maintaining more consistent indoor temperatures and air quality. Energy efficiency also enhances a building's resilience to energy price fluctuations and energy shortages, creating a more stable and predictable energy cost environment. Furthermore, energy-efficient buildings are often more attractive to buyers or tenants due to lower utility bills and the growing preference for sustainable living environments. Another critical factor is that many governments offer incentives, subsidies for improving energy efficiency in buildings, making it an appealing option for property developers and owners. Energy efficiency is also a key to meeting global and local climate goals, such as those outlined in the Paris Agreement, The European Green Deal and EU 2050 long-term strategy [4]. Implementing energy-efficient technologies reduces demand on energy resources, which can also alleviate the need for new power plants or infrastructure upgrades. Energy-efficient buildings also help reduce the load on national energy grids, especially during peak usage times, contributing to greater grid stability. In addition to environmental and economic benefits, energy-efficient buildings contribute to improving public health by reducing air pollution associated with energy production. As energy efficiency becomes more critical, particularly in urban planning and development, it plays a key role in advancing the broader goals of sustainable cities and communities.

5.1.3. Historical Context of Energy Efficiency

Ancient civilizations, such as the Romans and Greeks, implemented passive design strategies like south-facing windows and thick walls to conserve heat during winter and cool their buildings in summer.

Later, with increasing urbanisation and rapidly rising energy demands, energy efficiency in buildings has become much more important. The primary focus was on comfort and functionality, with little regard for how much energy was consumed. However, the 1973 oil crisis was an important turning point that made energy saving and efficiency a key focus of public policy and technological innovation [5]. Faced with rising energy costs and supply shortages, many governments and industries began to explore ways to reduce energy consumption. The concept of energy-efficient buildings started gaining traction, particularly in Europe, where policies and standards were introduced to encourage energy savings. In the 1980s and 1990s, advancements in insulation, window technologies, and HVAC systems made it easier for buildings to achieve higher levels of energy efficiency.

The concept of energy efficiency has evolved significantly over the past few decades, particularly as concerns about energy resources and environmental sustainability have grown. In the early 20th century, buildings were not typically designed with energy efficiency in mind, as energy was relatively inexpensive and abundant. During this period, green building movements such as LEED (Leadership in Energy and Environmental Design) in the United States and BREEAM (Building Research Establishment Environmental Assessment Method) in the United Kingdom emerged [6]. These systems helped establish clear guidelines and standards for energy-efficient building design, construction, and operation. By the early 2000s, the growing concerns over climate change and environmental degradation further accelerated the push for energy efficiency. Governments around the world introduced stricter regulations and incentives for energy-efficient buildings, spurring innovation in materials and technologies.

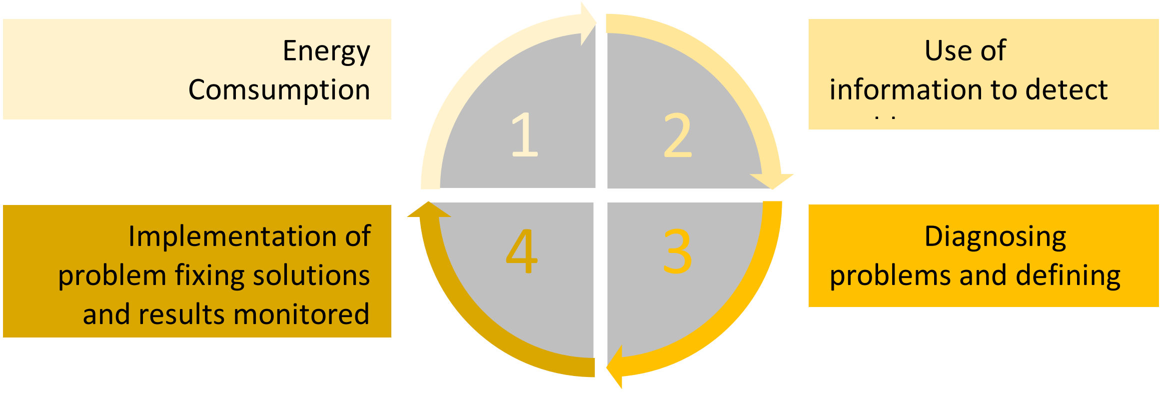
Today, energy efficiency is recognized as a key strategy in achieving sustainability goals, with smart technologies like the Internet of Things (IoT) and building automation playing critical roles in optimizing energy use in modern structures. In recent years, the rise of renewable energy technologies, such as solar panels and wind turbines, has been integrated into energy-efficient building designs.

The historical development of energy efficiency highlights the increasing recognition that buildings, as major consumers of energy, must be designed and operated to minimize their environmental impact. As the field continues to evolve, the lessons of the past provide valuable insights into how modern buildings can balance energy use with the need for comfort and sustainability.

5.2 – Energy Auditing and Benchmarking

Energy auditing and benchmarking are important steps in assessing and improving the energy performance of buildings. Especially in existing buildings, the first step to improve energy efficiency is to measure existing energy consumption. Energy audits provide detailed insight into how energy is consumed, helping identify areas for efficiency improvements [7].

Energy Benchmarking, also known as Energy Performance Tracking, on the other hand, is a way to see where the greatest improvements in energy efficiency can be made. It is often the first step towards achieving long term energy efficiency goals as it defines the building’s energy saving potential. Firstly, it is a process of tracking a building’s energy use and then it involves comparing a building's energy performance against standard metrics or similar structures, enabling a clear understanding of its relative efficiency. Benchmarking allows direct comparisons of building energy use by accounting for variables such as local climate, square footage, occupancy levels and operating hours.



5.2.1. Methods to Assess the Energy Use of Buildings

Several methods are used to assess the energy consumption of buildings, starting with energy audits. Energy audits are typically categorized into three levels:

- **Level 1 (Walk-through Audit):** This is a preliminary audit that involves a visual inspection of the building and a basic analysis of energy consumption. It identifies the most significant energy-saving opportunities with minimal data collection.

- **Level 2 (Energy Survey and Analysis):** Involves a more detailed analysis, including the use of energy bills and basic metering data. It provides a broader understanding of how different systems (lighting, HVAC, etc.) consume energy.
- **Level 3 (Detailed Analysis):** Known as an investment-grade audit, this method involves in-depth data collection and analysis of the building's energy systems. This includes the use of advanced tools such as energy modelling software to simulate energy performance under different conditions.

Another key assessment tool is Building Energy Management Systems (BEMS), which provide real-time data on energy consumption [8]. Additionally, technologies like thermographic inspections help identify thermal losses through walls, windows, and roofs. Sub-metering of specific areas (e.g., lighting, heating, and ventilation) provides a more granular view of energy use. Energy performance certificates (EPCs) also play a role in assessing and rating a building's energy efficiency on a scale, making it easier to understand its overall performance.

5.2.2. Ways to Establish Performance Benchmarks

Establishing benchmarks allows building owners and operators to compare their energy use against similar buildings or predefined standards. One common way to establish performance benchmarks is through energy use intensity (EUI), which measures energy consumption per square foot or meter of the building annually. Lower EUI values indicate better energy efficiency.

Benchmarking tools like the ENERGY STAR Portfolio Manager are widely used to track energy performance and compare it to national or regional standards. In Europe, the Energy Performance of Buildings Directive (EPBD) provides guidelines for energy benchmarking and certification.

LEED and BREEAM certification systems set performance benchmarks for energy use, awarding points based on energy efficiency and sustainability practices. These certifications encourage continuous improvement by offering higher certification levels for greater energy savings.

Another benchmarking method involves comparing a building's energy use to that of similar buildings within a peer group (e.g., similar size, type, or climate zone). This provides context for identifying whether a building is performing above or below industry averages.

Finally, internal benchmarking can be done by comparing the building's current performance to its historical data, allowing the identification of trends in energy use over time. This helps track the success of energy-saving measures.

5.3 – Energy efficiency solutions for buildings

5.3.1 Insulation and Building Envelope Design

The building envelope is critical in determining a structure's overall energy efficiency, as it acts as the barrier between the indoor environment and the external climate. Properly designed and insulated building envelopes help regulate indoor temperatures, reducing the need for excessive heating or cooling. The effectiveness of a building’s envelope relies heavily on insulation and various techniques aimed at minimizing energy loss.

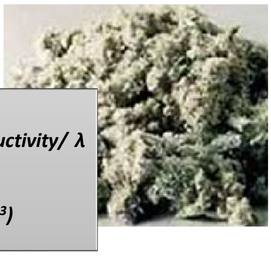
Techniques to Reduce Energy Loss and Improve Thermal Efficiency

There are several key techniques to reduce energy loss and enhance thermal efficiency. First, the use of high-quality insulation materials such as fiberglass, foam, and mineral wool is essential to trap heat inside during winter and keep it out during summer. Air sealing is another critical method, which involves closing gaps and cracks around windows, doors, and other openings to prevent air leakage and drafts. Additionally, double-glazed or triple-glazed windows offer enhanced insulation by creating an insulating layer of air or gas between panes, reducing heat transfer. In warmer climates, reflective roofing materials can help minimize heat absorption, while green roofs add insulation and naturally cool the building. Thermal breaks in structural components, like steel or concrete, can help interrupt the conduction of heat through the building's frame. The installation of vapour barriers also prevents moisture build up, which can degrade insulation performance over time. For more comprehensive strategies on optimizing the building’s thermal envelope, refer to the tutorial on building thermal envelope, which provides detailed guidance.

Comparison of different insulation materials:

WOOD FIBRE

- *Thermal conductivity/ λ (W/m^2K)*
  0.038
- *Density (kg/m^3)*
  30 – 300



CELLULOSE

- *Thermal conductivity/ λ (W/m^2K)*
  0.038 - 0.040
- *Density (kg/m^3)*
  30 - 80

WOOL

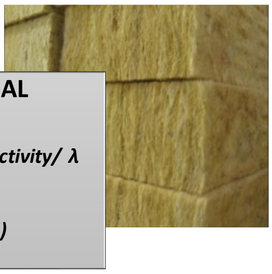
- *Thermal conductivity/ λ (W/m^2K)*
  0.038
- *Density (kg/m^3)*
  12 - 30

HEMP

- *Thermal conductivity/ λ (W/m^2K)*
  0.039 - 0.040
- *Density (kg/m^3)*
  20 - 190

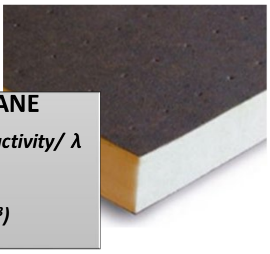
GLASS WOOL

- *Thermal conductivity/ λ (W/m^2K)*
  0.035
- *Density (kg/m^3)*
  10 - 70



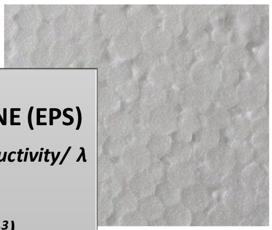
ROCK MINERAL WOOL

- *Thermal conductivity/ λ (W/m^2K)*
  0.032 - 0.044
- *Density (kg/m^3)*
  20 - 200



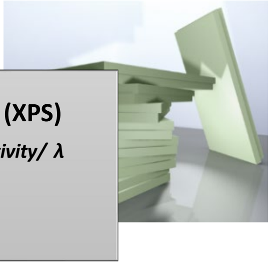
POLYURETHANE

- *Thermal conductivity/ λ (W/m^2K)*
  0.023 - 0.026
- *Density (kg/m^3)*
  25 - 100



EXPANDED POLYSTYRENE (EPS)

- *Thermal conductivity/ λ (W/m^2K)*
  0.034 - 0.038
- *Density (kg/m^3)*
  10 - 50



EXTRUDED POLYSTYRENE (XPS)

- *Thermal conductivity/ λ (W/m^2K)*
  0.014
- *Density (kg/m^3)*
  25 - 65

CORK

- *Thermal conductivity/ λ (W/m^2K)*
  0.036 - 0.06
- *Density (kg/m^3)*
  100 - 220

To learn more about building thermal envelope go to **Building thermal envelope** tutorial.

5.3.2. Thermal insulation systems

External Thermal Insulation Composite System – or ETICS – is a compact multilayer insulation solution designed to improve the energy efficiency of both new and existing buildings. It is sometimes known as EIFS (Exterior Insulation Finish System).

This external wall insulation system is made from many layers, including a base coat, reinforced mesh and finishing coat. Continuous external insulation improves thermal performance and reduces thermal bridges, storing heat in the walls to create a more comfortable living environment. The types of materials used can vary between systems, making it flexible to fit different building structures and designs.

Figure 4 https://globalescolha.pt/servicos/sistema-etics/

External Thermal Insulation Composite Systems (ETICS) can incorporate both conventional and eco-friendly materials to improve a building's energy efficiency while minimizing environmental impact. Common insulation materials include expanded polystyrene (EPS), extruded polystyrene (XPS), and mineral wool, which offer good thermal resistance. However, sustainable alternatives are becoming more popular. Cork and wood fibre insulation panels, for example, are renewable, biodegradable, and have a lower environmental footprint. Hempcrete and cellulose are other green options that provide excellent insulation while using natural, recycled materials. Over the insulation, a reinforcing base coat, typically made of cement or polymer-modified mortar, is applied with fiberglass mesh for stability. Eco-friendly mortars, using lime or clay-based mixtures, are also used in green ETICS systems. The final finishing layer, which offers protection and aesthetic appeal, can include breathable, natural coatings such as lime, clay, or plant-based renders. These green materials enhance the sustainability of the building while maintaining the core benefits of insulation and durability.

5.3.3. Building airtightness

Proper air tightness provides excellent thermal and acoustic comfort. It also helps protect the building from potential deterioration caused by water vapor infiltration through convection into structural elements. Additionally, it minimizes energy losses by preventing unintended ventilation through air leaks.

Key areas to focus on include:

- Overlapping membranes and the contact points between sheets and plates.
- Connections between the roof and walls, as well as any penetrations through the roof.
- Connections between windows, doors, and walls.
- All types of penetrations through the airtight layer and vertical shafts.

The air tightness is measured using a blower door test, which creates a pressure difference of 50 Pascals between the interior and exterior of the structure. This pressure allows the measurement of the air exchange rate.

5.3.4. Thermal bridges

Thermal bridges are areas in a building's structure where heat transfer occurs at a higher rate than through the surrounding materials, leading to increased energy loss. These typically happen at points of discontinuity, such as where different construction elements meet, like wall-to-floor junctions, roof edges, or around windows and doors.

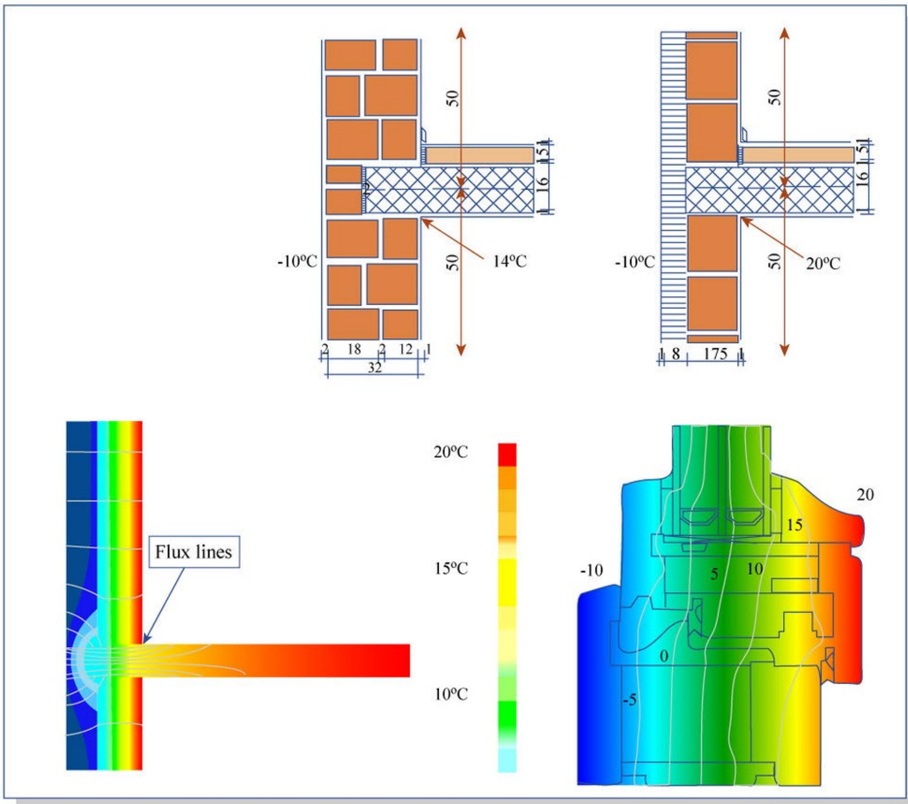


Figure 5. https://www.flickr.com/photos/mitopencourseware/3039165614/in/photostream/

Because they disrupt the continuity of insulation, thermal bridges can significantly reduce the overall energy efficiency of a building. They also create cold spots on interior surfaces, which can lead to condensation, mould growth, and potential structural damage over time. Effective design and construction practices, such as ensuring proper insulation and eliminating gaps between building materials, can help minimize the occurrence of thermal bridges. Addressing thermal bridges is crucial not only for energy savings but also for maintaining the durability and comfort of a building.

5.3.5. Requirements for normative U-values of partitions

In order for buildings to be constructed in compliance with the highest requirements, the heat transfer values of individual building structures are regulated. Also, in order to reduce the use of energy resources, the requirements are getting stricter. New buildings must comply with energy class A or higher.

Such elements as roofs, walls, floors on the ground (above unheated spaces), windows are regulated and it varies between the countries. Table below shows the minimal regulated requirements for different building elements:

U-values for:	Lithuania	Norway	Romania	Spain
Roof structures	0,16	0,18		
Wall structures	0,20	0,22		
Floors on the ground (above unheated spaces)	0,25	0,18		
Windows	1,60	1,20		

5.3.6. Heating, Ventilation, and Air Conditioning (HVAC) Systems

Together with lighting, these systems typically account for a large amount of a building's energy use, making them prime targets for efficiency improvements.

Ventilation: Optimizing ventilation involves installing heat recovery ventilation (HRV) systems, which reclaim energy from exhaust air and use it to precondition incoming fresh air. Variable air volume (VAV) systems can also modulate airflow based on demand, reducing unnecessary energy use.

Figure 6. https://pixabay.com/photos/hall-roof-ventilation-2560454/

Heating and Air Conditioning Efficiency: Improving heating and cooling efficiency can be achieved by using high-efficiency boilers and air conditioners that consume less energy while delivering the same level of comfort. Heat pumps, which transfer heat instead of generating it, are highly efficient and ideal for both heating and cooling in many climates. Ensuring proper insulation around HVAC ducts and using energy-efficient windows also helps to minimize heat loss and reduce HVAC load.

For HVAC systems, regular maintenance is key to ensuring that equipment runs efficiently. Changing filters, cleaning ducts, and inspecting components regularly can prevent energy waste. Installing programmable thermostats or smart controls allows for better temperature management, adjusting heating or cooling based on occupancy or time of day. Implementing zoning systems enables different areas of a building to be heated or cooled independently, reducing energy use in unoccupied spaces.

For further information, go to tutorial Efficient HVAC systems and Energy Vectors.

5.3.7. Energy-efficient appliances and equipment, Energy-Efficient Lighting

Energy-efficient appliances and equipment play a pivotal role in reducing a building's overall energy consumption and environmental impact. Modern appliances, such as ENERGY STAR-rated refrigerators, air conditioners, and washing machines, are designed to operate using significantly less electricity and water than their conventional counterparts, lowering utility costs and greenhouse gas emissions. Similarly, energy-efficient HVAC systems and smart thermostats help optimize heating and cooling by adjusting temperatures according to occupancy and outdoor conditions, minimizing unnecessary energy use. Light sources (lamps) are the largest Ecodesign product group in terms of installed units. In 2020, almost 11 billion lamps were in use in Europe, which is more than 24 lamps per EU27 citizen. Although a single light source uses a relatively small amount of energy compared to other Ecodesign products, the huge quantity of installed products makes lighting the third largest energy consumer (following industry components and space heating), covering 8% of the primary energy accounted in EIA for year 2020.

Comparison of different types of light bulbs used:

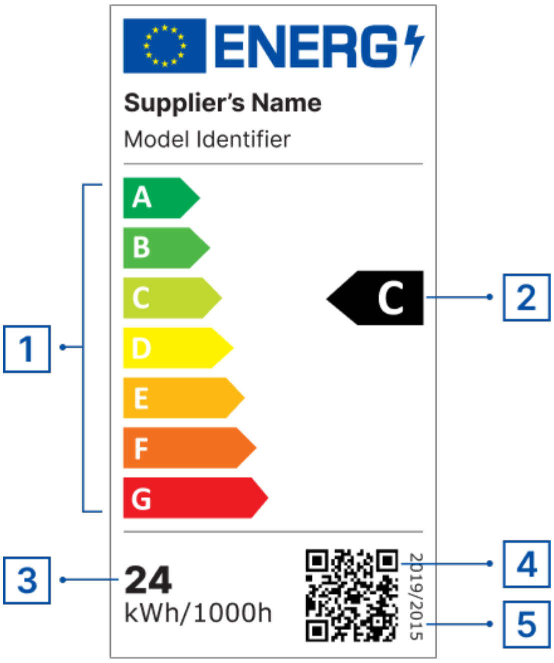
LED - Light Emitting Diode	LFL - Linear Fluorescent Lamp	CFL - Compact Fluorescent Lamp	Tungsten (Halogen, HL)	GLS - General Lighting Service
Efficiency 80 – 140 lm/W. Expected > 200 lm/W in future.	Efficiency of 80 – 90 lm/W	Efficiency 50-70 lm/W.	Typical efficiencies 12 to 20 lm/W.	Efficiency around 10 lm/W.
				

In addition to appliances, energy-efficient lighting is crucial for sustainable building design. LED lighting, which uses up to 75% less energy than traditional incandescent bulbs and lasts much longer, is now widely adopted in both residential and commercial buildings. These lighting solutions can be enhanced with smart controls, such as motion sensors and daylight-responsive dimming, to further reduce energy consumption by automatically adjusting based on room occupancy or natural light levels. By incorporating these advanced technologies, buildings can achieve substantial energy savings, reduce carbon footprints, and contribute to a more sustainable future. Building energy use can be considerably decreased by using energy-efficient equipment and appliances, such as those with the Energy Star rating. These appliances offer the same or better performance than their conventional counterparts while running more effectively.

Energy Label

Following the rescaling of the EU energy label for light sources from 1 September 2021, the new labels use a scale from A (most efficient) to G (least efficient). Because of the constant improvement in energy efficiency, most products under the original label had risen to A+ or A++ - and so a rescaling was made in order to be clearer to the consumer about which are the most efficient products on the market. The labels provide information on the product’s energy efficiency class and energy consumption.

The European Product Registry for Energy Labelling (EPREL) offers detailed information on models placed on the EU market by scanning the QR code featured on the new energy labels. The database provides information such as the luminous flux, colour temperature and cap type. The label is also available in monochromatic version. The label can be printed as part of the packaging.



1	Scale of energy efficiency classes from A to G
2	The energy efficiency class of this product.
3	Energy Consumption of the light source in on-mode, expressed in kWh of electricity consumption per 1 000 hours.
4	QR Code
5	The number of this Regulation that is '2019/2015'

Figure 7 https://energy-efficient-products.ec.europa.eu/product-list/light-sources_en

For further information, go to tutorial Building energy efficiency and Green Certifications.

5.3.8. Renewable Energy Integration

Integrating renewable energy sources into building designs is a important step toward achieving energy efficiency and reducing the environmental impact of buildings. Renewable energy systems, such as solar, wind, and geothermal, allow buildings to produce clean energy on-site, reducing reliance on fossil fuels and lowering greenhouse gas emissions.

Overview of Solar, Wind, and Other Renewable Energy Sources for Buildings

- **Solar Power:** Solar energy is the most common renewable source for buildings, primarily harnessed through photovoltaic (PV) panels. PV panels convert sunlight directly into electricity and can be installed on rooftops, façades, or as part of solar farms. Solar thermal systems, which use the sun's heat to produce hot water or power HVAC systems, are also effective for improving energy efficiency. With decreasing costs of solar panels and government incentives, solar integration has become increasingly viable for both residential and commercial buildings.

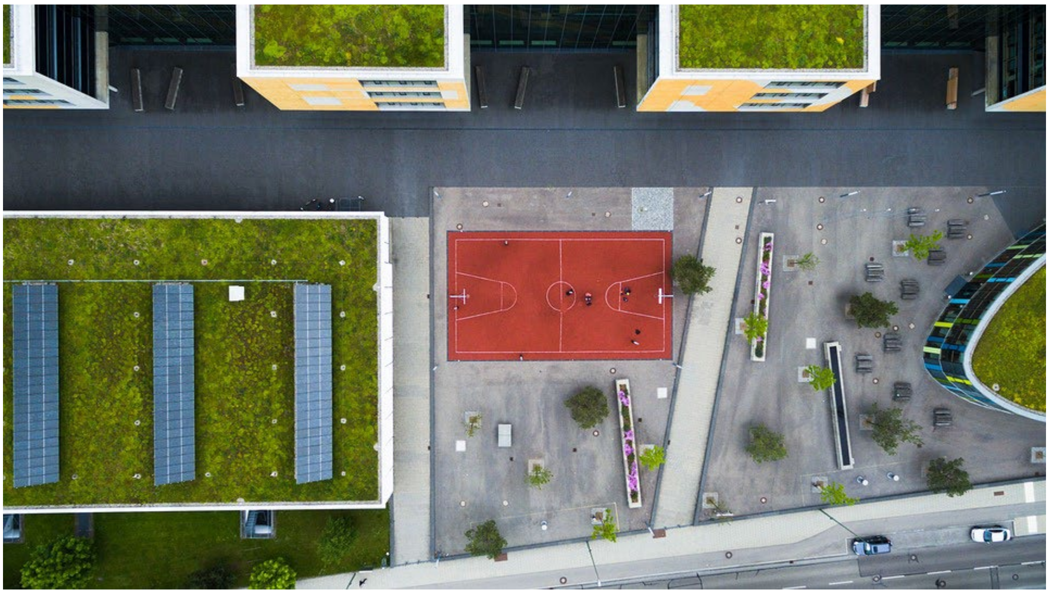


Figure 8 [https://pixabay.com/photos/architecture-building-residences-2564183/].

- **Wind Power:** Wind energy is typically used in larger-scale applications but can also be integrated into buildings through small-scale wind turbines. These turbines are usually mounted on rooftops or nearby open spaces, where wind patterns are strong. Although less common in urban areas due to space and noise considerations, wind energy is an excellent option for buildings located in rural or coastal regions with consistent wind flows.

Figure 9. https://pixabay.com/photos/wind-power-landscape-clouds-heaven-1357419/

- **Geothermal Energy:** Geothermal systems harness heat from the earth to provide energy-efficient heating and cooling for buildings. Geothermal heat pumps transfer heat between the building and the ground, offering a highly efficient way to regulate indoor temperatures with minimal energy use. These systems work year-round and are especially beneficial for larger buildings or facilities with constant heating or cooling needs.

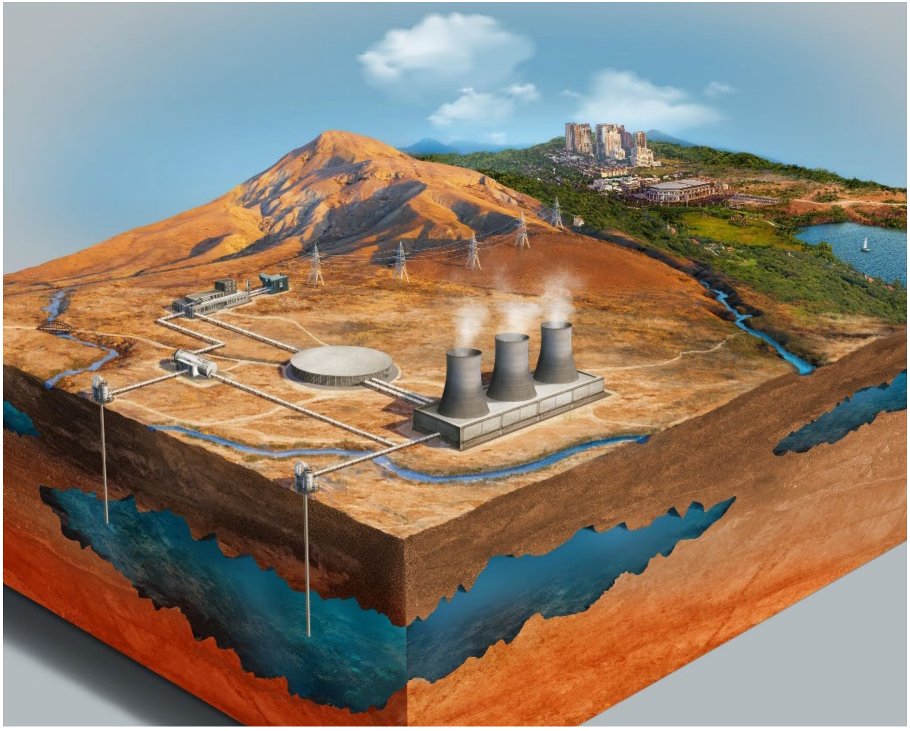


Figure 10. https://www.freepik.com/free-photo/high-angle-model-renewable-energy-with-geothermal-power_16713400.htm#fromView=search&page=1&position=1&uuid=df846b64-5988-45fb-8c9b-714b1b6f46e0

- **Other Sources:** Other renewable energy options for buildings include biomass systems, which use organic materials to generate heat and electricity, and hydropower, though the latter is more site-specific and limited to buildings located near bodies of water. Hydrogen fuel cells are also emerging as a clean energy solution for buildings, producing electricity through chemical reactions without combustion.

5.3.9. Smart Building Technologies

Smart building technologies are transforming how buildings operate, enabling more efficient energy use through the integration of advanced automation, sensors, and smart grids. These technologies enhance energy efficiency by providing real-time monitoring and control, enabling dynamic adjustments to energy systems, and optimizing resource use based on building occupancy and external conditions.

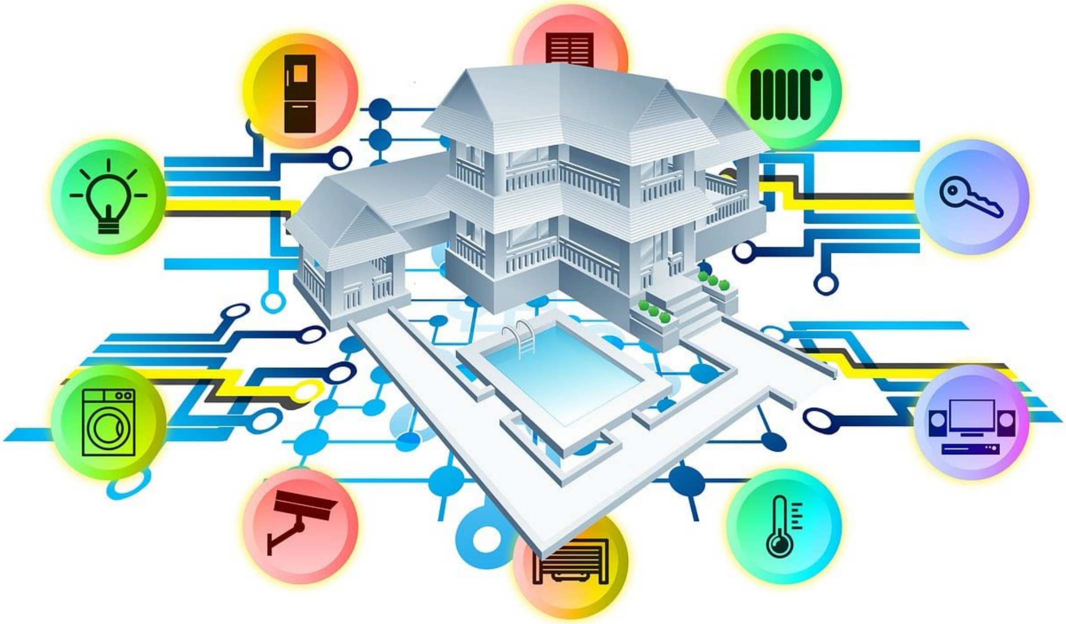


Figure 11. https://pixabay.com/illustrations/smart-home-house-technology-2769239/

Use of Automation, Sensors, and Smart Grids to Improve Energy Efficiency

- **Automation:** Automation in smart buildings allows for the intelligent control of heating, cooling, lighting, and ventilation systems without human intervention. By using Building Management Systems (BMS), buildings can automatically adjust HVAC settings, lighting levels, and window shading based on pre-set parameters such as time of day, occupancy, or even weather conditions. This reduces energy consumption by ensuring that systems are only in use when needed and at optimal levels.
- **Sensors:** Sensors play an important role in smart buildings by providing real-time data on a range of factors such as occupancy, temperature, humidity, and light levels. Occupancy sensors can detect when a room or area is empty and adjust the lighting or HVAC systems accordingly, turning them off or reducing their output. Temperature sensors can adjust HVAC systems to maintain comfortable indoor environments while minimizing energy use. Daylight sensors automatically dim or switch off artificial lighting when sufficient natural light is present.
- **Smart Grids:** Smart grids integrate renewable energy sources, such as solar or wind power, into building systems and allow buildings to communicate with the broader energy grid. Through the use of smart meters and dynamic pricing, buildings can shift energy usage to off-peak times when energy is cheaper or more abundant, further reducing costs and the load on the grid. Smart grids also enable demand response programs, where buildings adjust their energy consumption in response to grid signals, such as reducing usage during peak demand periods to avoid grid strain and reduce energy waste.

By incorporating automation, sensors, and smart grid technologies, buildings can significantly reduce their energy consumption, lower operational costs, and contribute to a more sustainable energy system.

5.3.10. Passive design solutions

Buildings that use passive design make the most of natural lighting, heating, and cooling. Mechanical systems can be kept to a minimum by employing techniques like orientation, shading, natural ventilation, and thermal mass use. Passive design increases tenants' comfort and well-being while reducing energy usage.

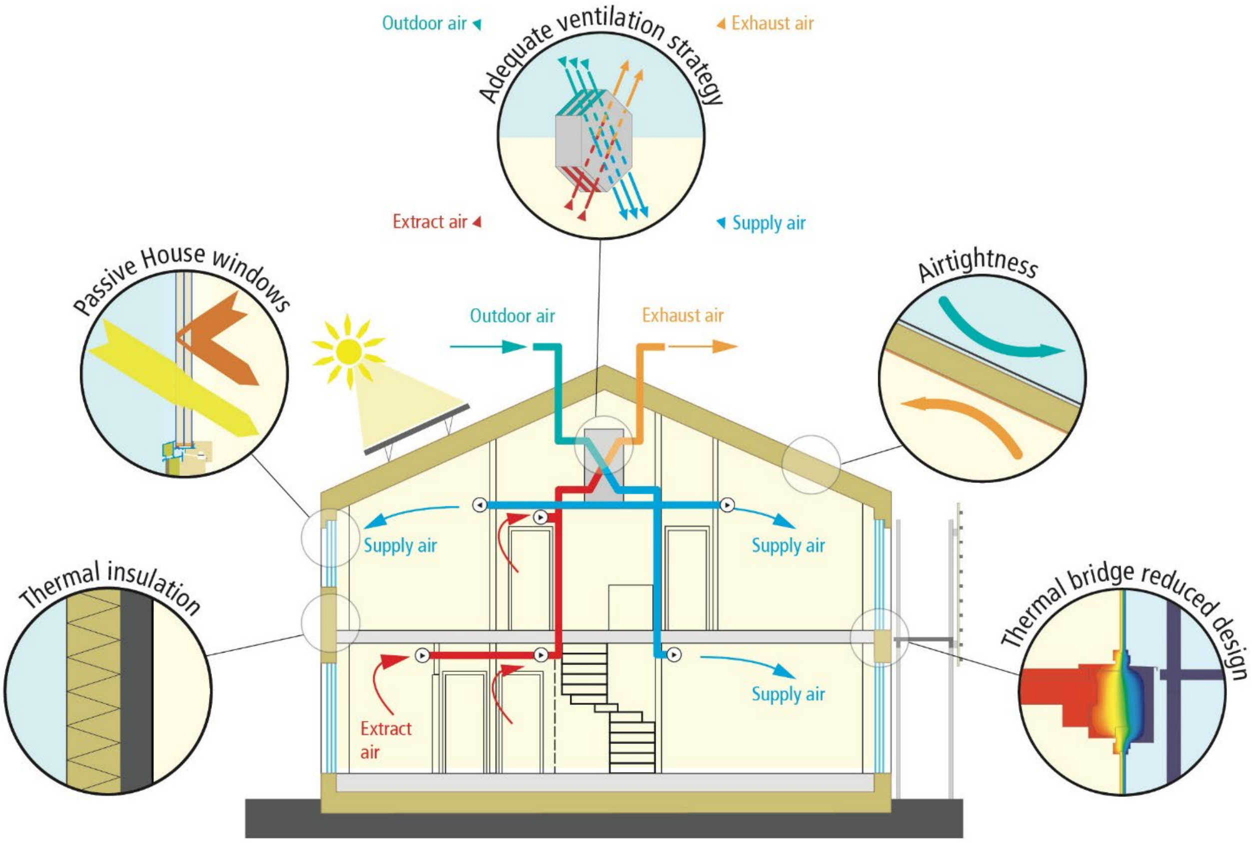


Figure 12. Diagram of the five main principles applied to Passive House construction (Passive House Institute, n.d.)

The orientation of a building plays a huge role in its energy efficiency and overall comfort. By strategically positioning a structure to maximize natural sunlight, especially in colder climates, passive solar heating can be optimized, reducing the need for artificial heating. South-facing windows (in the Northern Hemisphere) can capture the most sunlight, while shading devices or overhangs help control overheating during the summer. In warmer climates, orienting the building to minimize direct sun exposure can keep interiors cooler and reduce air conditioning needs. Wind direction and ventilation are also important factors, as proper orientation can promote natural cooling and airflow. Overall, thoughtful building orientation helps balance heating, cooling, and lighting needs, significantly enhancing a structure's environmental performance.

5.3.11. Sustainable Building Materials

Sustainable building practices are increasingly turning to the use of local materials as a key strategy for improving energy efficiency and reducing environmental impact. Local materials, sourced from nearby regions, offer a dual benefit: they significantly reduce the energy expended in transportation while also supporting the local economy. By using materials readily available in the area, builders can cut down on long-distance supply chains, which are often associated with high carbon emissions due to fuel consumption in transportation. This not only reduces the overall environmental footprint of construction but also minimizes delays and disruptions in the supply chain, making the building process more resilient and cost-effective.

In addition to the focus on local sourcing, the concept of the circular economy plays a vital role in enhancing sustainability. A circular approach to construction involves designing buildings with materials that can be reused, recycled, or repurposed at the end of their lifecycle. This reduces the demand for raw materials and helps in conserving natural resources. For example, materials like reclaimed wood, recycled steel, or repurposed concrete can be used to build new structures without the need for extensive processing. This not only lowers the embodied energy of the building materials—meaning the energy used in their extraction, production, and transportation—but also reduces construction waste, which is a significant contributor to landfill and environmental degradation.

Figure 13. https://pixabay.com/illustrations/recycle-recirculate-share-555645/

Moreover, incorporating principles of the circular economy supports closed-loop systems, where materials are continuously cycled through reuse and recycling processes. This contrasts with the traditional linear economy, where resources are extracted, used, and then discarded. By keeping materials in use for longer, the circular economy minimizes resource extraction, reduces waste, and ultimately enhances the energy efficiency of buildings, both in construction and during their operational life. In this way, sustainable building materials, particularly when sourced locally and used within a circular economy framework, not only reduce the environmental impact but also contribute to energy-efficient, resilient, and long-lasting structures. Sustainable building materials are essential for minimizing the environmental impact of construction and improving the overall energy efficiency of buildings. By using eco-friendly and energy-efficient materials, builders can reduce energy consumption, lower carbon emissions, and create healthier indoor environments. These materials are typically sourced from renewable resources or are designed to have a lower environmental footprint over their lifecycle.

By incorporating eco-friendly and energy-efficient materials, buildings can achieve significant energy savings, reduce their environmental impact, and contribute to the broader goals of sustainable development. For more in-depth coverage of these materials, refer to the tutorial on sustainable and energy-efficient construction materials.

5.4 – Future trends in Energy Efficiency

5.4.1. Smart Buildings and the Internet of Things (IoT)

Smart buildings use advanced technologies to automate and optimize various systems such as heating, cooling, lighting, and security. A key technology enabling this is the Internet of Things (IoT), which connects devices like sensors, thermostats, and meters to the internet, allowing them to collect and share data. In smart buildings, IoT plays important role in improving energy efficiency by continuously monitoring real-time conditions, such as temperature, occupancy, and energy usage. For example, smart thermostats can adjust heating and cooling based on whether rooms are occupied, while smart lighting systems can turn lights on or off depending on movement or the amount of natural light available. These systems help reduce energy waste by ensuring that the building only uses energy when and where it is needed. Additionally, IoT devices can help identify inefficiencies by providing data that can be analysed to predict equipment failures or recommend maintenance, further improving the building's overall energy performance. As we explore smart buildings further, we'll see how these technologies are reshaping the way we think about energy use in modern buildings.

Figure 14 https://pixabay.com/illustrations/computer-technology-connected-8045000/

In today's rapidly evolving technological landscape, smart buildings are at the forefront of innovations aimed at improving energy efficiency and sustainability in the built environment. A smart building integrates advanced automation systems that control various aspects of building operations—such as heating, ventilation, air conditioning (HVAC), lighting, and security systems—making the building more responsive to real-time needs and conditions. The key enabler of these capabilities is the Internet of Things (IoT), a network of interconnected devices that can communicate with one another to collect, exchange, and analyse data.

At its core, IoT technology relies on sensors, meters, and other connected devices to gather information about a building's performance. These devices monitor parameters like temperature, humidity, energy consumption, and occupancy levels, providing real-time data that can be used to optimize the building's energy use. For example, IoT sensors can detect when rooms or spaces are unoccupied, triggering smart systems to adjust or turn off lighting and HVAC systems to conserve energy. By making energy use more responsive to actual building conditions, IoT helps prevent energy waste, which is crucial in the context of sustainability and cost reduction.

One of the most common applications of IoT in smart buildings is in HVAC management. Traditional heating and cooling systems often run continuously, regardless of whether spaces are occupied or whether the temperature needs to be adjusted. Smart thermostats, connected through IoT, can automatically adjust the temperature based on real-time occupancy data, weather conditions, and even historical patterns of building usage. These adjustments ensure that energy is used more efficiently, reducing unnecessary consumption while still maintaining a comfortable environment for occupants.

Lighting systems in smart buildings also benefit from IoT integration. Smart lighting, equipped with motion sensors and daylight harvesting technologies, can automatically adjust the intensity and duration of lighting based on occupancy and natural light availability. For example, lights can dim or turn off when no one is present, or adjust their brightness to complement the amount of sunlight streaming in through windows. This not only reduces energy consumption but also enhances occupant comfort by providing optimal lighting conditions.

In addition to HVAC and lighting, IoT technology enables other smart building features that improve energy efficiency, such as predictive maintenance. IoT sensors can monitor the performance of building systems and detect early signs of wear or malfunction in equipment like boilers, air conditioning units, or elevators. By identifying problems before they result in major inefficiencies or failures, these systems can trigger maintenance alerts, allowing facility managers to address issues proactively. This minimizes downtime and ensures that building systems continue to operate at peak efficiency.

Beyond individual systems, IoT allows for the creation of a centralized energy management system (EMS) that monitors and controls all the building’s connected devices. An EMS can analyse data from across the building to identify trends, suggest energy-saving measures, and automate decision-making processes. For example, the system might analyse energy consumption patterns and suggest scheduling adjustments for heating and cooling based on when different areas of the building are typically in use. This holistic approach to energy management maximizes efficiency by coordinating the operation of multiple systems to work together rather than independently.

The data generated by IoT devices is also valuable for long-term energy planning. Facility managers can use historical data to track energy use over time, identify inefficiencies, and set more precise energy-saving goals. For example, analysing trends in energy consumption during different seasons or at different times of day can reveal opportunities for improvement, such as adjusting HVAC settings to better align with actual usage patterns. Furthermore, this data can be used to benchmark the building’s energy performance against industry standards or regulatory requirements, helping to ensure compliance with energy efficiency goals.

Overall, the integration of IoT in smart buildings offers a powerful solution to the challenge of reducing energy consumption while maintaining occupant comfort and operational efficiency. By continuously monitoring building conditions and making real-time adjustments to energy use, IoT-enabled systems can significantly reduce waste and lower energy costs. As buildings become more complex and energy efficiency becomes a higher priority, the role of IoT in smart building technology is expected to grow, providing even more opportunities for innovation in the design and operation of energy-efficient buildings.

In summary, IoT transforms traditional buildings into smart, responsive environments where energy use is optimized through automation and data-driven decision-making. By connecting devices, collecting real-time data, and automating systems like HVAC, lighting, and maintenance, IoT helps make buildings more efficient, sustainable, and cost-effective. As we move further into the digital age, the integration of IoT technology will be a key factor in the continued development of energy-efficient buildings, reducing environmental impact and contributing to a more sustainable future.

5.4.2. Advances in Building Materials and Technology

Energy efficiency in buildings has become a critical focus for architects, engineers, and construction professionals as the global demand for sustainable and eco-friendly buildings continues to rise. Advances in building materials and construction technologies are playing a vital role in achieving higher energy performance, reducing carbon footprints, and improving overall building sustainability. From innovative insulation materials to smart windows and advanced construction techniques, these developments are reshaping the way we think about energy efficiency in the built environment.

High-Performance Insulation Materials:

One of the most important advances in building materials for energy efficiency is the development of high-performance insulation. Traditional insulation materials, such as fiberglass, have been widely used for decades, but new materials are offering superior thermal performance while minimizing energy loss. Aerogels, for example, are ultra-lightweight materials known for their excellent insulating properties. Despite being extremely thin, aerogels can provide significantly better insulation than conventional materials. Similarly, vacuum-insulated panels (VIPs) are becoming popular for use in walls and roofs due to their ability to deliver high insulation values while taking up less space. These advanced materials help reduce the amount of energy needed for heating and cooling by limiting the transfer of heat between the inside and outside of buildings.

Phase Change Materials (PCMs):

Another innovative material used for improving energy efficiency in buildings is phase change materials (PCMs). PCMs have the ability to absorb and store thermal energy during the day and release it during cooler periods, such as at night. By regulating indoor temperatures naturally, these materials reduce the need for artificial heating and cooling, thus lowering energy consumption. For example, a building wall embedded with PCMs can absorb heat during the day and release it at night, keeping indoor spaces more comfortable without relying heavily on HVAC systems.

Smart Glass and Dynamic Windows:

Windows are often a source of significant energy loss in buildings, but advances in glass technology are helping to mitigate this. Smart glass, also known as electrochromic or dynamic glass, can automatically adjust its transparency based on the amount of sunlight or heat it is exposed to. During hot weather, the glass can darken to reduce the amount of heat entering the building, lowering the need for air conditioning. In colder conditions, the glass can become clearer, allowing more sunlight to penetrate and naturally warm the interior. This dynamic response to environmental conditions enables buildings to maintain a stable indoor temperature with less energy consumption. Furthermore, low-emissivity (Low-E) coatings on windows improve energy efficiency by reflecting heat back into the building in the winter and keeping heat out during the summer.

Green Roofs and Living Walls:

Advances in green building technologies have also led to the development of green roofs and living walls, which provide both aesthetic and energy-saving benefits. Green roofs, covered with vegetation, help to insulate buildings by absorbing heat, providing natural cooling, and reducing the urban heat island effect. This reduces the amount of energy needed to cool a building in the summer. Similarly, living walls—vertical gardens installed on building exteriors—can improve insulation and reduce energy costs by shading walls and regulating temperatures naturally. In addition to improving energy efficiency, these green features also contribute to improved air quality and biodiversity in urban environments.

Prefabrication and Modular Construction:

New construction technologies, such as prefabrication and modular construction, are contributing to energy efficiency by improving the precision and speed of the building process. Prefabricated building components, such as walls, floors, and roof sections, are manufactured in controlled environments, which allows for tighter construction tolerances and better integration of energy-efficient materials. This reduces the risk of air leaks and thermal bridging, which can significantly impact a building's energy performance. Modular construction, where entire sections of a building are constructed off-site and then assembled on-site, also reduces waste and ensures that buildings are more energy-efficient by design. These methods enable the integration of advanced insulation, high-efficiency windows, and airtight construction from the start.

Advanced HVAC Systems and Building Technologies:

The integration of advanced heating, ventilation, and air conditioning (HVAC) technologies with building materials also plays a significant role in improving energy efficiency. For example, radiant heating and cooling systems, where pipes are embedded in the floor or ceiling, provide more efficient temperature control than traditional forced-air systems. These systems work particularly well when combined with high-performance insulation and thermal mass materials that store and radiate heat. Additionally, smart building technologies that integrate IoT systems can enhance energy efficiency by monitoring and optimizing building systems such as HVAC, lighting, and water heating in real-time.

The continuous evolution of building materials and technologies offers numerous opportunities to enhance the energy efficiency of modern buildings. From innovative insulation solutions like aerogels and PCMs to dynamic windows, green roofs, and precision construction techniques, these advances are helping to reduce energy consumption while improving comfort and sustainability. As these materials and technologies become more widely adopted, they will play an essential role in creating buildings that not only meet but exceed energy efficiency standards, contributing to a more sustainable and resilient built environment.

6 - Deliverables

To evaluate the success of the application, students will have to answer an online questionnaire.

7- What we have learned

Basic understanding about energy efficiency in buildings.

Various passive and active solutions applied in the building to achieve better energy efficiency.

Get acquainted with future energy efficiency in buildings trends and advancement of materials and technologies.

8 - References

1. Technical construction regulation STR 2.01.02:2016 *Energy performance design and certification of buildings*. D1-754 Dėl statybos techninio reglamento STR 2.01.02:2016 „Pastatų energinio naudingumo projektavimas ir... (accessed 2024 06 07)

2. Energy efficiency. https://www.eea.europa.eu/en/topics/in-depth/energy-efficiency (accessed 2024 06 07).

3. European Commission. *In focus: Energy efficiency in buildings*. https://commission.europa.eu/news/focus-energy-efficiency-buildings-2020-02-17_en (accessed 2024 06 07).

4. European Commission. *2050 long-term strategy*. https://climate.ec.europa.eu/eu-action/european-climate-law_en (accessed 2024 06 07).

5. Deringer, J. J., Iyer, M., & Huang, Y. J. (2004). Transferred just on paper? Why doesn't the reality of transferring/adapting energy efficiency codes and standards come close to the potential. In *Proceedings of the 2004 American Council for an Energy-Efficient Economy (ACEEE) Summer Study on Energy Efficiency in Buildings.*

6. *Sustainable building certifications: an overview*. https://hagergroup.com/en/blog/sustainability/sustainable-building-certifications (accessed 2024 06 10).

7. Martinaitis, V., Rogoža, A. ir Šiupšinskas, G. (2012). *Energijos vartojimo pastatuose auditas*. Vilnius: Technika. 124 p.

8. Kylili, A., Fokaides, P. A. (2015). *European smart cities: The role of zero energy buildings*. Sustainable Cities and Society. Volume 15, 86 -95 p.

Figure Front page https://pixabay.com/illustrations/save-energy-energy-saving-7382276/
Figure 1 https://globalescolha.pt/servicos/sistema-etics/
Figure 2. https://www.flickr.com/photos/mitopencourseware/3039165614/in/photostream
Figure 3. https://pixabay.com/photos/hall-roof-ventilation-2560454/
Figure 4 https://energy-efficient-products.ec.europa.eu/product-list/light-sources_en
Figure 5 [https://pixabay.com/photos/architecture-building-residences-2564183/].
Figure 6. https://pixabay.com/photos/wind-power-landscape-clouds-heaven-1357419/
Figure 7. https://www.freepik.com/free-photo/high-angle-model-renewable-energy-with-geothermal-power_16713400.htm#fromView=search&page=1&position=1&uuid=df846b64-5988-45fb-8c9b-714b1b6f46e0
Figure 8. https://pixabay.com/illustrations/smart-home-house-technology-2769239/
Figure 9. Diagram of the five main principles applied to Passive House construction (Passive House Institute, n.d.)
Figure 10. https://pixabay.com/illustrations/recycle-recirculate-share-555645/
Figure 11 https://pixabay.com/illustrations/computer-technology-connected-8045000/