Spread of Innovative Solutions for Sustainable Construction

Handbook

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Co-funded by the Erasmus+ Programme of the European Union

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Introduction

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Introduction

Most people have very limited knowledge about the environmental impacts and their causes in general and especially related to the construction industry. Hence four international professional organisations teamed up in October 2019 to start the project IS-SusCon funded by the Erasmus + program.

The project outcomes are both online and offline education materials. These shall be easy to use and to understand with the aim to improve the users' background knowledge and environmental awareness. The content includes easy-to-read concept descriptions, practical examples, suggestions and best practices for non-experts. In addition to the present handbook a website (https://www.oneclicklca.com) is also available for comparison of the building materials and potential cost-saving solutions.

The coordinator of the project is the LCA Centre (http://howtobuildgreen.eu/en/webapp-3). LCA Centre Hungarian Association of Life Cycle Analysts is working in the field of environmental protection with the aim to introduce life cycle analysis and to promote environmentally conscious way of thinking.
ÉMI Non-Profit Llc for Quality Control and Innovation in Building (www.emi.hu) is Hungary's largest complex institute in the construction and building materials industry. Its activities are issuing technical approvals and assessments, testing, inspection, expert reports, research and development, certification and trainings for professionals from blue collar workers to engineers and inspectors.
One Click LCA Ltd (oneclicklca.com), formerly Bionova Ltd., is the developer of the cloud software One Click LCA, which is specializing in construction life-cycle metrics and circular economy. The software is used in projects in 100+ countries and supports 40+ rating/certification systems and standards.
Ecoinnovazione is an Italian based consultancy firm, born as a research spin-off of ENEA, offering tailor-made life-cycle based sustainability assessments for private and public entities.

In this handbook we briefly describe the relation of the building and its surroundings (Chapter 1), as well as the materials, structures, and building services systems (Chapter 4 and 6) that contributes to the forming and operating of the house., Moving on from simple conceptions, we summarise in detail why and how our buildings affect their environment and what sustainable construction stands for (Chapter 1). Our book presents the scientific method used to quantify and measure sustainable construction, life cycle assessment (Chapter 2), which makes different materials, structures,buildings, and even settlements comparable. We discuss in separate chapters (Chapter 3) the opportunities to improve sustainability at different stages of a building's life, during design, use, maintenance, renovation, and demolition, and then, describe such currently-known passive- (Chapter 5) and active solutions (Chapter 6), which are considered good and recommended. In the annexes, we regrouped the descriptions and properties of the most typical building materials and we present some already implemented, good examples from the participating countries.

We would like to emphasize that the issues raised shall be examined in a complex way; there are no absolute solutions. Each solution has its advantages and disadvantages. For example, no matter how perfect a building technology solution may seem in terms of energy savings, if its noise causes difficulties for the neighbourhood's life in case of a densely built-in area. However, in such a case when the nearest neighbours are out of hearing distance or the architectural sound insulation solutions could reduce the noise load to a tolerable degree, this technology may also end up as the right choice, for instance

It is quite difficult to phrase how should we relate to the environment. At first glance, it seems really simple: trying not to harm the environment and to use only as much from the goods provided by nature as it is really needed. But if we think about it again these are more complex queries. What do we understand under wasting and not wasting? If it is clear that it is not sufficient to care about the present and to think about the future, but it is also true on the other way around: we cannot live without consuming and building anything in the present and just save everything for the future. The challenge is rather to find the right balance: how much can we use now from the natural resources without depriving the present, but also leaving enough for our descendants. Our handbook aims to help in finding this balance and solving the problems outlined above by providing basic information.

The information written in this manual is intended to increase the reader's knowledge. Our target group is the public, young adults visiting housing events and webpages, everybody who is involved in house building or renovation. We recommend that you study and rethink the contents of the book carefully, without taking anything for granted and turn to professionals and specialists for more accurate and specific information. Doubt is the freedom of thought and everyone shall make their own decisions accordingly.

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1

The Building and its Environemnt

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1 The Building and its Environment

The preparation of the construction starts with the conception of the idea, when the owner(s) decides that they want to build a house. There may be several reasons behind this decision, which cannot be detailed here, in any case, after polishing the sparks of thought and refining the ideas, the basic decisions have to be made at this stage. A design program must be developed, a designer be picked and a decision shall be taken regarding where to build the house. It is recommended to do these three processes parallelly, at the same time, approximately. It is a common case that the construction site is a starting point, however, if it is possible to choose from several plots, it is useful to involve the designer in the process and finalize the planning program together, considering the possible locations. The building site and the design program, which is the basic idea behind the future house, interact closely with each other, just as the designer has a significant impact on both. Unfortunately, it is often neglected, but the designer plays a key role in the whole construction process, so it is highly important to select the right architect and, of course, further specialist designers. The best solution is if they form a team. In order to design an energy- and environment-conscious house, it is essential for the designers to be committed to sustainable construction, as well as they possess qualification and in-depth knowledge in this area. Besides that, of course, the skills and knowledge needed to achieve architectural, construction- and technical quality are essential, as well as a sense of reality and empathy for the builder's budget.

At first glance, it may seem that we have set the bar very high, but we are pleased to announce that there are many designers working in Hungary (and in Europe as well) who meet the conditions described above.

1.1 The environmental load of buildings

The environmental impact of buildings is significant in terms of energy consumption and greenhouse gas emissions, as well as waste generation. This is especially true when looking at the entire life span of a building (from building material production, through construction and use to demolition).
(see chapter 2 for Life Cycle Assessment)

Sustainability is difficult to define. It means that we use only the necessary amount of resources. The aim is to protect, maintain the current state and prevent further destruction of air, soil, surface and groundwater, wildlife (plants, animals) and the landscape, as well as the built environment while supporting the health and wellbeing now and in the future.

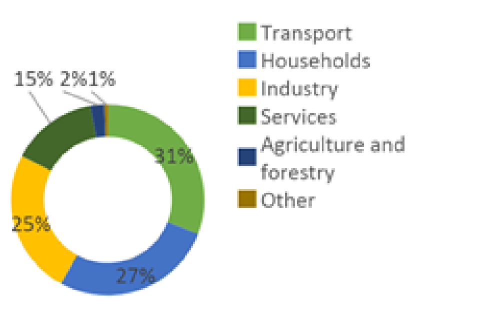

Figure 1: Total energy consumption by sector, 2017[*1]*

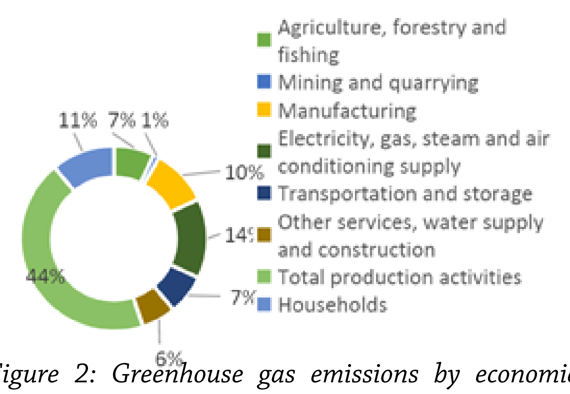

Figure 2: Greenhouse gas emissions by economic activity, 2016[2]

In Europe, the industrial sector accounts for 24.6% of the total energy consumption and 36.4% of waste generation, in which construction plays a significant role. In addition, 27.2% of the total energy consumption, 11% of the greenhouse gas emissions and 8.5% of the waste generation come from households.[3]

1 Source of data: Eurostat Statistical Books Energy, transport and environment statistics, 2019
2 Source of data: Eurostat Statistical Books Energy, transport and environment statistics, 2019
3 Eurostat Statistical Books, Energy, transport and environment statistics, 2019

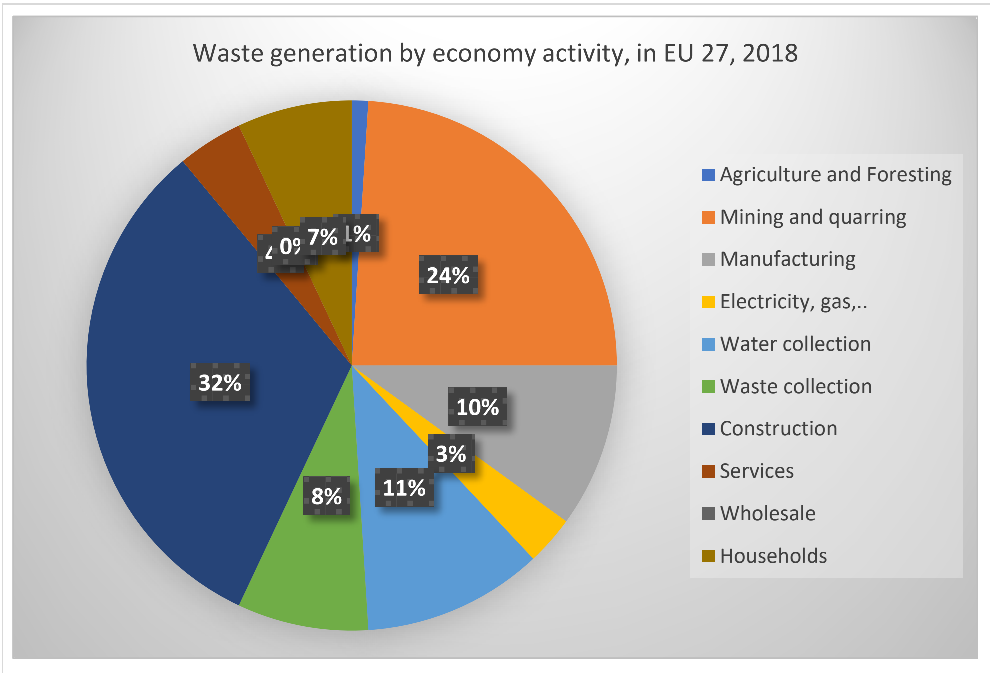

Figure 3 : Waste generation by economic activity, in EU27, 2018[4]

For this reason, it is important to dedicate attention to reducing the environmental impact during both construction and the use of buildings. Looking at the entire life cycle of a building construction accounts for 50-80% of the total environmental load (the ratio depends largely on the energy-related properties of the building, for example thermal insulation, heating system). Most of the energy consumption, on the other hand, occurs during use.

During building use, energy consumption is divided between different functions. In an average European household, 64.1% of total energy consumption is used for heating, 14.8% for hot water production, 14.4% for lighting and other electrical appliances, 0.3% for cooling and 0.9% makes up for other consumers. It can be seen that the most energy-intensive element is heating (although this depends largely on the local climate as well as the characteristics of the buildings). For this reason, during the construction and renovation of buildings, a great emphasis is placed on reducing the need for heating energy (with thermal insulation and efficient cooling systems). But it is not only large-scale interventions that can reduce energy consumption of households.

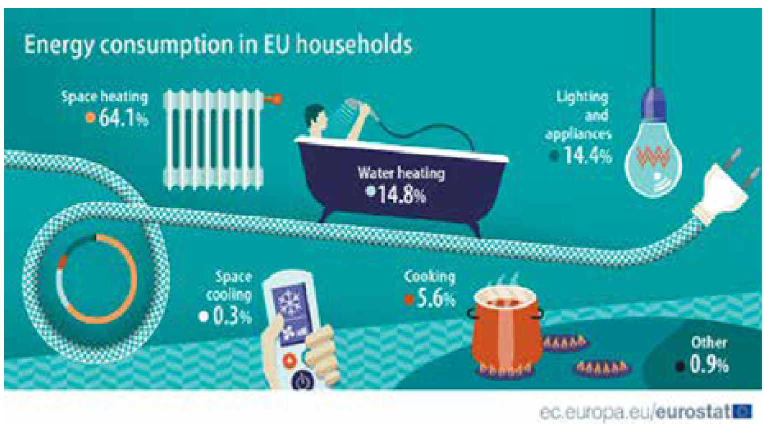

Figure 4: Energy consumption in EU households[5]

4 Source of data: Eurostat Statistical Books Energy, transport and environment statistics, 2019
5 Source: Eurostat Statistical Books, Energy, transport and environment statistics, 2019

In many cases, smaller investments (e.g. replacing light bulbs with energy-saving ones), as well as changing consumer behaviour (e.g. preferring natural daylight) can also make a significant difference. See Chapter 6 for further suggestions.

However, it matters which source the energy comes from. On one hand, the type of energy (e.g. electricity, heat) is an important environmental aspect, and on the other hand so is the energy source which this energy is produced with (e.g. solar energy, natural gas). It is important to strive to use the given energy carrier in the most efficient way and, in parallel, to produce the required energy with the least environmental load (e.g. natural gas can be used more efficiently for heating than electricity generation, and electricity can be generated with less environmental load with solar panels as a coal-fired power plant). To achieve this, the aspects of environmentally conscious construction must be taken into account during the design of the building, the selection of building materials and building services systems as well.

More specific statistics related to the building sector in terms of waste generation and use of resources are available here:

in English:
https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_2&format=PDF

in Hungarian:
https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0003.02/DOC_1&format=PDF

https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0003.02/DOC_2&format=PDF

1.2 Sustainable construction

The construction industry is facing new challenges. Sustainability in this case depends on achieving the lowest possible environmental impact, while encouraging social and economic development. Society demands new infrastructure, a reduction in the consumption of energy and resources, and the implementation of sustainable or "green" constructions.

Following the definition provided by Charles J. Kibert, sustainable construction is "the creation and responsible management of a healthy-built environment based on resource efficient and ecological principles".[6] In comparison with the traditional concerns in construction (performance, quality, cost), the criteria of sustainable construction has become resource depletion, environmental degradation and healthy environment and there were also 6 principles set for it:

- Minimise resource consumption (Conserve)
- Maximise resource reuse (Reuse)
- Use renewable or recyclable resources (Renew/Recycle)
- Protect the natural environment (Protect Nature)
- Create a healthy, non-toxic environment (Non-Toxics)
- Pursue quality in creating the built environment (Quality)

From the point of view of **environmental impact**, a sustainable construction involves

- The design and management of built structures, whether at the scale of build ings, infrastructure, or urban agglomerations
- The performance of materials across all scales and throughout their whole use-cycles
- The use of renewable energy resources, as well as their related technologies in building, operation and maintenance to reduce global greenhouse gas emissions.

6 Charles J. Kibert: Sustainable Construction

From the point of view of **economic impact**, sustainable construction involves regarding renewable energy generation, the transition from a linear to a circular economy recycling material and waste, water harvesting and preservation, transferability of technologies, and the adaptability of structures to changes in use; innovative financing models premised on an economy of means that yields more with less; and the reinvestment of returns back into the common domain for collective benefit.

From the point of view of **social impact**, sustainable construction involves adherence to the highest ethical standards in business, as well as to industry practices throughout all project phases; the promotion of socially-viable living and working environments, including occupational health and safety standards for labour forces and users; and the democratization of all processes pertaining to the production and use of the built environment as a commonwealth.

A building finalised by a circular-solution method is built without wasting resources, polluting the environment and damaging the ecosystem, and it can be recycled after use. It is built in an economically responsible way, contributing to the well-being of people and the biosphere. Circular buildings generally have a positive impact on materials, energy, waste, biodiversity, health and well-being, on human culture and society.

Regarding sustainable construction, we have to consider, on one hand the building stock, our built heritage, which we cannot eliminate for technical, cultural or economic reasons, nor can we replace them with new ones, and on the other hand, the limiting factors that frame our ideas when implementing new facilities.

In terms of the built environment, the existing building stock accounts for - by far - the most carbon emissions and where the greatest opportunities for savings can be found.

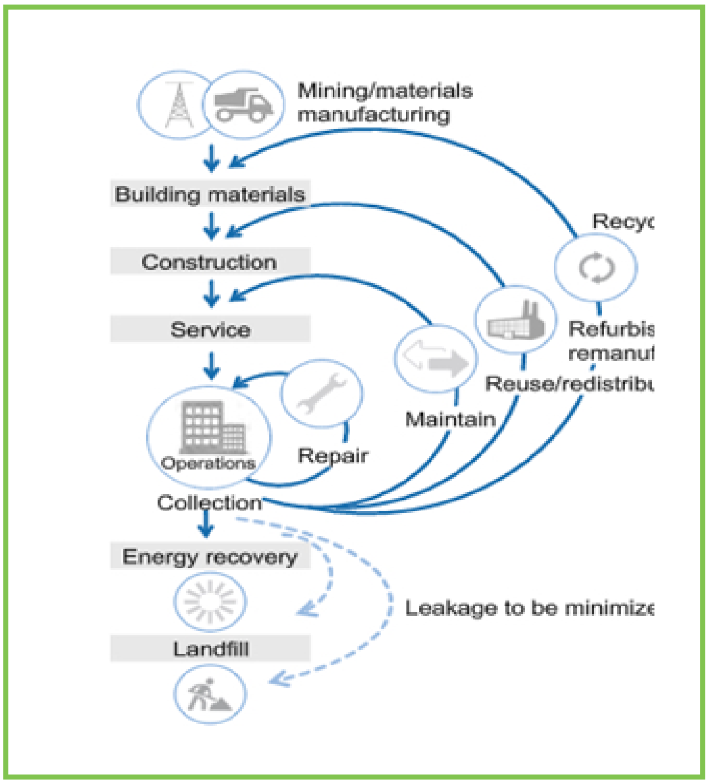

Figure 5: Circularity in building industry[7]

7 Source: Ellen MacArthur Foundation; World Economic Forum; Boston Consulting Group

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2 Life Cycle Assessment

IS-SusCon

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2 Life Cycle Assessment

2.1 What is life cycle assessment (LCA)?

Life cycle approach and LCA

Our everyday life has direct and indirect impacts on the environment. **Direct impacts** are quite clear and evident: whenever we directly take a raw material from our surrounding environment, or something gets directly into the soil, surface waters or burns into the air, have a direct impact. For example, when one has a garden and that person takes ground water from an own well or puts fertilizers into the soil or pesticides on the plants. Or when someone burns gas in their boiler or wood in their stove, smoke appears in the chimney representing their direct air emissions.

It is more difficult to understand our **indirect impacts** as they do not happen in front of our eyes. These impacts are "hidden" and so they can be even more dangerous if we are not aware of them.

Where are these indirect impacts? They are related to the many products we use during our life, meaning food, clothing, building materials, electricity, transport etc. All these products have been produced somewhere in the world and then transported to us. These production and transport processes have their own direct impacts: on a larger scale, resource extraction activities can lead to serious resource depletion, water scarcity or deforestation; emissions of greenhouse gases leads to climate change, while emission of other substances may cause acid rains, smog or eutrophication. When we use these products, we are indirectly responsible for these damages to the environment.

After the usage of the products, there can be different types of wastes: transport and treatment of these waste – such as landfill disposal, incineration, recycling or reuse - have also their direct impacts, which are also unseen from our homes.

If we call this long chain and network of processes – production, transport, usage, end of life – as “life cycle” of a product then we can understand all impacts with “**life cycle approach**”.

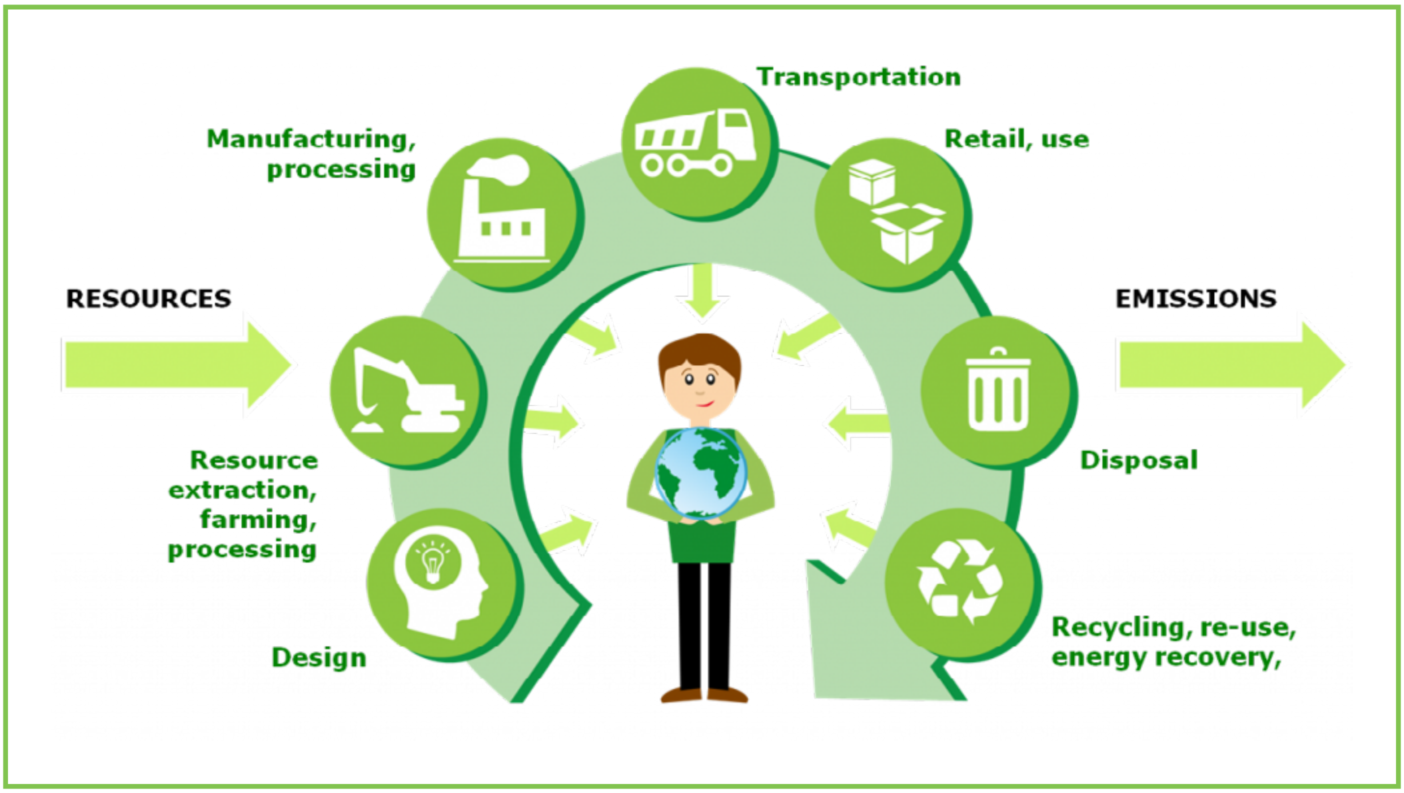


Figure 6: Life cycle approach[8]

Life Cycle Assessment (LCA) is a standard method to quantify potential impacts applying such a life cycle approach. LCA gives us numbers that help to manage our environmental impacts: we can identify the so called “hot spots” where our impact is the highest, and so it spots where and how can we achieve the highest possible reduction of our direct or indirect impacts.

8 Source: https://areeweb.polito.it/ricerca/LCA/ (last access in April 2021)

If we understand our impacts in depth with a life cycle approach, and we can quantify them through LCA, then we realize our decision-power to reduce these impacts. The kind of products we purchase and use and the amount may significantly influence our environmental impacts. Think of all the materials, energy sources, transporting services that we use during our everyday life! We can make plenty of decisions to decrease our direct, but mainly our indirect impact by using a life cycle approach.

The phases of LCA

LCA is called also as a "from cradle to grave" analysis, but according to the concept of circularity "from cradle to cradle" would be more appropriate. LCA is a special science where experts can work on LCA with software and database with huge number of processes.

According to the ISO 14040 and ISO 14044[9] standards an LCA shall include the following phases:

- **goal and scope definition,**
- **inventory analysis**, when resources consumptions and emissions of the life cycle are quantified,
- **impact assessment**, when potential environmental impacts due to resource consumptions and emissions are assessed,
- **interpretation** of results.

The connection of these phases can be seen in the following figure of the ISO 14040 standard:

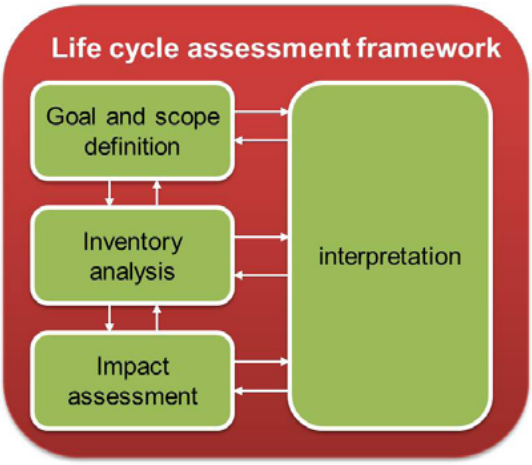


Figure 7: Methodological steps according to ISO 14040[10]

9 ISO 14040/14044 (2006): Environmental management — Life cycle assessment — Principles and framework / Requirements and guidelines
10 Source: ISO 14040

The process of preparing an LCA is perfectly covered in keywords by the ISO 14040 standard. Based on this, we need to clarify the goal of the analysis at the beginning of the work, namely why the analysis is performed (for example, we wish to make our operations more sustainable and therefore we wish to reduce our environmental impact; we wish to communicate to our customers our commitment to the environment by declaring the environmental performance values of our activities etc.) The answer to this first question influences also the definition of the additional initial aspect, i.e., what is the scope of the analysis:

- **functional unit:** e.g.: one piece of product, 1m^2 surface of product; 1-year production, etc. for which we calculate the results expressing the environmental impact,
- **system boundaries:** considering only our own activity (from gate to gate) or including the previous phases (from cradle to gate), or the whole life cycle (from cradle to grave), etc.

In practice, the **data collection** represents the most important part in the preparation of an analysis - it determines the data quality - and it is also the most time-demanding step. The best and most recommended approach is to collect the data related to the activity directly: that is to collect the manufacturing data of the product under investigation. It is also possible to work with secondary data for other life cycle processes: calculated and estimated data, industry data, databases, literature data, etc.

The analyst is taking then the further steps in the LCA: inventory analysis, impact assessment, and interpretation of the results. As a matter of course, these steps are also strongly influenced by the goals defined in the first step, as it determines for example, the applied impact assessment method or impact category (e.g. carbon footprint), and the interpretation of the results and possible definition of recommendations as well.

An environmental life cycle assessment most often considers the following impact categories:

▶ **climate change:**

The impact category is known by different names: global warming impact, climate change, carbon footprint depending on the chosen impact assessment method and the targeted audience. Our everyday speech uses most often the carbon footprint value, but also the name "climate change" is frequently applied. How should we interpret the results of this category? In each case, the quantities of greenhouse gases released into the atmosphere are aggregated and assessed in kg CO_2 equivalent. This simply means that 1 kg of carbon dioxide emission is considered as 1 kg of CO_2 equivalent in this category. Any other greenhouse gases are weighted differently. For example, the value of methane is currently (in 2021) 36.8 kg of CO_2 equivalent. The time of the data / analysis is also important as 15 years ago, this value was only 21 kg CO_2 equivalent in the same category. It also shows that the effects of climate change has become more serious; they are present in our daily lives and are strongly influencing our future. Different multipliers are applied also to the other greenhouse gases, for example the potential release of 1 kg of freon-12 (difluorodichloromethane) into the atmosphere would mean a 11500 kg CO_2 equivalent. (In fact, this material was removed due to this reason from the refrigerant in old refrigerators.)

The results of the other **impact categories** are calculated in a similar way. An equivalent has been determined for each one, to which the weights of the other relevant elements were compared and then summed, so that the impact category can be characterized by one number:

- acidification (e.g. SO_2 kg or mol H + equivalent),
- eutrophication (e.g. PO_4, P or N kg equivalent),
- ozone depletion (e.g. CFC-11 equivalent),
- resource depletion (e.g. kg Sb equivalent),
- photochemical ozone formation (e.g. ethylene or NMVOC " non-methane volatile organic compounds equivalent),
- human, aquatic, terrestrial, marine ecotoxicity (complex equivalent types exist).

IMPACT CATEGORIES 1(*)

Climate Change

Covered environmental issue: All inputs or outputs that result in greenhouse gas emissions. The greatest contributor is generally combustion of fossil fuels such as coal, oil and natural gas. The consequences include increased average global temperatures and sudden regional climatic changes. Climate change is an impact affecting the environment on a global scale.

This impact category can be further subdivided in:
• Climate change fossil that covers greenhouse gas emissions originated from the transformation or degradation of fossil fuels (i.e. combustion)
• Climate change biogenic that covers greenhouse gas emissions originated from the transformation or degradation of biomass
• Climate change land use change that covers carbon uptakes by the soil or the biomass and emissions originating from carbon stock changes caused by land use change and land use, such as deforestation, road construction or other soil activities
Unit of measurement: Kilogram of Carbon Dioxide equivalent (kg CO_2 eq).

Ozone Depletion

Covered environmental issue: The stratospheric Ozone (O_3) layer protects us from hazardous ultraviolet radiation (UV-B). Its depletion can have dangerous consequences in the form of increased skin cancer cases in humans and damage to plants. The stratospheric ozone depletion is an impact which affects the environment on a global scale. Unit of measurement: kilogram of CFC-11 equivalent (kg CFC-11 eq).

Acidification

Covered environmental issue Acidification has contributed to a decline of coniferous forests and an increase in fish mortality. Acidification can be caused by emissions getting into the air, water and soil. The most significant sources are combustion processes in electricity, heating production and transport. The contribution to acidification is greatest when the fuels contain a high level of Sulphur. Acidification is an impact which mainly affects the environment on a regional scale.
Unit of measurement: Mole of Hydron equivalent (mol H+ eq).

(*)https://ec.europa.eu/environment/eussd/smgp/communication/impact.htm (last assess: April 2021)

IMPACT CATEGORIES 2(*)

Eutrophication freshwater

Covered environmental issue: Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). If algae grow too rapidly, it can leave water without enough oxygen for fish to survive. Nitrogen emissions into the aquatic environment are caused largely by fertilisers used in agriculture, but also by combustion processes. The most significant sources of Phosphorus emissions are sewage treatment plants for urban and industrial effluents and leaching from agricultural land. Eutrophication is an impact which affects the environment at local and regional scale.

Unit of measurement: kilograms of Phosphorus equivalent (kg P eq).

Eutrophication -marine

Covered environmental issue: Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). As a rule, the availability of one of these nutrients will be a limiting factor for growth in the ecosystem, and if this nutrient is added, the growth of algae or specific plants will be increased. For the marine environment this will be mainly due to an increase of nitrogen (N). Nitrogen emissions are caused largely by the agricultural use of fertilisers, but also by combustion processes. Eutrophication is an impact which affects the environment at local and regional scale.

Unit of measurement: kilogram of Nitrogen equivalent (kg N eq).

Eutrophication - terrestrial

Covered environmental issue: Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). These nutrients cause a growth of algae or specific plants and therefore, limit the growth in the original ecosystem. Eutrophication is an impact which affects the environment at local and regional scale.

Unit of measurement: Mole of Nitrogen equivalent (mol N eq).

(*)https://ec.europa.eu/environment/eussd/smgp/communication/impact.htm (last assess: April 2021)

IMPACT CATEGORIES 3(*)

Photochemical ozone formation - human health

Covered environmental issue: While stratospheric ozone protects us, ozone on the ground (in the troposphere) is harmful: it attacks organic compounds in animals and plants, it increases the frequency of respiratory problems when photochemical smog ("summer smog") is present in cities. Photochemical ozone formation is an impact which affects the environment at local and regional scale.

Unit of measurement: kilogram of Non-Methane Volatile Organic Compound equivalent (kg NMVOC eq).

Resource use, mineral and metals and energy carries

Covered environmental issue: The Earth contains a finite amount of non-renewable resources, such as metals, minerals and fossil fuels like coal, oil and gas. So, extracting a high concentration of resources today will force future generations to extract lower concentration or lower value resources. For example, the depletion of fossil fuels may lead to the non-availability of fossil fuels for future generations.
The impact categories that analyse this phenomenon are:

• Resource use, mineral and metals that covers the depletion of metal and minerals

Unit of measurement: kilogram of Antimony equivalent (kg Sb eq)

• Resource use, energy carriers that covers the depletion of fossils fuels

Unit of measurement: MJ of energy.

Water scarcity

Covered environmental issue: The withdrawal of water from lakes, rivers or groundwater can contribute to the 'depletion' of available water. The impact category considers the availability or scarcity of water in the regions where the activity takes place.

Unit of measurement: cubic metres (m3) of water use related to the local scarcity of water.

(*)https://ec.europa.eu/environment/eussd/smgp/communication/impact.htm (last assess: April 2021)

So in the LCA practise we should answer the following three questions at the beginning of the analysis:

Questions	Example answer
What is the goal?	I would like to know the carbon footprint of my insulation product
What is the functional unit?	1m^2 insulation (100mm thickness) with 0,0389 W/m°K thermal conductivity
What are the system boundaries?	From cradle to gate – from the production of base materials to the end of the manufacturing process

If an LCA expert can get the important information for the assessment from the owner, following that the real impacts can be defined. In this example, the most important result is the carbon footprint, but an LCA also can determine many other potential impacts on the ecosystems, humans and natural resources.

Returning to the example: the carbon footprint of the examined insulation can be 6 kg CO_2eqv. divided in 3 parts: the pre-manufacturing of the base materials (5 kg CO_2eqv.), the transport of the base materials to the factory (0,5 kg CO_2eqv.) and the manufacturing of the insulation product (0,5 kg CO_2eqv.). As a comparison: manufacturing one loaf of bread has about 1,5kg CO_2 equivalent.

All of these data and results are summarized in an LCA study, which finally contains also the interpretation of the results.

The life cycle approach and assessment provide the basis of other evaluation methods, e.g.: EPD – Environmental Product Declaration (see details in Ch.2.3a), PEF – Product Environmental Footprint or LCC – Life Cycle Costing, etc. Which one we use depends on the goal of the LCA.

2.2 The role of LCA in the construction industry

LCA is one of the most effective methods for assessing the environmental impact of building products and constructions. Application of LCA has two primary benefits:

- It helps the consumer and construction professionals in their decisions from design through the construction process by objective information.
- It encourages manufacturers to improve the environmental performance and quality of their product through the innovation.

An LCA shows the amount of energy necessary to a building or the amount material saving possible over the life of the building, as well as how they have a positive impact on environment during investment and maintenance.

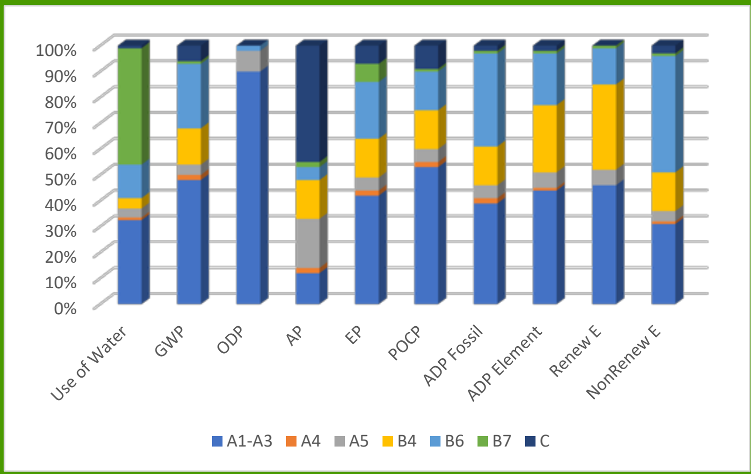
The role of LCA has increased in the construction industry in recent years, given that the **construction sector is one of the most burdensome sectors** in terms of both resource use and environmental impact. 36% of the global energy consumption and 39% of emissions are related to the construction sector and buildings (IEA & UN 2019[11]). Construction accounts for 11% of global CO_2 emissions (WGBC, 2019[12]). Reducing loads requires a more in-depth, life-cycle approach to material flows. It is no coincidence that in the construction sector, in addition to energy efficiency, the goal has been to build near-zero or zero-energy buildings. This is true for both newly built and renovated buildings.

11 IEA & UN (2019): 2019 Global Status Report for Buildings and Construction: Towards a zero-emission, efficient and resilient buildings and construction sector https://www.unenvironment.org/resources/publication/2019-global-status-report-buildings-and-construction-sector (las access in April 2021)
12 World Green Building Council (2019): Bringing Embodied Carbon Upfront https://www.worldgbc.org/bringing-embodied-carbon-upfront-report-webform (last access in April 2021)

Impact of building life cycle:

The examination of the environmental performance of buildings over their entire life cycle can be applied to the following stages (ISO EN 15643): from the extraction of building materials and raw materials to their production and transport, the installation phase "A1-A5", the use phase "B1-7" and the end of life after the demolition of the building "C1-C4".

*Relative contribution of building life cycle stages to environmental impacts **



Nearly half of the environmental impacts are related to the A1-A5 modules, the other half derives from the use phase. The end of life impacts constitutes to 5%.

A representative survey was also carried out in the EU about sustainable consumption and production, and a part of it assessed the environmental impact of the building stock (EU 27). As 60% of the building stock is residential, the environmental impacts per capita and per year was examined, as well as the impacts of the average European dwelling were examined and compared with the impact on an average European citizen. The age and type of the housing stock, the size of the living space and climatic conditions were assessed per capita and the load on the life cycle stages of the building stock were examined through 24 models. Taking into account the average greenhouse gas emissions of the life cycle of buildings were 6.36 tonne CO_2 eq. per dwell per year, compared to the average 2.62 tonne CO_2 eq. per capita. The use phase (energy and water consumption) was the most important aspect, followed by the production and maintenance of building materials. It was found that single-storey houses are responsible for the greatest impact. The same building has different effects in different climatic zones, especially due to differences in heating needs. In general, electricity consumption and space heating contribute the most to the environmental impact. **

Concerning average impact of building is Europe the value is 6.78 t CO_2 equivalent per capita, while this value is 8.8 t in Finland; 5.8 t in Italy and 5.4 t in Hungary ***.

(*) Source: Delem, L. Wastiels, and J. Van Dessel (2013): Assessing The Construction Phase In Building Life Cycle Assessment, Delemetal_avniRConference

(**) Source: Lavagna, M., Baldassarri, C., Campioli, A., Giorgi, S., Dalla Valle, A., Castellani, V., & Sala, S. (2018). Benchmarks for environmental impact of housing in Europe: Definition of archetypes and LCA of the residential building stock. Building and Environment, 145, 260–275. doi:10.1016/j.buildenv.2018.09.008

(***) Source: EU publications: Fossil CO_2 and GHG emissions of all world countries, 2019 report Study

Driving forces of LCA application in the industry: Why companies apply LCA?

The application of LCA provides important information in the **design** process – that can be based on BIM-method (Building Information Modelling) digital solution to model the design and construction - and in the maintenance and demolition phase. In addition to measuring the environmental performance of the materials used in a building, LCA can be used at an early stage in the design in order to identify aspects of the building that are important for the environmental impact regarding the impact categories considered. For materials which have a higher environmental impact, a life cycle assessment of sustainable building materials can help in finding alternative materials with lower impacts. In this way, environmental impacts can be reduced, less waste would be generated, buildings would have a more efficient use of energy and water, and costs can be optimised as well.

The main users of LCA are manufacturers of construction products, as they may have a legal obligation or **market pressure** to submit an LCA-based Environmental Product Declaration (EPD) (see Ch.2.3a) for their products. Architects use their monetised LCA data during design to compare different product types. In addition to energy efficiency aspects, eco-design and circular solutions also strengthen the role of LCA in the construction sector. When reusing materials, their impact should be assessed in a life-cycle approach.

For certification schemes of newly built buildings, such as BREEAM, LEED, DGBN, LCA is used as an objective method to quantify the environmental impacts of the selected building elements. (see Ch.2.3b) The requirement of these schemes present one of the main drivers to perform the LCA for entire buildings. Additionally, there are existing regulatory requirements in some countries (e.g. the Netherlands), while similar regulations are on the way to be implemented in countries, such as France, Denmark, Finland, Sweden.

Databases

LCA in the construction sector is supported by a number of databases. Databases to perform **products** LCA include manufacturing processes in different territorial coverage (Switzerland, Europe, USA, North America, France) and various material categories (e.g., metals, plastics, wood and cement, as well as concrete). A European database is the Swiss-developed Ecoinvent, which is also used by many LCA software solutions, such as One Click LCA, SimaPro, GaBi, openLCA and Umberto due to its consistency and transparency. The ELCD, created with the support of the European Commission, contains hundreds of processes, including some key materials, transport and waste management systems, but other parts need to be complemented to the building materials sections. The GaBi database is one of the largest databases on the market with thousands of processes, including building materials as well. Data for some substances are from Plastics Europe, ELCD or Eurofer. Manufacturers usually perform a building product LCA in order to publish an Environmental Product Declaration (EPD). For **building** LCA, the calculations for most commercial applications are typically based on manufacturer-specific or industry average EPD, and further generic data that are published by national authorities or other parties. These data contain information for building materials and products, such as use of resources, as well as impacts causing climate change, acid rain, smog, eutrophication etc. A well-known example of EPD database is the German online database ÖKOBAUDAT, and there are many other EPD databases such as NMD in the Netherlands and Inies in France. Finland and Sweden also recently published official generic LCA data that is mandatory to be used - along with EPDs - for building LCAs that are in accordance with the upcoming national regulations. In U.S., the database Athena contains a range of data on building materials, energy, transportation, construction and demolition processes, maintenance, repair, and waste management processes, some of which are derived from the U.S.LCI database.

a. The EU policies for the sustainability of the construction sector

In the European Commission's **Integrated Product Policy (IPP)**[13], Life Cycle Assessment (LCA) has emerged as the best framework for assessing the potential environmental impact of products. The Integrated Product Policy (IPP) defines tools and measures to reduce the environmental impact of products, taking into account their entire life cycle. With this, the impact of products and services on the environment has become a key element in decision-making processes, and LCA has become increasingly important in supporting community policies and businesses. "Life cycle thinking" has become a central pillar of environmental policies and sustainable business decision-making. The creation of EPLCA has been defined within the framework of the IPP.

The **European Platform for Life Cycle Assessment (EPLCA)**[14] provides assistance in the availability, coherence and quality assurance of data and information, as well as mainstreaming of LCA and related environmental footprint methods in business and policy. It supports the methodological development of LCA, the analysis of supply chains and end-of-life waste management. The efficient and effective operation of the platform and its action programs contribute to the progress of environmental sustainability.

The review of the **European Commission's strategy for the construction sector**[15], which also includes circular principles, also aims to promote the realisation of a sustainable built environment, taking into account the whole life cycle of buildings. It covers among others, the recycled product content and the requirements of construction products, the design of buildings, the promotion of the circularity, the improvement of durability and adaptability, the development of digital logs for buildings and the integration of life-cycle assessment into public procurement and into the EU sustainable financing framework.

13 COM (2003) 302 Integrated Product Policy Building on Environmental Life-Cycle Thinking
14 https://ec.europa.eu/jrc/en (last access in April 2021)
15 COM (2012) 433 final: Strategy for the sustainable competitiveness of the construction sector and its enterprises

Within the framework of the "**Single Market for Green Products Initiative**[16]" , the EU developed the **Environmental Footprint** methodology including the assessment of the environmental performances for products (PEF-product environmental footprint) and organisations (OEF-organization environmental footprint). **PEF** is also based on LCA, and aims to provide a uniform method for measuring environmental performance for those companies that wish to market their products within the EU. It contributes to the achievement of sustainability goals, as does the Environmental Product Declaration (EPD). A product assessment performed with the PEF methodology covers numerous impact categories (see details in Chapter in 2.2b).

A European initiate for the building sector is the COM (2014)445 "**Resources Efficiency Opportunities in the Building Sector**", which recognizes the relevance of addressing impacts all over the building's life cycle through better design and planning, promoting resource efficient manufacturing of construction products as well as more efficient construction and renovation works.

The importance of LCA is mentioned also in the EU **Circular Economy Action Plan**[17] aiming the development of sustainable product policy. The new Action Plan identifies the key value chains of the transition towards circular economy. Construction is among these key sectors as the built environment has a significant impact on different aspects of the economy (e.g. local jobs, quality of life etc.)

The **EU Green Deal**[18] is related to the goal of the EU concerning carbon neutrality for 2050. A key element of the action plan of the Green Deal is the EU Renovation Wave initiative aiming for making more environmentally friendly buildings, job creation, increasing life quality, reaching carbon neutrality. Environmental assessment of the new, planned technologies and solutions (carbon footprint) is based on LCA.

16 https:// ec.europa.eu/environment/eussd/smgp/ (last access in April 2021)
17 https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf (last assess in April 2021)
18 https://ec.europa.eu/clima/policies/eu-climate-action_en (last assess in April 2021)

b. LCA standards in the construction sector

Construction product scale

The main reference for the assessment of environmental footprints of construction products is the European Standard **EN 15804**[19]. Its first version was published in 2012 and last version in 2019. The standard is the main reference for the LCA studies in the construction sectors as well as for the Environmental Product Declarations (EPD) of construction products and services. EPD is such a voluntary declaration that can be used by companies to communicate towards the market the environmental performance of their construction products and services (see Ch.2.3a).

The standard EN 15804, on the one hand while keeps consistency with the general intersectoral standard ISO 14040 and 14044 on the Life Cycle Assessment (LCA) methodology, on the other hand it establishes specific rules concerning the 5 main methodological aspects of the LCA, namely the functional unit, the system boundaries, the allocation, the Life Cycle Impact Assessment (LCIA) methods, and the requirements of data quality.

As described in chapter 2.1, the **functional unit** in LCA identifies the function of the studied system (e.g. the product) and provides a reference to which the impacts are referred. For example, the function of a thermal insulation panel is to avoid heat loss and therefore, the value of the insulation power is presented through a specific parameter (i.e. the thermal conductivity, measured in W/mk).

However, the impacts due to the use stage of the building products and components are often strongly related to the specific application. For example, a specific thermal insulation panel will allow higher or lower energy consumption for heating, based on the specific wall system in which it is integrated and the context (including climatic conditions) in which the building is located.

19 EN 15804 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products

Due to the utilisation of each single building product or component, the EN 15804 allows that environmental impacts to be quantified excluding the use stage and using what is called a "**declared unit**", instead of a functional unit. The declared unit uses the quantity of product/component (e.g. m^2 or kg) as a reference unit for expressing the environmental impacts. Thus, if we consider the thermal insulation panel, the impacts on Climate Change, for example, will be expressed as follow:

- greenhouse gas emissions per 1 W/mk achieved by the panel, in case of functional unit
- greenhouse gas emissions per kg of panel, in case of declared unit.

The decision to use a functional or declared unit as reference to express the environmental impacts of a product is linked and affects the **system boundary**. The system boundary identifies which life cycle stages are going to be included in the study and to be represented in the resulting impacts. The EN 15804 adopts a modular structure for the definition of the system boundary, which is represented in the following figure.

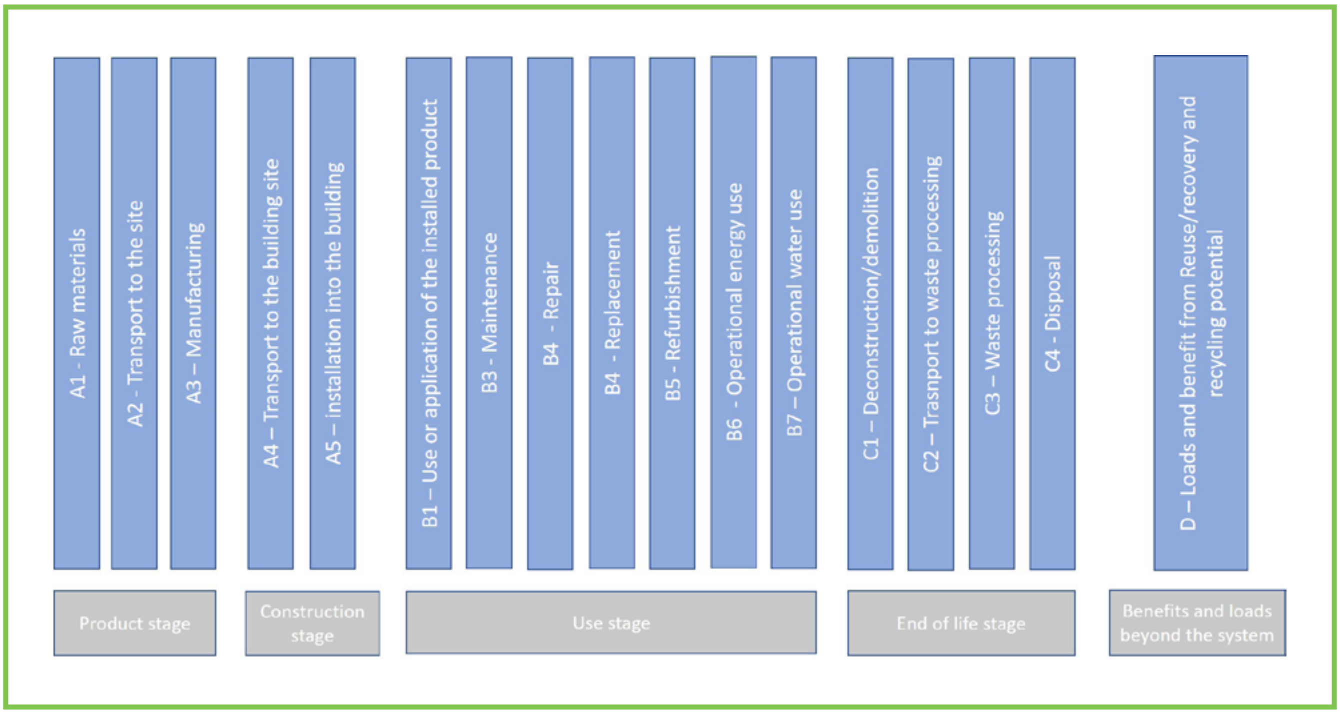


Figure 8: Modules used by EN 15804 for the definition of the system boundary[20]

20 Source: EN 15804

Allocation

A key aspect of the LCA methodology is allocation. The allocation is defined by the ISO 14040 as the procedure for the division the input or output flows of a process or a product system between the product system under study and one or more other product systems. In other words, the purpose of the allocation is to present such a procedure that allows that the impacts of a multifunctional process are properly allocated among the functions of the examined system/process. For better understanding, the example of energy recovery process from waste incineration can be considered. The waste incineration is a disposal method (first function), however, the process also produces energy (second function). Allocation is the procedure, the specific approach, applied to calculate the share of impacts to be allocated to one function and the share to be allocated to the other. The EN 15804 provides a set of methodological approaches which can be applied. Among the possible criteria there is allocation based on a physical reference (e.g. impacts allocated proportionally to the mass of each main product/output from a multifunctional process) or on an economic reference (impacts allocated proportionally to the economic value of the output). The decision of use depends on the specific case (not all approaches can be applicable in all cases) and affects the final impact of the involved products. For this reason, the standard specifies the order of priority in the approach selection. Such priority order is in line with the order specified by ISO 14044.

Concerning the life cycle impact assessment – **LCIA** – several methods exist, all of them allowing to report impacts on different number of environmental aspects, calculated according to specific scientific environment models. The earlier version of **EN 15804 (2012)** requires the use of a specific LCIA method, which is CML 2001. Impacts assessed according to this version of EN cover the following impacts categories:

- Abiotic Depletion (ADP fossil) [MJ]
- Abiotic Depletion (ADP elements) [kg Sb-Equiv.]
- Acidification Potential (AP) [kg SO_2-Equiv.]
- Eutrophication Potential (EP) [kg Phosphate-Equiv.]
- Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]
- Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]
- Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]

In the new version of **EN 15804 (2019)**, the LCIA method is different. It is the latest adopted one within the EF methodology and the minimum environmental aspects to be covered by the study includes an extended set of impact categories. In addition, for some elements already covered by the old standard, the scientific model has been slightly updated. The minimum list is reported below:

- Climate Change – total (GWP total) [kg CO_2 eq];
- Climate Change - fossil (GWP fossil) [kg CO_2 eq];
- Climate Change - biogenic (GWP biogenic) [kg CO_2 eq];
- Climate Change - land use change (GWP luc) [kg CO_2 eq];
- Ozone Depletion (ODP) [kg CFC11 eq];
- Acidification terrestrial and freshwater – AP [Mole of H+ eq.]
- Eutrophication freshwater (Epfr) [kg P eq.]
- Eutrophication marine (Epmar) [kg N eq.]
- Eutrophication terrestrial (Ep ter) [Mole of N eq.]
- Photochemical ozone formation - human health – (POCP) [kg NMVOC eq.]
- Resource use, mineral and metals (ADP elements) [kg Sb eq.]
- Resource use, energy carriers (ADP fossil) [MJ]
- Water scarcity (WS) [m^3 world equiv.]

Other additional impact categories can be introduced as well, which however are optional.

Data quality

In line with ISO standard for LCA, the quality of data must be documented. The quality of data used for the assessment, significantly affects the results on one hand. On the other hand, the data quality description provides a better understanding and interpretation of the information for the results of the assessment. Two main types of data are used in the LCA studies:

• generic data (also called secondary data) Generic data are not available/accessible directly from the manufacturer. These can typically be data from database, literature and other selected sources.
• specific data (also called primary data). Specific data are those collected at the specific manufacturing site where products are manufactured (for example, the electricity consumption of the manufacturing plant).

EN 15804 essentially refers to ISO, according to which the data quality description should address:

• representativeness (temporal, geographical, technological)
• precision
• completeness
• consistency
• reproducibility
• source of data
• uncertainty

Further specifications could be, for example, the data used cannot be older than 10 years in case of generic data or 5 years in case of specific data.

Building scale

As far as a whole building is concerned, two main tools can be used to evaluate environmental aspects of building. The first one is the standard for the environmental footprint of building, i.e. the **EN 15978[21]** , which is the standard to quantify the performance of buildings in the environmental pillar of the three main (environmental, social and economic) pillars identified by the ISO 15643[22] and which basically extends to the level of buildings, the methodology and reporting rules established at product level by the EN 15804.

The second type of tool is the rating scheme, which addresses the environmental quality of buildings through the use of qualitative criteria and requirements (see Ch.2.3b), including, for example the use of construction products with EPD declaration.

Standard EN 15978 relies on EN 15804, which remains the key reference for the methodological aspects. EN 15978 is intended for the quantification of the environmental performance of buildings, both in case of renovation and new constructions, with the following main aims:

- to support decision process, for example the comparison between diferent design options or scenarios and the definition of strategies for improvement,
- to help prepare the declaration of the environmental performance against specific requirements,
- to document the environmental performance of buildings, for the aim of labelling, declarations and marketing,
- to support the environmental policies of the building sector.

However, in standard EN 15978, key methodological aspects are partly adapted to the characteristic of the whole building. Two aspects to be highlighted concern the **functional unit and the system boundary**.

While EN 15804 has been revised and its latest version was published in 2019, this is not valid for EN 15978, for which one single version exists.

21 EN 15978 (2012): Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method
22 EN 15643 (2011): Sustainability of construction works - Assessment of buildings

EN 15978: functional unit and system boundaries

The concept of functional unit is substituted by the "functional equivalent" which is the set of quantified functional requirements or technical requirement of a building (or of a part of building) to be used as a reference for comparison. In the definition of the functional equivalent, it is needed to consider at least the intended use of the building (e.g. school, office, etc), the technical and functional requirements as for example defined by the legislative and by the client, the use model and the service life.
The identification of the system boundary basically follows the modular structure defined in EN 15804. Thus, all impacts have to reported in the modules exactly where they are generated. For example, if during the service life of the building a window is broken and repaired, the impacts associated with the repair activity is reported in the related module (module B3 "Repair"), including the production of the needed materials and the disposal of waste generated by the activity. In addition, the standard specifies that for a new construction the whole building in the whole service life has to be fundamentally considered, whereas for refurbishments, only the added parts and/or related works in the remaining building service life shall be included in the assessment.

Sustainability performance of buildings can be evaluated also according to **ISO 15643**-2; 15643-3 and 15643-4[23] . These standards help to perform assessment from an environmental, economic and social perspective.

Building energy certification can be carried out according to **ISO 52000[24]**.

23 EN 15643 (2011): Sustainability of construction works. Assessment of buildings.
24 ISO 52000 (2017): Energy performance of buildings. Overarching EPB assessment.

2.3 Market tools for the environmental sustainability

a. Environmental product declaration (EPD) for the construction sector

EPDs are so called **type III. environmental labels and declarations** regulated by **ISO 14025**[25], which establishes general rules for EPDs development and management. Basically, EPDs are declarations which have to be verified by a third-party body and registered within a specific EPD program, which establishes its own (additional) rules for the EPD development, validity and communication format (Product/sub-product Category rules – PCR/Sub-PCR) and which is in charge of make EPD publicly accessible within its own website. EPD should not be confused with Declaration of Performance (DoP). Indeed, while DoP addresses the technical performance of interest for a specific product category and is a mandatory declaration required by the Construction Product Regulation, EPD is a voluntary declaration which addresses environmental potential impacts arising from the production process and the use of a product.
Several EPD programs currently exist compliant to ISO 14025 and covering one or more economic sectors. With reference to the construction sector, **EPD programs** existing at European level are for example the International EPD System (Sweden), the IBU (Germany), Inies (France), EPDItaly (Italy). EN 15804 always represents the basis of the product/sub-product categories rules (PCRs/sub-PCRs) defined by the mentioned programs and thus of the EPD issued within the programs.
The mentioned EPD programs have all been developed within the frameworks of national initiatives. Some have highest number of registered EPDs, for example the International EPD System, as it covers several other sectors beyond construction and it has been the first EPD program put in place, and IBU, as it is focused only on the construction sector and is supported by industrial associations. Although EPD programs can set additional requirements for developing and achieving EPD compared to those ones defined by EN 15804, this one remains the common basis.

25 ISO 14025 (2010): Environmental labels and declarations - Type III environmental declarations - Principles and procedures

For this reason:

- several program operators have decided to put in place a **mutual recognition**, which allows the EPD issued with a program to be promoted also within a different program, with the consequent advantage of a higher visibility for the products and the manufacturer.
- a platform, called **Eco-platform**, has been created to promote EPD har monization of compliant to EN 15804 and issued within the different programs. When companies develop the EPD for their products in com pliance to EN 15804, they can decide to have the EPD registered and pro moted within the Eco-platform, again with the consequence of higher visibility.

It has to be underlined that EPDs compliant to EN 15804 can be essentially used in the same way and for the same aims, disregarding the specific EPD programs within which specific EPD programme they have been issued[26]. The basic content of an EPD includes:

- The name and address of the manufacturer, and the production site
- The description of the products, its simple visual representation such as a picture, and the description of main product components and/or materials
- Declaration regarding content, including at least those substances listed in the "Candidate list of substances of very high concern for authorization" (SVHC list, published by the European Chemical Agency) in case the content exceeds the limit for registration.
- The reference to the EPD program used
- The publication data and the validity period
- Information on which life cycle stages are excluded, if any
- The intended use of the product and the functional or declared unit to which environmental impacts data refer to
- Environmental impacts indicators, reported by module, although impacts in modules from A1 to A3 can be presented aggregated
- Life cycle inventory indicators, which provides additional information on resource use (e.g. use of secondary materials), on output flows (e.g. quantity of materials sent to recycling or reuse) and on waste (e.g. amount of hazardous waste produced).

26 It has to be underlined that national regulations, for the aims of specific applications, can officially require for EPD registered in a national program, if any. Thus, a check on national regulations is always suggested to support the selection of the EPD program operator.

As mentioned in the previous chapter, the EPDs and/or information included in the EPDs are becoming more and more used in the context of building rating schemes or in the context of green public procurement. For example, the LEED Scheme for "Building Design and Construction", in the section "Materials and Resources – Building Product Disclosure and Optimization", awards credits for the use of secondary materials (recycled content). There, EPD is mentioned as one of the means to demonstrate the recycled content.

b. Building rating schemes

The building rating schemes are tools developed to evaluate the building from the aspect of its environmental **sustainability**. The evaluation is based on a multi-criteria method. Criteria considered in the method can address different aspects of sustainability, affecting both the environment, such as the energy consumption or use of material resources, or the users, such as the indoor air quality and thermal comfort. **Several rating schemes** currently exist. Mentioning a few of them follows:

- LEED, developed U.S. Green Building Council
- BREEAM, developed by the U.K. Building Research Establishment
- DGNB, the German scheme promoted by the Deutsche Gesellschaft für Nachhaltiges Bauen
- ITACA, the Italian scheme promoted by the Istituto per la trasparenza, l'aggiornamento e la certificazione degli appalti
- Level(s), the scheme developed by the European Commission

Criteria can be organized by main sections, e.g. Management, Materials, Health and Wellbeing, Energy etc. **Credits** are achieved in each criterion, based on qualitative requirements or quantitative assessment of the performance, contributes to the definition of the overall score of the building and its final classification. Different scales can be adopted for classification, e.g. based on colour (silver, gold) or qualitative statement (good, very good).

All mentioned schemes were recognized to a different extent on considering the materials included in the buildings to evaluate the environmental sustainability of the buildings and/or its potential impacts resource consumption. Most of them evaluates by achieving credits if parts of products used in the building are covered by EPD and/or include recycled content.

Spread of Innovative Solutions for Sustainable Construction

Handbook

3 Possibilities to Improve Sustainability at Different Life Stages of a Building

IS-SusCon

Co-funded by the Erasmus+ Programme of the European Union

3 Possibilities to Improve Sustainability at Different Life Stages of a Building

The growing demand for green buildings presents both challenges and opportunities in terms of used raw materials. The aim is to encourage the use of materials that have a lower environmental impact during their life cycle, and to recognize and encourage the use of materials produced in a responsible way, in both the starting and finishing phases of the construction.

The choice of more sustainable materials can mean, on one hand, the choice of materials from a local source that contain fewer toxic components or are recycled to a greater extent, and this can lead to reduce environmental impact. Besides that, life cycle, reuse and recycling all reduce the impact on the overall life cycle, as fewer materials enter the manufacturing and waste processing process.

There is a growing industry using renewable construction products, which in the right context can lead to buildings with higher levels of environmental properties - such as more efficient use (energy consumption, thermal properties, easier maintenance) and end-of-life management (recycling, recovery or disposal).

3.1 Design

It is not an easy task to choose a building site, at least if there is even a possibility to do it. This aspect is often neglected, but it is of utmost importance what the neighbours are like. This is not a direct urban geographical, technical, nor an architectural question, and it is not directly related to sustainability. However, this factor will have the greatest impact on the lives of the residents for decades to come. It is not just about the fact that the neighbours own a pig farm, a cable burner, or a nightclub as these could ruin shortly the joy of a new home. The culture, the restraint and cooperating ability of those living in the neighbourhood can turn life pleasant for the community, while their loudness, carelessness, and conflict of interest can make life in such a neighbourhood hell.

These are social considerations, but the location and orientation of the building plot are both very important for the topic of our handbook, as they have an impact on energy consumption and the load on the environment as well. From the point of view of the plot, the solar radiation and thus the solar gain, and unsurprisingly, the wind conditions are the most important aspects. The air movements are also affected by the topography, the vegetation and the buildings too. In installations with more density, the distance between buildings and the height of the surrounding houses are also important because they affect the solar gain of the facades and the natural lighting of the rooms of the building.

It is not insignificant whether the plot is located on flat terrain, or possibly on a northern or southern hillside, as these will play a major role in the location, orientation and consequent architectural design, as well as the structural details of the building to be built on it. In Hungary, the south-direction inclination of the plot is the most favourable in terms of energy gain. Of course, it is also possible to build a useful house on a slope with an eastern, western or even northern slope, provided that it receives sufficient sunlight for at least in one part of the year. In such cases, there is a necessity for the architectural tricks of the trade, so those architectural solutions that allow sufficient sunlight to enter the building even in unfavourable terrain conditions.

Once the building site, the legal framework and financial limits have been all clarified, and also the planning program has been put together, the meticulous work of planning then shall begin. Based on the design program, it becomes clear the architectural and energetic vision, as well as the structural and building technology solutions the designer is targeting. The planning is moving towards the right direction when the designers work closely together. The detailed solutions that are related to the individual environmental load elements are developed in this phase. The materials, structures, equipment, and systems relevant to the topic of our handbook, will be discussed in more detail below, will also be selected at this phase. The used materials do influence the way of construction, the shape of the building, its architectural appearance, the structure and the costs, and have a significant impact on the internal and external environment.

The choice of materials must also take into account ecological aspects, such as the optimal use of resources, the lifespan, the avoidance of not easily degradable materials where possible, and the use of recycled materials as much as possible.

When designing a building, shaping the house and designing the spaces, the basic design decisions concerning the dimensions, shape, orientation and relationships of the spaces determine the environmental impact of the building and the relationship between the user of the building and their environment. From the point of view of the spatial design, the environmentally conscious approach means a conscious and careful application of well-sized spaces that are in intense contact with the natural environment, natural daylight as well as air currents, and the sun heat.

Let's have a look at two examples differing in space and time, but they are essentially related. The ancient Greeks used to build their dwellings preferably on the northern side of the plot with thick northern walls without openings. An overhanging roof structure, supported by columns on the south side prevented the summer sun from entering the interiors and heating them up. However, the light and heat of the sun shining at a lower angle in winter was able to get into the building. Concerning the location of the basic element of Hungarian folk architecture, the farmhouse, the dominating wind direction as well as the positive and negative effects of sunlight were also taken into account. These houses were preferably built on the worse, usually northern side of the site.

A common and characteristic architectural element of the Hungarian farmhouses is the porch that was built on the more favourable side of the building, open from the side, protected from rain and wind, which, among other functions, played a significant role in the thermal protection of the building, similar to the ancient Greek houses. Whether it was energy awareness or energy instinct may not even matter. The porch of the farmhouse lives on in the indoor-open spaces, which are also used in today's architecture and are aesthetically, functionally and energetically useful.

The design of the house is related to environmental protection and energy use in many points. One such connection is the surface/volume ratio, which would lead the designer to form compact masses, but a number of other considerations, such as usability, architectural appearance, or the possibility of utilising solar energy, all urge against the mass spread of igloos. During the design of the house, continuously decisions must be made, the shaping of the building and its integration into the environment is the art of reconciling different aspects and interests and of resolving conflicts. It has become fashionable and it also conquered our rural settlements, the design of houses with low pitch or flat roofs. There may be many reasons for such a decision at from the builder's or designer's point of view, here it is now worthwhile to mention that the placement of energy-collecting elements on high roofs is much simpler and more feasible aesthetically than on flat roofs.

Finally, some thoughts about the implementation of the construction. The builder has little influence on the construction process and its organisation, but the environment can and must be kept in mind at this stage as well. This starts with the fact that the distance between the places of purchase must be taken into account when choosing the materials used for the building, as the transport of building materials is a very serious load on the environment. Most of the processed materials do not come directly from the manufacturer, but from a warehouse or a trader, so significant differences can occur here. However, this issue necessarily contradicts the use of prefabricated, industrialized materials and structures with the use of locally produced, close-to-nature building materials. It is a difficult task to find the optimum. The environment must also be taken into account in the organisation within the building site, so in the location of the contractors' work and storage areas and in the organisation of the work processes as well. One of the basic ways to do so is to conserve the existing vegetation.

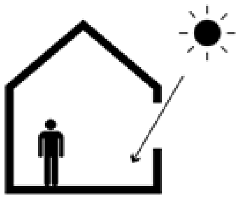
3.2 Use

By living in our homes, apartments or using any building we all constantly get in contact with the issues of environmental awareness, energy awareness and life cycle without even noticing it. When using a building, with many little acts a lot that can be achievend for sustainability. These are such small acts that we might not even think about the underlying connections and the consequences behind them. Looking at an outdoor example, one walks down the street and sees someone throwing a cigarette stub. First, one might be outraged about the character of the person we have met, their impoliteness and carelessness. Litter thrown away in such a manner is ugly and can be even harmful to our health.

After that, two outcomes can happen, in case we disregard the most favourable solution as telling off the littering, who picks it up and puts the cigarette stub in the right waste bin. One possibility is that after a while, a road sweeper passes by and removes the trash. In this case the littering man makes the road sweeper work, as that person would have to collect the garbage littered. This is unnecessary working time that could have been used for something else. The other option is that no road sweeper passes by so after a while the rain washes it into the sewer. So, on one hand, such a substance enters into the sewer that should not have a place there, so it burdens the system unnecessarily. In addition, a toxic substance gets into the system. It may seem insignificant, but if we multiply it by a larger number, it turns out that recyclable materials are also included in the waste.

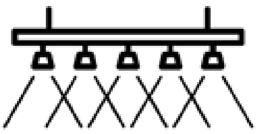
It also shows how small actions also have significance. We will briefly review these options. You can read more about some of them in other chapters of the book.

Taking advantage of natural daylight [27]



It is not necessary to prove how much energy the lighting requires. The light sources wear up, break down, increasing the number of devices to be purchased again and the amount of waste as well. It is easy to save on lighting. Take advantage of the possibilities provided by nature regarding lighting. By the windows the necessary lighting is provided in many cases. This can be used well by placing furnitures properly. Keep the reading chair and desk near the windows. The bathroom and toilets of the apartment can also have a window. If properly designed, there is no need to turn on the light on the corridors either during the day. Windows, glazed doors, and possibly skylights make this possible. With a little attention, a lot of energy can be saved by avoiding unnecessary use of artificial lighting. It is also worth considering that the sunlight has been scientifically proven to have a good effect on the state of mind.

Turning on the light, but only where it is needed[28]



Significant savings can be achieved with well-chosen light sources and well-designed lighting. This action also aims to reduce the purchase of devices and to reduce the amount of waste. With controlled lighting and several lighting units directed to the specific work area, we can achieve adequate lighting and more efficient work with significant energy savings. The equipment of the rooms must be carefully designed and the lighting needs must also be taken into account. We put a “two hundred watts” bulb in a lamp in vain when the light comes from behind us. Thus, it will be worth nothing, and would only mean unnecessary purchases, unnecessarily used energy and unnecessarily generated waste. When designing the building, the apartment, general lighting must be planned in the rooms, it is wrong to influence the light use in advance. A general lighting can be used to serve normal needs. The design of the electrical network must enable to accommodate mobile light sources that meet changing needs. The parts of the rooms used for work and study, the tables should be illuminated with direct day light of adequate intensity.

27 Source of the picture: Seona Kim, KR from Noun Project
28 Source of the picture: Nuttapon Pohnprompratahn, TH from Noun Project

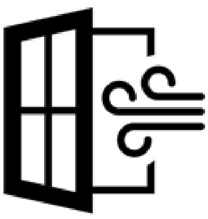
Choosing the right lighting units[29]

Modern, energy-saving light sources, such as LED lamps, are commercially available. We only mention it here as a non-negligible act, but you can read more about this topic in Chapter 6.2.

Taking advantage of natural shading[30]

One of the biggest problems in our buildings is keeping away the unwanted solar radiation. Cooling overheated buildings consumes a lot of energy, so it is necessary to keep the rate of mechanical cooling to the lowest possible level. The first step is to properly orient the building. There is no doubt that there is a contradiction between the need for shading to keep heat and thus light away, and the need for lighting that provides as much natural daylight as possible, and the need for energy from solar radiation in winter. Of course, this problem also varies by geographical region. This contradiction must be resolved by a well-prepared designer. In addition to orientation, there are adequate tools and structures to simply prevent excess sunlight from entering into the building and thus heating the rooms. The vegetation can be beautifully used for shading. Also, in the past, they used deciduous trees with lush foliage in summer for offering good shading, then losing their leaves in winter and allowing sunlight to pass through. The design of the building, the eaves, the porches and loggias all provide adequate help to keep out unwanted solar radiation. There are also many shading structures made of natural materials. No doubt it is a convenient solution, but if possible, it is essential to avoid the use of motorized shading devices. More detailed description about shading solutions can be found in chapter 5.2.

Taking advantage of natural ventilation[31]

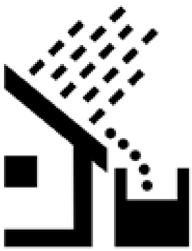


It is easy to save on ventilation. One shall take advantage of the opportunities provided by nature regarding ventilation. In an environment where the air is good, where the users, residents of the building do not need to be particularly protected from health risks, ventilation

29 Source of the picture: icon 54 from the Noun Project
30 Source of the picture: H Alberto Gongora from the Noun Project
31 Source of the picture: Tomas Knopp from the Noun Project

can be achieved by allowing direct fresh air inside. It is an undeniable fact that there is a serious debate in this area representing different views. Many people prioritize mechanical ventilation and there is a lot of truth in that option. Ventilation systems with adequate heat recovery are sufficiently energy efficient by using the heat of the exhaust air. In addition, they provide constant, continuous air exchange. It is not a negligible consideration either that suitable filters can be placed in the ventilation system to filter out various pollens and other particles are responsible for allergic diseases. It is not necessary to abandon these benefits. In cases where the risk of allergies does not exist or is limited to well-defined periods, and the building is located in a geographical region with a climate where heating is not required for a significant part of the year, it is advisable to develop a natural ventilation solution. A detailed description about built-in ventilation can be found in chapter 6.1.b.

Saving water[32]



Water is the strategic raw-material of the future. There is no doubt that drinking water is a huge asset and it is not evenly distributed across different geographical regions. It is extremely important to save water. Of course, saving does not mean that you have to avoid taking a bath or drink water. Saving must be achieved through thinking and preplanned solutions. A lot of water can be saved by paying attention while showering, doing the washing up, washing dishes, cleaning or doing plant care. On one hand the properly selected equipment and faucets do save a lot of water in the bathrooms and kitchens. However, in the event of improper use, even the most professional and purposeful structures do not save water. Personal attention is also needed. Washing machines and dishwashers consume a lot of water, so it is important to consider their water consumption when purchasing them. Water saving should be considered already at the design phase of a building. In order to be able to use grey water to flush the toilet a properly designed and constructed pipe system is required. This must be considered well in advance. Building such a network means a slightly higher investment cost, but it can save a lot of water. If possible, no tap water should be used for plant care, such as garden watering. The easiest way to save water in this instance is to collect rainwater. This is not only possible by using rainwater collection tanks in family houses. On a smaller scale, also in multi-apartment houses, there is a solution for collecting rainwater, which can then be used to care plants.

32 Source of the picture: Luis Prado from the Noun Project

Producing as many vegetables and plants ourselves as possible[33]

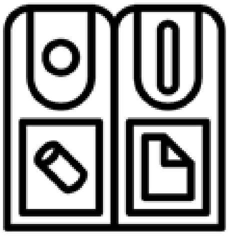
At first glance, this question seems independent from the topic of the building. While it might be true, there are still many minor correlations. When we grow plants ourselves, we choose what we really need and only as much as we will consume. We pay more attention to our own plants, we care more about them, and they also require less chemicals. Self-grown vegetables do not have to be transported from distant places, possibly from foreign countries, therefore, less transport is needed, so there will be less pollution caused by transport and vehicles. It is possible to grow our own plants in larger quantities in garden houses, however consumable plants that can be grown in small quantities on the terrace, balcony or even on the windowsill of an apartment. We can adapt the cultivation of our own plants to our needs, and we can strive to consume seasonal plants, so we need less storage space and refrigeration equipment. The amount of home-grown vegetables can be better planned, so less waste is produced.

Composting[34]

Composting has several benefits. There is no need to transport waste and no need to deliver nutrients. This fact reduces the pollution coming from vehicles and the use of chemicals. The compost can be recycled back into the soil of our self-grown plants, thus providing a high-value of nutrients to them. There is a large literature available about composting where relevant information is available for everyone. It is important to inform ourselves about the appropriate solutions. Professional storage and handling larger quantities of compost is possible primarily in garden houses, but composting is possible also in multi-apartment residential buildings. With care and proper handling, compost will not have an unpleasant odour, and with proper disposal it will not disturb the occupants. The best solution is if the residents design and operate the composter in collaboration.

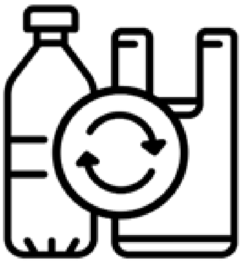
33 Source of the picture: Icongeek26 from the Noun Project
34 Source of the picture: Bakunetsu Kaito from the Noun Project

Separating the waste right at the beginning[35]



If we manage a problem right at the beginning of the process, it can be solved with less work and more simplicity. The treatment of selective waste must begin at the place and time of its generation. Selecting the parts to be removed selectively from the mixed waste is an inconvenient and unnecessary activity. This can be easily prevented with a properly designed waste collector and waste container and care. The possibilities and rules differ from country to country and settlement to settlement, so it is necessary to find out about the appropriate methods. The separate waste collectors must be designed according to the conditions. It then quickly becomes routine to immediately place the generated waste in the appropriate container. The selectively collected waste saves unnecessary work and unnecessary fuel consumption. With this behaviour, we enable used materials to be reused.

Reusing materials[36]



There are many opportunities to reuse used or surplus materials. Many of them are already existing best practices that should be replicated. New solutions can be developed according to the habits of everyone's own household and must be used regularly.

It is a good practice to use plastic bottles for storage instead of throwing them away. There are also many possibilities for reusing paper, but in most settlements the selectively collected paper is transported separately. The appropriate part of the organic waste can be composted by sorting it properly, thus saving its removal and obtaining new, useful nutrients.

The importance of recycling is well known by all of us. Recycling generates less waste. There will be less pollution by vehicles; fewer raw materials should be used when using recycled materials.

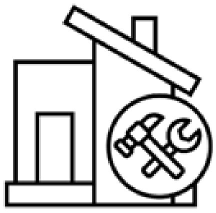
35 Source of the picture: mynamepong from the Noun Project
36 Source of the picture: Chanut is Industries from the Noun Project

Smart homes, control systems

Smart home solutions are becoming more and more wide-spread. By using them, we can plan better the use of our house and apartment and thus our energy consumption. Pre-programmable thermostats have been used for a long time, with their use, heating can be pre-set according to the planned needs. With the help of smart solutions and control systems, not only the temperature and heating can be controlled programmatically, but also the lighting, shading and, if required, the planned operation of household appliances. By pre-planning in such a way, we can save not only time but also a significant amount of energy. With the help of smart home systems, the house can be controlled remotely, thus creating an opportunity to make the necessary changes.

You can read more about smart home solutions in chapter 6.4.

3.3 Renovation, maintenance



Planning the maintenance of the building[37]

If we plan in advance the maintenance of the building, we reduce the damage caused by malfunctions. The first steps to take are presented at the phase of design and construction of the building. The basis of a good building is a floor plan corresponding to the function, proper lighting, a well-planned energy design and the use of modern building engineering systems. In the design phase, it is necessary to select construction products of adequate quality and to accurately determine the expected technical performance. This is the responsibility of the designer. This is one of the essential elements of ensuring good quality. By installing quality construction products, which are suitable for a given function we can ensure that the building gets out of order less often and less maintenance will be required.

37 Source of the picture: Lihum Studio from the Noun Project

A building management manual is needed, which includes a maintenance plan. The inspection cycle of each construction product and building structure can be defined. This can be specified by the designer or the manufacturers of the construction products. The first element of a scheduled maintenance is a routine inspection. For example, the manufacturer specifies in the operation manual of the doors and windows, the frequency of inspection and how they should be handled. Similarly, the manufacturers of the mechanical equipment and fittings provide inspection and maintenance instructions.

There are also areas, which are not linked to construction products and where frequent but preventable failures cause damage for the buildings. Most problems are caused by water presenting itself in inappropriate locations. Cleaning the gutter, anti-clogging measures and maintenance can prevent soaking. Hidden pipe breaks can be noticed by checking the water consumption from time to time. Wasting water and damaging structures therefore, can be prevented.

Another important element of scheduled maintenance is the prompt correction of failures that occur during an inspection or unexpectedly. By the replacement of a displaced tile, a full-surface soaking can be prevented, which would cause much more damage. Usually the resident rarely looks at the flat roof insulation; a planned inspection is required. A failure noticed in time can prevent more serious defects like soaking, wetting of the thermal insulation and thus a decrease in the thermal insulation capacity, and less frequently even damaging the supporting structure could all be prevented.

The damage of an element of the facade cladding or of a small part of the facade plaster can be easily repaired. Failing to repair may result in further damage to the facade cladding or facade plaster. The damage to the façade surface is not just an aesthetic problem. For example, water entering into the structure of a building can cause damage over a much larger area and of much greater significance.

It is advisable to document the scheduled maintenance in writing, giving the dates of the inspections in tabular form and recording the detected faults, the measures taken and the repairs. When selling an apartment or a building, this booklet helps the buyer and enhances their confidence.

3.4 Demolition

Demolition is essentially not the responsibility of the user or the resident. Demolition should be left to professionals. When the demolition takes place, neither the residents nor the owners are present.

Demolition activities must be planned in advance, taking into account the general occupational health and safety regulations and other local legal regulations in force. The legislation may require permission, notification, or acknowledgment, but it is also possible that there is no obligation to do so at a given location. It is needless to say that buildings under heritage protection cannot be demolished in any country without strict control and permission. It is also important that the demolition of connecting buildings or those which are structurally connected to adjacent buildings is subject to strict regulations. It is the responsibility of the demolition specialists to ensure that the work is carried out as planned, in a professional and safe way. Strict regulations apply to work with various materials, as well as the protective equipment to be used when dismantling and moving hazardous materials. These rules apply to the shortages caused by the closure of the facility, the safety of neighbours, and the professionalism of work and safety.

During the demolition a lot of debris and waste is generated, which must be constantly monitored and accounted for, therefore the amount of expected waste must be planned when preparing the demolition work. However, demolition waste is can be seen not only as a problem but can also be useful, as it plays a significant role in the rational management of natural resources and material management. **Waste management** helps to reduce the amount of waste generated, to protect against the harmful effects of waste and to recover waste.

Due to their large volume and quantity the European Union has classified construction and demolition waste as a priority 'waste stream' and aims to recycle 70% of the amount produced in the EU by 2020. To achieve this, the European Parliament published a resolution on a resource-efficient Europe on 24 May 2012. Despite these efforts, we are still experiencing across Europe serious obstacles to recycling and reusing waste, as there is a high level of distrust towards materials produced from construction and demolition waste in terms of quality and health risks.

The European Commission adopted the New Circular Economy Action Plan in March 2020 which is Europe's new agenda for sustainable growth. [38]

Waste generated during construction and demolition can consist of a wide variety of materials. It can include bricks, roof tiles and other ceramics, wood, glass, bitumen, metal, concrete and much more. The waste regulations specify the different materials, how they should be handled, stored and transported.

According to their material, construction and demolition waste is classified into eight major groups:

- excavated soil,
- concrete debris,
- asphalt debris,

38 https://ec.europa.eu/environment/strategy/circular-economy-action-plan_hu

- wood waste,
- metal waste,
- plastic waste,
- mixed construction and demolition waste,
- waste building materials of mineral origin

Waste and rubbish belonging to the given groups must be collected separately from each other. Waste, which cannot be recovered locally must be disposed in an appropriate landfill.

Waste generated during construction and demolition mostly belong to the group of solid, inorganic, non-hazardous wastes, but in many cases they also contain substances that are unsafe and harmful to health. Examples of such substances are paints, solvents, wood preservatives, etc., which can be flammable and explosive, toxic, irritating, corrosive, allergenic, carcinogenic. These should not be mixed with others under any circumstances.

The construction and demolition waste however, may be used as raw materials or suitable for manufacturing new products in case they are collected separately and treated properly. There is no need to specify that iron and steel or non-ferrous scrap can be recycled by metallurgy. The recycling of aluminium is particularly significant in terms of energy savings. Paper, glass, rubber and plastic can also be reused. Concrete elements, gravel, sand, brick and stone debris can be well used for soil consolidation, backfilling, construction of substructures, embankments or noise barriers.

The builder acts correctly if the selection of building materials and construction products also considers the type of demolition waste generated during the attrition of the building and in case of its renovation or demolition. We must strive to use as few materials as possible that cannot be reused or that will generate hazardous waste.

Spread of Innovative Solutions for Sustainable Construction

Handbook

4 Products, Structures Building Services Systems

IS-SusCon

Co-funded by the Erasmus+ Programme of the European Union

4 Products, Structures, Building Services Systems

For the reader to be able to use the book usefully, it is necessary to have a common understanding about the same phenomena and titles and, conversely, to define the same things in the same way. To this end, of course, we list a non-exhaustive list of some of the more important concepts and expressions. It is essential to know that different things are named variably by the everyday language use, differently by professional language, and again differently by legal language and terms.

In ancient times, mankind first sought shelter and later, once construction work of mankind started, they made a home for themselves, that is, they transformed their surroundings. By demarcating a part of the environment as a result of conscious construction, the built environment was established. Mankind built a house with this activity, but the professional and legal language coins it differently, namely a structure, which is a collective term. Structures that are typically used for human habitation are called buildings.

Our home, in other words, our apartment, is a stand-alone destination unit that serves the purpose of a long-term residence and includes living quarters, cooking rooms, sanitary rooms, moving rooms, and storage rooms. Buildings comprise of building structures, the components of building structures are building materials with their exact name, construction products, which are permanently built into the structures and play a significant role in the "operation" of the structure.

Different building types also have their own precise definitions. From the point of view of our topic, residential buildings, namely buildings that typically include dwelling and the associated service rooms are relevant. There are also several types of residential buildings. The best-known of these are single-family detached houses, commonly known as family houses and multi-storey multi-apartment buildings, commonly known as condominiums. It is also worth mentioning the semi-detached house, which has two independent buildings with independent building structures on the common side of two adjacent building plots, which externally show the image of one building. The group house is a separate category; the group house also has several versions, the terraced house, the chain house and the atrium house. What they have in common is that they are built in one phase, connected to a series with independent building structures, and typically have the same or similar architectural design.

4.1 Requirements related to building structures, buildings

We set basic requirements towards the building materials and building structures that compose our buildings to ensure long-lasting, healthy and safe usage.

These essential requirements are the following:

Mechanical resistance and stability

The supporting structure of buildings are expected to withstand the expected loads - additional building structures (e.g. roof), own weight, effects due to use (e.g. furniture, people), etc. - without damage, at least for their intended life phase.

Fire Safety

During the design phase, buildings should be configured to minimise the possible damages from fire. The primary purpose of fire protection is life- and protection safety. Appliances (evidently in addition to fire prevention) of active fire protection equipment (extinguishing systems) and passive systems - this means choosing building materials, designing structures so that they do not facilitate or hinder the spread of fire, and retaining their supporting and separating function at least for the duration of the rescue process.

Hygiene, health and the environment

Buildings must be harmless to health. Therefore, all building materials must be established in a way that no harmful substances (e.g. volatile compounds, small elemental fibres) can escape during use. In addition, the environmental impact of production and transport during the production of building materials have to be reduced as much as possible (the specific environmental impact of different building materials is described in more details in the Annex.)

It also includes the protection of buildings against water and moisture. During the use of the building, a significant amount of vapour is generated (e.g. from people breathing). This condensation must be avoided indoors because - apart from possible damage to the building structure - it creates a favourable environment for the appearance of mould. This can be avoided if our structures are "open towards the outside" in terms of vapour, which means that by moving from the inside, the material layers are more and more vapour permeable (their so-called vapour diffusion resistance is lower). In addition, the design should take into account – significantly on the colder points of the structure - to avoid the formation of thermal bridges. Moisture from the soil has a similar effect to humidity (it can damage the structure and favour mould), so we need to protect against it with waterproofing.

Protection against adverse environmental effects (e.g. radon radiation) is also part of this basic requirement.

Safety and accessibility in use

We expect safe operation during use. This includes that there are no hazardous elements (e.g. splinters) in places where they can cause injury during proper use (e.g. walls, windows, etc.), that the floor coverings are non-slip surfaces and that the expected use does not cause damage to the building material (e.g. the stair railing does not break if we lean on it).

This also includes the fact that the delimiting structures of the buildings (wall, roof, window, and door) must also ensure the protection of property.

Protection against noise and vibration

N

We distinguish between two types of sound propagation: airborne sound and body sound. Airborne sound spreads through the air (such as a conversation in an adjacent room), protection against it can also be achieved by using a high-mass containment structure and a soft acoustic as well (e.g. rock wool, glass wool). Body sounds spread within bodies — building structures — (e.g., a person walking in a room above us, hence also called a step sound). The higher the density of a building material, the better it conducts body sounds, so we can protect against them with soft materials - with the right structural design.

Energy saving and heat retention

E

Thermal protection has a key role to play in making buildings as energy efficient as possible. In this respect, the relevant concepts are heat storage and thermal insulation. An example of heat storage is when the temperature of a heated room is taken in by the wall in winter and then when the temperature drops inside it "radiates" it back. The higher the density of a material, the higher its heat storage capacity is. Thermal insulation, on the other hand, prevents the material or space behind it from absorbing the temperature on the other side (thus protecting the heated space from cooling). In this case, the ratio is reversed, typically lighter materials are good thermal insulators.

Sustainable use of natural resources

Sus

This essential requirement applies partly to manufacturing of building materials and partly their environmental impact during use. The production of building materials is a burden to the environment, but we must strive to do as little burden as possible. This depends partly on the manufacturing technology, but it also includes using only the necessary amount of materials. For example, in case of thermal insulation, there is a certain level of thickness after which energy saving can no longer be felt by applying more insulation. It is also typical for thermal insulations that if a material with better thermal insulation can be produced with almost the same production environmental load (e.g. smooth EPS and graphite ESP thermal insulation), it is more sustainable.

4.2 Building structures

Our buildings consist of several main building structures and we have different expectations from them. This chapter provides an overview of building structures, their function and their most typical structural build up.

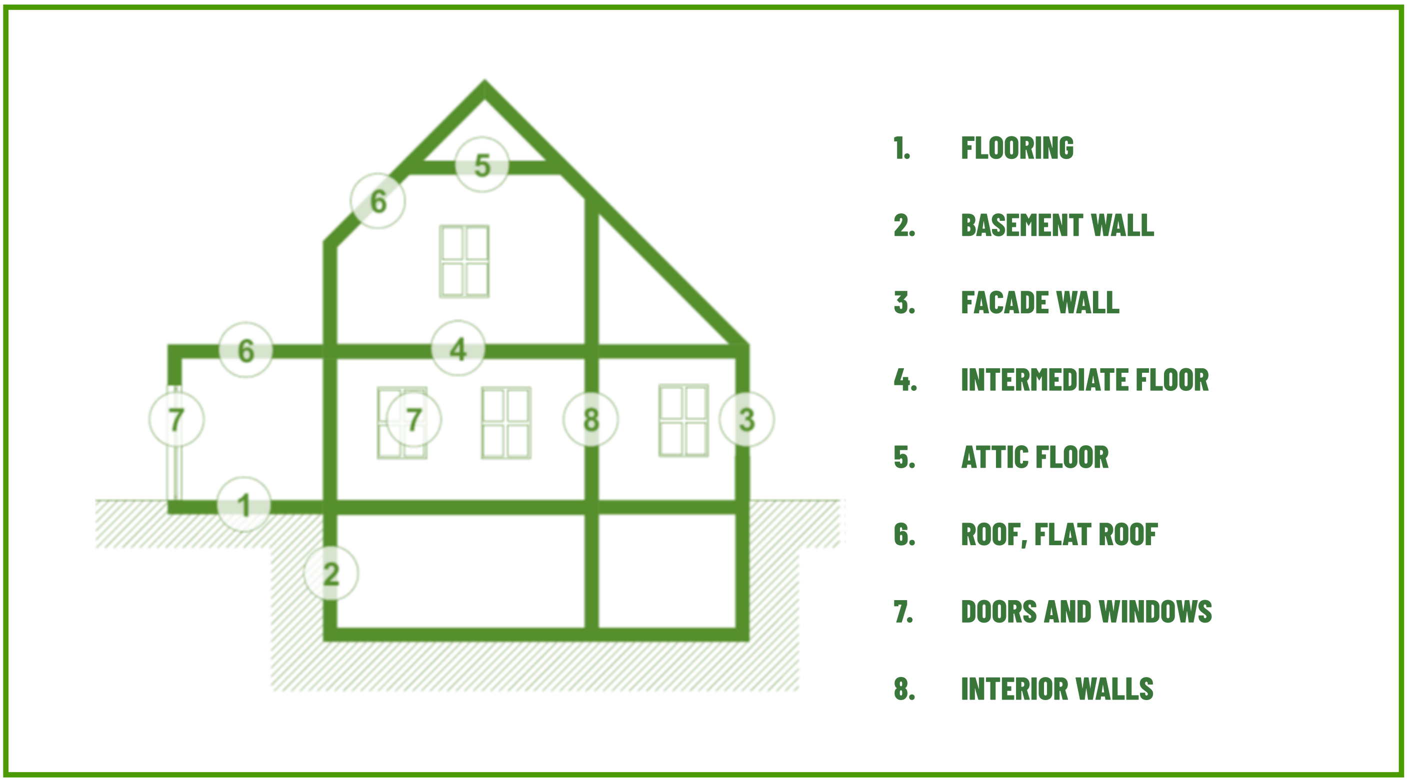


Figure 9: Main building structure types

Flooring

As the name mentions, this structure seals the lowest level of the building, which is in direct contact with the ground. In case of a basement building, it is the basement, in case of a building without a basement, the floor structure of the ground floor.

Requirements and consequent function:

- forms a solid, flat, walkable surface
- insulation against moisture from the ground (soil vapour, soil moisture, groundwater)
- thermal insulation from the ground
- insulation against radon from the ground[39]

Typical structures

1. Monolithic structures

In the vast majority of cases, a monolithic structure (usually concrete – as also referred to subgrade concrete) forms the basis, and additional layers built into and below it, depending on the location, soil moisture conditions and local climate conditions. These are water, radon and thermal insulation layers, as well as floor coverings and related technical layers.

Advantages
- economically feasible
- durable

Disadvantages
- high demand of on-site labour
- weather-dependent design
- subsequent repairs / renovations are more difficult

2. Lightweight structures

In the case of lightweight construction technologies, the floor of the lowest building level may not be monolithic, and is rather made up from some kind of frame structure (wood or steel). In this case, the structure usually does not rest on the ground directly, but is elevated from it to a greater or lesser extent. In such a case, it is also necessary to install layers that allow the required functions to be performed (flat, solid, continuous surface; water, heat and radon insulation, establishment of tread design). Here, more emphasis is placed on thermal insulation.

Advantages
- low demand for labour on site
- less weather-dependent design
- easy to repair / renovate

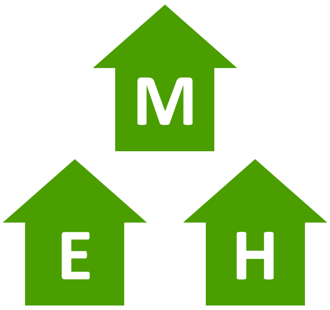
Disadvantages
- more sensitive structural design
- requires a high level of expertise

39 Radon is a colourless, odourless, natural radioactive gas found in the earth's crust. It enters into homes through the soil. Its radioactive decay products adhere to dust particles in the air, which, when inhaled, can damage the lungs.

Basement wall

In basement buildings, it is the wall section that rests on the foundations and extends to the wreath above the basement. This is the vertical boundary structure between the cellar and the ground. It also has a supporting structure role, so the vertical loads of the building are transferred to it, but it can also have a different design.

Requirements and consequent function:



- supporting structure (not always) - bears the vertical loads of the building
- resistance to ground pressure
- waterproofing
- thermal insulation

Typical structures

1. Monolithic structure

Concrete made on the construction site or, in case of higher loads, a reinforced concrete structure on which heat and water insulation can be applied. This solution is usually used when it has to withstand a higher load (e.g. large amounts of groundwater, deep cellar, tall building).

Advantages
- high load bearing capacity
- withstands side pressure with proper reinforcement
- waterproofing failure causes fewer problems

Disadvantages
- high demand of on-site labour
- requires shuttering
- expensive

Typical structures

2. Remaining shutter monolithic structure

A wall structure made of lightweight concrete or concrete shuttering elements, its cavities are poured concrete into them, on site. As an additional layer, heat and water insulation can be applied.

Advantages
• fast construction
• does not require a high level of expertise
• waterproofing failure causes fewer problems
• economically feasible

Disadvantages
• high demand of on-site labour
• less resistant to side pressure

3. Masonry constructed/Built of blocks

A wall made of stone, concrete or brick masonry units. The most common and well-proven masonry material for basement walls is small brick. They also produce frame ceramic products specifically, called cellar masonry. As an additional layer, heat and water insulation can be applied.

Advantages
• preparation does not require a high level of expertise
• economically feasible

Disadvantages
• more sensitive to waterproofing failure
• high demand of on-site labour
• less resistant to side pressure

4. Prefabricated basement wall

Prefabricated reinforced concrete structure, which is lifted to its final location by crane at the construction site. Large, high-level elements.

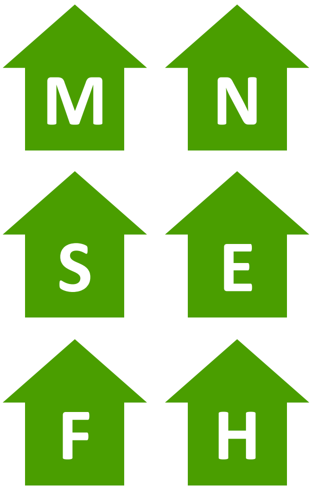
Advantages
• fast construction
• its preparation does not require a high level of expertise
• low demand of on-site labour
• plant prefabricated

Disadvantages
• expensive
• complex on-site work organization

Facade wall

Vertical boundary structure between the exterior and the interior. Often, especially in the case of family houses, it also has a supporting role, so the vertical loads of the building are transferred to it, but it can also be of a different design.

Requirements and consequent function:



- space delimitation
- load bearing
- thermal insulation
- architectural appearance
- reception of doors and windows
- sound insulation

Typical structures

1. Monolithic structure

A wall structure cast between formwork/shuttering, typically of concrete material, this solution rarely used in family houses and smaller condominiums. Additional thermal insulation is required as concrete alone is a poor thermal insulator.

Advantages

- high load bearing capacity

Disadvantages

- high demand of on-site labour
- requires formwork/shuttering
- expensive

Typical structures

2. Remaining shutter monolithic structure

A wall structure made of formwork elements, which is poured with concrete at the construction site. Formwork elements are most often made of lightweight concrete, polystyrene, or wood wool/wood concrete, and they are sized to be moved by hand. The design of formwork elements made of a good thermal insulation material (e.g. polystyrene) allows the wall structure to be made without additional thermal insulation.

Advantages

- high load bearing capacity
- preparation does not require a high level of expertise
- no additional layers required if properly designed

Disadvantages

- high demand of on-site labour
- less commonly used solution

3. Built of masonry

This is the most commonly used solution for residential buildings. Sometimes it is made of stone or concrete, more often of fired ceramics, aerated concrete, wood concrete elements. It is usually necessary to provide additional thermal insulation.

Advantages

- a traditional, well-known solution
- preparation does not require a high level of expertise

Disadvantages

- high demand of on-site labour
- allows a lot of moisture entering into the structure
- time consuming construction

4. Lightweight structure

Some kind of frame structure (typically wood or thin-walled steel) provides the supporting structure; the cavities between them are filled with thermal insulation. Both sides are bounded by building boards (usually gypsum board inside, OSB board outside, but gypsum fibre and cement-bonded chipboard are also common). An important element of the structure is the vapor barrier layer, which is a kind of film preventing excess moisture entering the structure, which could then precipitate and lead to mould. It can be partly or completely prefabricated or assembled on site.

Advantages

- fast construction
- less weather-dependent construction work
- lower on-site labour requirements
- can be prefabricated in operation
- good thermal insulation

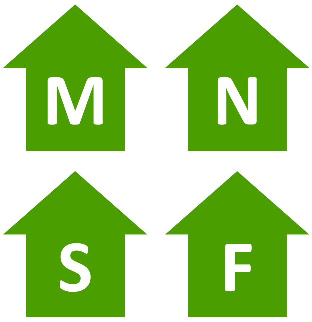
Disadvantages

- sensitive to fire
- preparation requires a higher level of expertise
- complex structure

Intermediate floor

A horizontal boundary structure between two functional levels of a building.

Requirements and consequent function



- forms a solid, flat, walkable surface
- forms the ceiling of the level below it
- bears the resulting loads and transfers them to the vertical load-bearing structures (wall, column)
- sound insulation (both airborne and body / step sounds)
- thermal insulation if the temperature requirements of the separated two levels are very different (e.g. slab between living room and garage)

Typical structures

1. Monolithic structure

Reinforced concrete structure with formwork on site. The formwork can also remain in the structure, thus simplifying the construction. It is characterized by high load-bearing capacity, so it is often used in places where the span (distance between support points) is large or the expected load is larger. Adequate sound insulation is provided by the installation of additional layers.

Advantages
- high load bearing capacity
- fireproof

Disadvantages
- heavy
- formwork required (which remains in place)
- high demand of on-site labour
- construction is more time-consuming

Typical structures

2. Beam and block structure (beam and block)

Load-bearing is provided by beams (nowadays they are typically made of concrete or concrete-ceramic composite material, but in the past steel beams were also common), and the sections between them are filled with block elements. Block elements can be made of concrete, lightweight concrete, or ceramic (or other load-bearing material). This often involves an extra layer of concrete, as well as additional layers providing sound insulation and layers of the pavement.

Advantages

- fast construction
- a traditional, well-known solution
- fireproof

Disadvantages

- heavy
- high demand of on-site labour

3. Lightweight structure

Load-bearing is provided by beams (typically made of wood or thin-walled steel), and the cavities between them are filled with thermal insulation. It is bordered at the bottom and top by building boards (usually at the bottom by drywall, at the top by OSB board). Additional layers of insulation are used to achieve adequate sound insulation.
It can be partly or completely prefabricated or assembled on site.

Advantages

- fast construction
- less weather-dependent construction work
- lower on-site labour requirements
- can be prefabricated in the factory

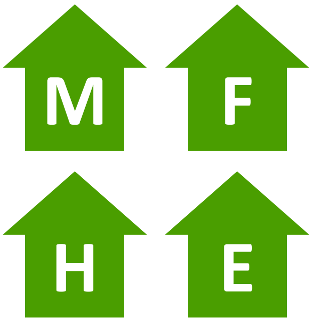
Disadvantages

- sensitive to fire
- preparation requires a higher level of expertise
- complex structure

Attic floor

Horizontal boundary structure between the uppermost functional level and the unheated attic. As it typically has little load, its main function is not load bearing but thermal insulation and space delimitation.

Requirement and consequent function



- spatial delimitation
- forms the ceiling of the level below
- thermal insulation
- in the case of a walkable attic, providing floor structure there as well

Typical structures

1.Monolithic structure

Reinforced concrete structure with formwork on site. The formwork can also remain in the structure, thus simplifying the construction. It is a very rarely used solution, as the main advantage of a monolithic structure - high load-bearing capacity - is typically not required in case of a slab (except for a large span), however, concrete is a poor thermal insulator. Additional thermal insulation layers are used for proper thermal insulation.

Advantages
- high load bearing capacity
- fireproof

Disadvantages
- heavy
- poor thermal insulation
- high demand of on-site labour
- more time-consuming construction

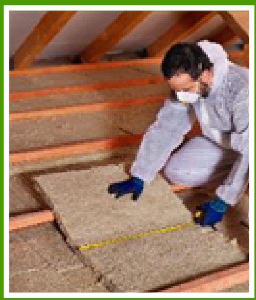
2. Beam and block structure (Beam and liner)

Load-bearing is provided by beams (nowadays they are typically made of concrete or concrete-ceramic composite material, but in the past steel beams were also common), and the sections between them are filled with block elements. In addition to conventional concrete, lightweight concrete or ceramic liners, the closing slab may be made of a heat-insulating material (e.g. polystyrene). It is a solution not as commonly used, for reasons similar to the monolithic structure.

Advantages
- high load bearing capacity
- fireproof
- fast construction
- a traditional, well-known solution

Disadvantages
- heavy
- high demand of on-site
- usually poor thermal insulation

Typical structures



3. Lightweight structure

Load bearing is provided by beams (typically made of wood or thin-walled steel), and the cavities between them are filled with thermal insulation. At the bottom, it is bordered by building boards (usually drywall). The attic-facing walkway is formed with OSB or decking, if necessary. Providing vapour barrier is especially important in this case, it is provided with foil. If necessary, additional insulating layers are used to achieve adequate thermal insulation.
It can be partly or completely prefabricated or assembled on site.

Advantages

- fast construction
- less weather-dependent construction work
- lower on-site labour requirements
- lightweight
- can be prefabricated in the factory

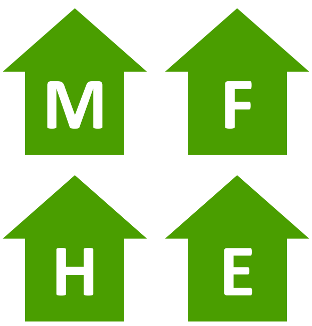
Disadvantages

- sensitive to fire
- preparation requires a higher level of expertise
- complex structure

Roof, flat roof

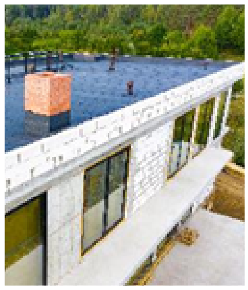
The top closing structure of the building. It can be designed with a high roof - at an angle closing more than 8 degrees to the horizontal - and a flat roof with a horizontal angle of up to 8 degrees. Various designs are possible, as well as materials that prevent water from entering. In case of a flat roof, a surface-continuous waterproof insulation sheet provides protection against precipitation, while in case of a high roof, two layers do accordingly: the roof cladding (e.g. tile, sheet metal, bituminous shingles) and the underlying foil together provide protection.

Requirements and consequent function



- insulation against precipitation
- space delimitation
- thermal insulation (flat roof and high roof in case of attic installation)
- sound insulation (flat roof and high roof in case of attic installation)

Typical structures



1. Monolithic structures

Reinforced concrete structure with formwork on site. The formwork can also remain in the structure, thus simplifying the construction. This solution is usually used for flat roofs where the distance between the supporting structures is large (large span). Thermal, sound and water insulation are provided by the installation of additional layers.

Advantages
- high load bearing capacity
- fireproof

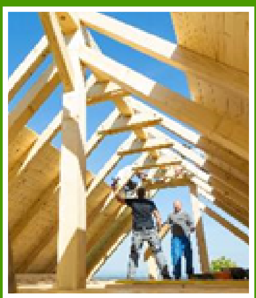
Disadvantages
- heavy
- poor thermal insulation
- formwork required (which can be left in place)
- high demand of on-site labour
- construction is more time-consuming

2. Beam and Block Structure (Beam and block)

Load bearing is provided by beams (nowadays they are typically made of concrete or concrete-ceramic composite material, but in the past steel beams were also common), and the sections between them are filled with block elements. This solution is used in case of flat roofs. Thermal, sound and water insulation are provided by the installation of additional layers.

Advantages
- high load bearing capacity
- fireproof
- fast construction
- a traditional, well-known solution

Disadvantages
- heavy
- high demand of on-site labour
- generally poor thermal insulation



3. Lightweight structures

High roofs typically have this type of structure but these solutions are also applied in flat roofs. In case of a flat roof, the difference compared to the intermediate slab is that additional layers are applied to provide thermal and water insulation (sloping layer, waterproofing sheets, additional thermal insulation, etc.). In case of a high roof, the sloping load-bearing beams are called rafters, and the horizontal ones are called slats. The rafters or slats (depending on the structural design) are covered with roofing and with the necessary structural layers (underlay, roof slats, tiles, etc.). In case of an attic, the parts between the supporting structures are filled with thermal insulation material and are covered from the inside (usually with plasterboard or other building board). Vapour barrier is provided as foil.
It can be partly or completely prefabricated or assembled on site.

Advantages
- fast construction
- a traditional, well-known solution
- lower on-site labour requirements
- can be prefabricated in operation
- light
- good thermal insulation

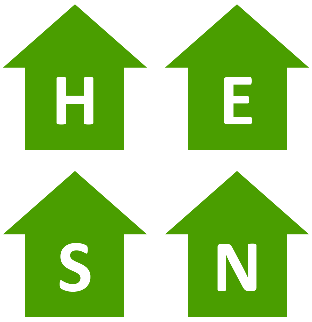
Disadvantages
- sensitive to fire

Doors and windows

A predominantly vertical (typically the roof plane window located in the plane of the roof) boundary structure between the exterior and the interior. It has no load-bearing function. Its tasks are to ensure at least one of the following:

- access;
- view;
- natural ventilation;
- lighting with natural daylight;
- favourable facade appearance.

Requirements and consequent function



- space delimitation
- thermal insulation
- sound insulation
- safe operation
- architectural appearance

Typical structures

1. Wood

The traditional material for doors and windows. Today's complex and high-level requirements are met by complex structure designs developed by professional engineering work.

Advantages
- pleasant surface

Disadvantages
- expensive
- high maintenance
- UV sensitive

Typical structures

2. Aluminium

Light metal frame covered door and window, which is made for various profiles and appearances.

Advantages
• high load capacity
• stability
• long service life
• not sensitive to UV
• low maintenance

Disadvantages
• expensive
• less pleasant feel of the metal surface
• worse heat insulating capacity

3. Plastic

Doors and windows with a plastic (usually PVC) frame structure and cover, which are made for various profiles and looks.

Advantages
• economical (good value for money)
• long service life
• good thermal insulation
• low maintenance

Disadvantages
• UV sensitive

4. Wood / aluminium, plastic / aluminium

It combines the advantages of doors and windows of different materials. Primarily, the outdoor aluminium cladding is important, it prevents damage from UV radiation

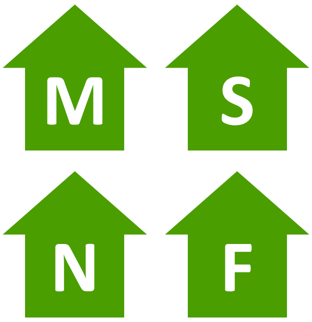
Advantages
• UV resistant
• low maintenance necessity

Disadvantages
• expensive

Interior walls
(partition wall, interior bearing wall, sound proofing wall)

A structure that vertically separates the interiors of the building. Its length and height are multiplied compared to the values of structural thickness. In addition to space separation, it can also have other functions: load-bearing, sound insulation, in rare cases thermal insulation.

Requirements and consequent function



- in case of internal load-bearing walls, load-bearing, stiffening
- fire demeanor appropriate to its role in the building
- impact resistance
- carrying equipment and fittings
- sound insulation according to the level of demand

Typical structures

1. Monolithic structures

A wall structure, typically of concrete material, cast between the formwork. Due to its high load-bearing capacity, it is used as a load-bearing wall. A solution rarely used in family houses and smaller condominiums.

Advantages
• high load-bearing capacity

Disadvantages
• high demand of on-site labour
• requires formwork
• slow construction
• expensive

Typical structures

2. Remaining shutter monolithic structure

A wall structure made of formwork elements, which is poured with concrete at the construction site. Formwork elements are most often made of lightweight concrete, polystyrene, or wood wool / wood concrete, and can be moved by hand.

Advantages
- high load-bearing capacity
- not require a high level of expertise

Disadvantages
- high demand of on-site labour
- less common solution

3. Built of masonry

The most commonly used solution for residential buildings. Occasionally made of stone or concrete, more often brick (fired clay masonry element), aerated concrete, wood concrete, gypsum elements.

Advantages
- traditional, a known solution
- not require a high level of expertise

Disadvantages
- high demand of on-site labour
- it allows a lot of moisture entering into the structure
- time consuming construction

4. Lightweight structure

Some kind of frame structure (typically wood or thin-walled steel) provides the supporting structure, the cavities between them are filled with thermal insulation. Both sides are bordered by building boards (usually gypsum board inside, OSB board outside, but gypsum fibre and cementitious chipboard are also common). It can be partly manufactured, completely prefabricated, or assembled on site.

Advantages
- fast construction
- less weather-dependent design
- lower on-site labour requirements
- can be prefabricated

Disadvantages
- sensible to fire
- its preparation requires a high level of expertise
- complicated structural build up

4.3 Building materials

There are many types of building materials and with the improvements of manufacturers, more and more new products are appearing on the market. In the following section, we present the most frequent building materials, grouped by functionality. Their detailed properties are described in the annex of this handbook.

Concrete – a mixture of cement, water, aggregate (typically gravel -with a professional expression: sandy gravel) and in some cases, admixtures. It is incorporated in a wet-plastic state and acquires its final shape and load-bearing capacity during the chemical transformation that takes place during drying-solidification (usually within 28 days). It usually has high load-bearing capacity and strength, but its load-bearing capacity depends on many factors (amount of cement, type of aggregate, etc.). Steel bars and nets are often used to increase the load-bearing capacity, in which case they are referred to as reinforced concrete. Prefabricated elements can also be made from it. It is not combustible. It can be waterproof if properly formulated. It is versatile and can be used for almost any supporting structure from base to flat roof.

Masonry elements

–building blocks of a size movable with hands from which masonry can be made. Masonry elements are usually clamped to each other with a mortar or a special adhesive mortar, but the geometrical design of the adjacent elements can be (so called groove design) that does not require fastening material.

Most common types:

brick (fired clay masonry element) - building elements made of clay, which, after moulding, burned out at an ambient temperature of 1000 ° C. Its main varieties are solid, hollow bricks. Not combustible. Moderately sensitive to water. Fired clay is also used as a slab lining element and a bridge in various building systems, and can be used also as a facade cladding element. One of the most common masonry elements is the frame ceramic brick, which in case of light load - e.g. it can also be used as a 1-2 storey house - load-bearing wall, but it is built as a space delimiting, space dividing and facade infill masonry.

aerated concrete - a masonry element based on lightweight concrete or aerated concrete. A pore-forming additive is added to the fresh concrete mix, which will thus have a “perforated” structure. It is significantly lighter than conventional concrete, so masonry elements have a manually movable mass and are better thermal insulators. Not combustible. Less sensitive to water. In addition to masonry elements, large wall, ceiling- and roof planks can also be made of aerated concrete.

Most common types:

clay/loam- a mineral additive mixed with organic fibres (e.g. straw), a mixture of clay, sand and occasionally sludge. The mineral part can also come from clay soil or an artificial mixture of clay and sand. A homogeneous structure can be made of it by compaction (so-called beat wall), or it can be made of moulded and compacted bricks. It is one of the basic building materials of folk architecture. It is not combustible, but its load capacity is reduced by fire. Sensitive to water. It is usually used for walls.

natural stones - materials rarely used today, these masonry materials are carved natural stones, e.g. andesittufa, rhyolite tuff, basalt. They are not combustible. They are sensitive to water to varying degrees. In the past, they were used for both priming and wall making in easily accessible areas.

Thermal insulation materials – low-density building materials for thermal insulation. They are also varied in material and construction. They are usually in the form of boards, quilts or bulk. If they absorb water, it greatly impairs their thermal insulation capacity. Their important property is vapour permeability, which affects the type structures they can be incorporated into.

Most common types:

ESP (expanded polystyrene) - thermal insulation made of foamed plastic (polystyrene), which consists of small spheres. They can be enriched with graphite, which improves its thermal insulation. It is usually low-solidity, but there is also a “step-resistant” version with increased firmness. Combustible. It can absorb water. Moderately vapour permeable. Uncompressed spheres typically sold in slabs, but also used also as concrete additive. Its main areas of application are thermal insulations for facade walls, flat roofs and floors on the ground.

XPS (extruded polystyrene) - homogeneous, foamed plastic (polystyrene) thermal insulation. It usually has a low-solidity, but there is also a “step-resistant” version with increased firmness. Combustible. It does not absorb water (this is the most significant difference in terms of use between EPS and XPS). Its vapour permeability is low. They are sold in boards of different thicknesses. Its main areas of application are the thermal insulation of plinths, flat roofs and floors on the ground.

PUR - homogeneous, foamed plastic (polyurethane) material for thermal insulation. Due to its very good thermal insulation ability, it often used in cold stores and other areas where a thinner layer requires more thermal insulation performance. Its solidity can even be extremely high, depending on its chemical composition. Combustible (there are versions that are less combustible – e.g. PIR foam). It does not absorb water. Its vapour permeability is low. It used in several forms. It can be panelled, sandwich panelled, or foamed on site (two-component). Its main areas of use are sandwich panels and cold stores.

Most common types:

rock wool - a thermal insulation material made mainly of glassy fibres and thermosetting (usually phenol-formaldehyde) binder resin made from a melt of a mixture of volcanic and sedimentary rocks (e.g. basalt, diabase, limestone, etc.). Its solidity ranges from relatively high (step-resistant versions) to negligible. Non-combustible and even is used as a flame retardant. It has the ability to absorb water. Due to its fibrous structure, it is vapour permeable. It can also be in the form of boards and quilts. The panel version is used for the insulation of facades and flat roofs, the quilt (which is sold in rolls) is used to fill the frame structures (walls, ceilings, roofs).

glass wool - a thermal insulation material made of mineral fibres similar to rock wool. Its raw material is sand, recycled glass and binder resin (usually phenol-formaldehyde). Its solidity ranges from relatively high (step-resistant versions) to negligible. Not combustible. It has the ability to absorb water. Due to its fibrous structure, it is vapour permeable. It can be in the form of boards, quilts, or bulk fibres. The panel version is mainly used for sound insulation, but there is also a version suitable for facade thermal insulation. The quilt (which sold in rolls) used to fill frame structures (walls, ceilings, roofs). Bulk fibrous glass wool, which is blown in with a special machine, can be used to insulate hard-to-reach places (e.g. cavities).

cellulose - bulk thermal insulation made from recycled paper to which additives (usually boron, boric acid and phosphate) added to protect against fire and biological pests (mould, rodents). The solidity of the material is negligible and it is not loadable. Not combustible. It has the ability to absorb water. Vapour permeable. They are introduced into the building structure by machine blowing, it also fills irregular or small gaps and gaps between the frame columns and beams.

straw - a natural thermal insulation material, an agricultural by-product consisting of the stalks of cereals after ripening. Its use in construction is limited. Combustible. It has the ability to absorb water. Vapour permeable. Its most common application is the filling thermal insulation of frame structures, which can be in bales or in bulk and compacted. It is extremely important that the structural design have to provide protection against fire, water, and biological pests.

wood wool - a thermal insulation product made of wood fibres with the addition of a binder or adhesive. The binder can be an organic or inorganic resin, or even cement. It is made with a variety of fibre sizes and densities. It can also be heavy duty. It is hardly flammable (but it depends on the density and the binder). It has the ability to absorb water. Vapour permeable. Manufactured in slabs, used for facade, flat roof and ceiling thermal insulation.

Frame materials - in lightweight structures, load bearing is provided by beams and columns, as they do not form a continuous wall or ceiling surface, therefore, their function is limited to load-bearing capacity. In larger buildings (for high loads) they are made of concrete or thick-walled steel profiles, while for lower loads, wood and thin-walled steel are common.

Most common types:

wood - a natural building material. Its strength properties can be very assorted, strongly depending on the species of wood, moisture content, cramping, etc. In the construction industry, typically pines are used. Common methods of improving the properties of construction wood products are longitudinal expansion, artificial drying and ply gluing. Wood is treated with wood preservatives against fire and biological pests.

thin-walled steel - the various profiles (U, C, Z - these symbols refer to the shape of the profile) are produced by cold rolling, from sheet steel. It must be protected against corrosion (galvanizing). It is non-combustible, but loses most of its load-bearing capacity at temperatures around 600 ° C. It is resistant to biological pests, but its protection against water must be ensured with a layer of zinc.

Most common types:

bituminous insulation - bitumen is a black, thermoplastic hydrocarbon mixture which remains after the distillation of mineral oil. It can be used in several forms as insulation: lubricated insulation (bitumen emulsion, solvent bitumen), thin and thick sheets, which can be provided with surface protection if necessary. They are sold in rolls. They are usually made in multiple layers. It is also widely used as an insulation against soil- moisture and vapour, rainwater, service water and vapour.

plastic waterproofing materials - waterproofing sheets can be made of different types of plastics. They can be thermoplastic so-called plastomer (e.g. plasticized PVC (polyvinyl chloride)) or non-thermoplastic elastomeric (rubber-like, e.g. butyl rubber, EPDM) materials. They are usually made in a single layer. They are rarely used as insulation against soil moisture and soil vapour, usually used as insulation against rainwater.

polyethylene (PE) film - a thin film made of polyethylene, its main mode of application is vapour barrier. Fibre reinforcement is used to improve its mechanical properties.

aluminium foil - a thin aluminium foil used for vapour barrier. It can be multilayer and fibre reinforced.

Water and vapour insulation - we use different insulation sheets and foils against water and vapour. In case of insulations, durability and UV resistance in locations that are exposed to sunlight, as well as the formulation of waterproof design of splices and fixings are important. Insulating materials are bitumen, plastic (most commonly PVC and polyethylene) or aluminium. Based on function, we distinguish between insulation against soil- moisture and vapour, rainwater, service water (e.g. bathroom) and vapour.

Roofing - building materials used for covering high roofs. They are diverse in both material and form. Their primary function is to prevent rainwater from entering the structure. At the same time, it is important to emphasize that they are not waterproof as they only form a watertight surface, so underlay is necessary under them. As an outermost layer, it also strongly influences the architectural appearance of the building.

Most common types:

tile (clay and concrete) - a single-element roofing material that can be made of fired clay or concrete. It characterized by a variety of formal designs. The tiles are fixed to roof slats, the elements overlap. The angle of inclination of such covered roofs is preferably 35-45 °.

bituminous shingles - self-adhesive roofing material made of bitumen applied on a strong substrate, its surface is covered by granules. It must be fixed on a continuous substrate (e.g. OSB) and the elements overlap. It can also cover a variety of roof shapes and can be used at an angle of between 15 and 90 °.

Most common types:

sheet metal - roofing materials made of thin sheet metal, usually with surface protection against corrosion. Their materials can be varied, the most commonly used are galvanized steel, titanium-zinc, aluminium and copper. In terms of form and fixation, the most common types are:

> *metal roof* - a metal plate forming a tile in its appearance, it is fixed to roof slats with the elements overlapping each other. The roof inclination is at least 15 °.
>
> *trapezoidal plate* - a self-supporting plate with a characteristic of a trapezoidal cross-section, it is fixed to flanges. The minimum roof inclination is 5 °
>
> *standing seam metal roof* - long sheets are fastened together at their edges with special tools. They need full-surface support. The roof angle is at least 10 °.

slate - single-element roofing material, made of natural slate rock. Once the use of asbestos slate (of which there was a single-element and a large-element so-called corrugated slate) was widespread, which is a roofing material made of asbestos and cement. Usage is now banned, as asbestos presents a serious health hazard. Fibre cement is a slate-like roofing material produced with asbestos-free technology. The slate fixed to the surface-continuous substrate by nailing or stapling, the elements overlapping each other. The minimum roof inclination is 22 °.

wooden shingles - one to two centimetres thick, six to fifteen centimetres wide, thirty to sixty centimetres long, split or sawn wood roofing material. They fastened to the roof battens with nails and the elements overlap. The minimum roof inclination is 10 °.

reed - a natural roofing material, the reed is tied into sheaves and fixated to the roof slats with a large thickness (50-100 cm). It has good thermal insulation, but it is highly flammable. The angle of inclination of the roof is usually 30-45 °.

Facade cladding (and cladding systems) - the outer layer of the facade walls, which, in addition to significantly contributing to the appearance of the building, has the main function of protecting the underlying layers from mechanical damage and precipitation. It is characterised by a variation in terms of appearance and material use.

Most common types:

plasters - the most common facade-forming materials. The plaster mixture is applied to the wall after mixing it with water. It usually consists of several layers with different functions. To improve their mechanical properties, plaster reinforcement mesh is installed. It is applied directly to the thermal insulation system or to the masonry unit.

metal cladding - thin, shaped metal sheets that are attached to some secondary structure (i.e. not directly to the retaining wall). The material can be varied, the most common is galvanized steel, titanium-zinc and the aluminium. According to their design, the most common types are:

trapezoidal plate - a self-supporting plate with a characteristic trapezoidal cross-section.

cassette cover - small and medium-sized bent sheet made of rectangular elements.

panel cladding (sandwich panel) - not only wall cladding, as it also provides space and thermal insulation as an element. There is a thermal insulation core (usually PUR, PIR, rock wool) between two metal sheets.

Most common types:

wood cladding - coverings made of planks, planks or plywood, which are fixed to secondary structures (e.g. slats), there is an air gap behind them (therefore it is advisable - in Hungary it is mandatory - to use non-combustible thermal insulation for such coverings). It is necessary to protect it from the weather with surface treatments. The high fluctuations in temperature is not well-tolerated in terms of the material.

stone cladding - natural stones used as facade coverings cut into 2-8 cm tiles. It is usually fixed to the secondary support structure with special fastening elements, but - if the wall structure is suitable, it can also be fastened with gluing. Their durability and the demand for maintenance depend on the material of the stone and surface treatment.

brick cladding - fired clay cladding material. The brick of normal thickness (10-12 cm) is fixed to a secondary support structure, the covering brick, which is 2-3 cm thick, is fixed by gluing. It gives a distinctive look to the building. Minimal maintenance is required for this covering.

Building boards - surface-continuous, self-supporting boards, fastened usually to the back structure mechanically (by nailing or clamping). Their use is extremely versatile, in case of lightweight construction it can be used as a cladding plate, as an underlayer itself for roofing, and in many other cases with the aim of covering gaps and cavities.

Most common types:

gypsum board - the basic material of gypsum and cardboard. It is non-combustible and even has excellent fire protection properties (there is also a version with increased fire protective properties). It is normally sensitive to water but this property can be improved by impregnation. Its stiffness and impact resistance are not outstanding. It can be used indoors.

gypsum fibre board - building board made of gypsum, paper fibres and mineral wool additives. It has high rigidity and high impact resistance. It is non-combustible and it has good fire protective properties. It is less sensitive to water, so it can be used outdoors with adequate surface protection.

cement-bonded chipboard - made of wood chips, cement and additives. It has a high surface hardness, it is rigid and the material is impact resistant. Not combustible. It is not water sensitive and can be used outdoors.

OSB (Oriented Strand Board) - it is a wood-based material. The name refers to its material structure, which ensures the strength of the product. In terms of its structure, it is a three-layer sheet, the position of the chip-layer in the middle is perpendicular to the longitudinal side and in the extreme layers, it is parallel to it. The fibres are compressed under high pressure with a water and heat resistant resin. It has good mechanical properties, is a flexible, impact-resistant and combustible material. It is less sensitive to water, so it can be used outdoors with adequate surface protection.

plywood - a wood panel made up of an odd number of peeled veneer layers. The wood species and thickness of the symmetrically placed layers are the same. The layers used to be glued together, now it is more recently done with resin. The fibre direction of the layers is always perpendicular to the previous one. It has good mechanical properties, flexible, impact resistant. Combustible. It is sensitive to water but can also be used for outdoors with impregnation and adequate surface protection.

a. Construction products, declaration of performance (DOP)

In the minds of builders, such as designers and constructors, a building is made up of structures as well as building engineering, heavy and light current systems. The building engineering and electrical systems include wiring and "units," i.e., items of equipment such as an electric boiler, plumbing, bathtub, and faucet. The building structures consist of building materials and products, such as a slab of slab beams, lining bodies, concrete on top of them and additional reinforcing bars.

Some of the building materials, products, as well some of the equipment and devices are collectively called construction products. It is no coincidence that we wrote that "some" – as in the case of complex structures like buildings for example the whole systems is so complex that overlaps and exceptions quickly peek behind simplifications, but the above approach can be considered as a good one.

Construction is a serious matter as houses are built for a long time and a significant amount of money is involved, so it is essential to appropriately and precisely regulate the processes and conditions by means of law. The above-mentioned Building Act stipulates that a construction product may only be designed or installed in a construction if the basic requirements for construction are met. These basic requirements are also defined in the already mentioned government decree, Government Decree 253/1997 on national settlement planning and construction requirements, abbreviated and commonly known as OTÉK.

The essential requirements are described in more detail in Chapter 4.1 of the Handbook.

A product is considered suitable for a given design and installation situation if the essential requirements for construction works are met either directly or indirectly by the performance of the installed product. This means that the construction products are suitable, if the house built from them functions well and safely for a long time.

A construction product may be used if - with a few exceptions -, its performance is certified by a declaration of performance (DOP). This is a document issued by the manufacturer of the product, and it contains the characteristics required for its use, more specifically the performances at related to the essential requirements at least.

The DOP has been invented by the European Union. The EU regulation No 305/2011 of the European Parliament and of the Council entered into force on 1 July 2013, and it sets harmonised conditions about the distribution of construction products. This decree regulates the distribution of some construction products within the Union. The DOP summarizes in a document what we need to know about the product from a technical point of view. Its legitimate existence enables the product to hold a "passport", the well-known CE mark, which allows free travel throughout the internal borders.

DOP, as a type of document, therefore derives from this EU regulation, called CPR according to its abbreviation in English, which entails the EU market, the free movement and distribution of goods. A special Hungarian legislation, Government Decree no. 275/2013 about the design and installation of a construction product into a building and about the detailed regulation of certification regarding performance states that a construction product can be used only if it holds a DOP. This decree is only valid in Hungary, although the requirements are similar in many countries of the EU.

From the above-mentioned aspects, we can already see how it is important for all participants in the construction process, including the builder and the future residents, that the designed and installed materials, so the construction products have their appropriate DOP.

For a better understanding, we will briefly and, of course in a simplified way summarise the related elements of the design and construction process.

To provide an example, the client wants to let build a house. The client has a vague or general idea on how the building should look like, and then together with the designer they discuss and finalise their ideas in a so-called designer program. This is also important because this way a competent professional can help in formulating the ideas, and in clarifying processes that can be done and whether if it is worth to be done as well as what cannot be implemented as of the constructors' thoughts.

After that, the architect designs the house, getting there in numerous steps to think about how the building will be implemented. This includes determining the expected technical performance of the construction product to be used in relation to the essential requirements already listed above. It is also based on the effects arising from the construction and the use of the building, as well as on the legal requirements and professional rules. This is also part of the design process.

The constructor may only install such construction products into the house whose performance - as specified by the manufacturer in the declaration of performance - corresponds to the expected technical performance specified by the designer. Finally, all the process is documented by the declarations of performance.

4.4 Building services systems - heating, cooling, ventilation

Residential buildings today are almost unimaginable without various technical building systems. Most of these have become a part of our everyday lives that we hardly even notice there functioning. But what are these systems? To put it very simply, any equipment that is related to piping or wiring within a building can be considered. It includes plumbing, electricity and natural gas, as well as the chimney and associated machinery and fittings (boiler, vents, thermostat, radiators, etc.).

Building services systems play a variety of roles. They provide adequate comfort, such as heating in winter, and pleasant cooling in summer, hot and cold-water supply, drainage of the generated wastewater, and more and more often ventilation as well. Furthermore, these systems make sure that electricity from the grid is properly supplied to our electrical gadgets and equipment, or we can even produce our own energy using solar panels, solar collectors and so on. Further relatively common systems are alarm and access control systems, elevators and, much less frequently, central vacuum systems and automatic shielding systems.

From an environmental point of view, such equipment must be produced in the same way as building materials and, eventually, once they cease functioning, they will become waste. More importantly, however, their operation involves energy consumption, which is not only costly, but energy production is one of the most polluting industries.

The different building services systems are detailed in chapter 6.1.

Spread of Innovative Solutions for Sustainable Construction

Handbook

5

Energy conscious architecture - passive solutions

IS-SusCon

Co-funded by the Erasmus+ Programme of the European Union

5 Energy Conscious Architecture - Passive Solutions

A demand of heating and cooling energy of buildings can be reduced by passive solutions. In contrast to active methods, these solutions use only the building elements and the energy of the Sun without the need for any additional energy sources. It is a generally accepted approach that energy efficiency should be the first step towards a low energy house: saved energy is the cheapest energy. It is only worth installing active renewable energy systems if demand is already reduced by passive means.

Looking at the whole life cycle, passive measures also have the advantage that their embodied impact is usually very low or even zero – caused by the production and manufacturing of the materials-, while their saving contribution in the operational energy demand of the building. For example, a favourable building shape or a well-chosen orientation has no additional embodied impact, while thermal insulation has a relatively low impact. (see chapter 4.3 for more details).

The applicability of passive solutions depends on the climate. There are many different climate classification systems but we will use a simple and practical classification of Europe, which depends on the need for heating or cooling:

- Cold (heating-dominated climates), e.g. Finland
- Moderate (heating- and cooling-dominated (mixed) climates), e.g. Hungary
- Warm (cooling-dominated climates), e.g. the southern part of Italy

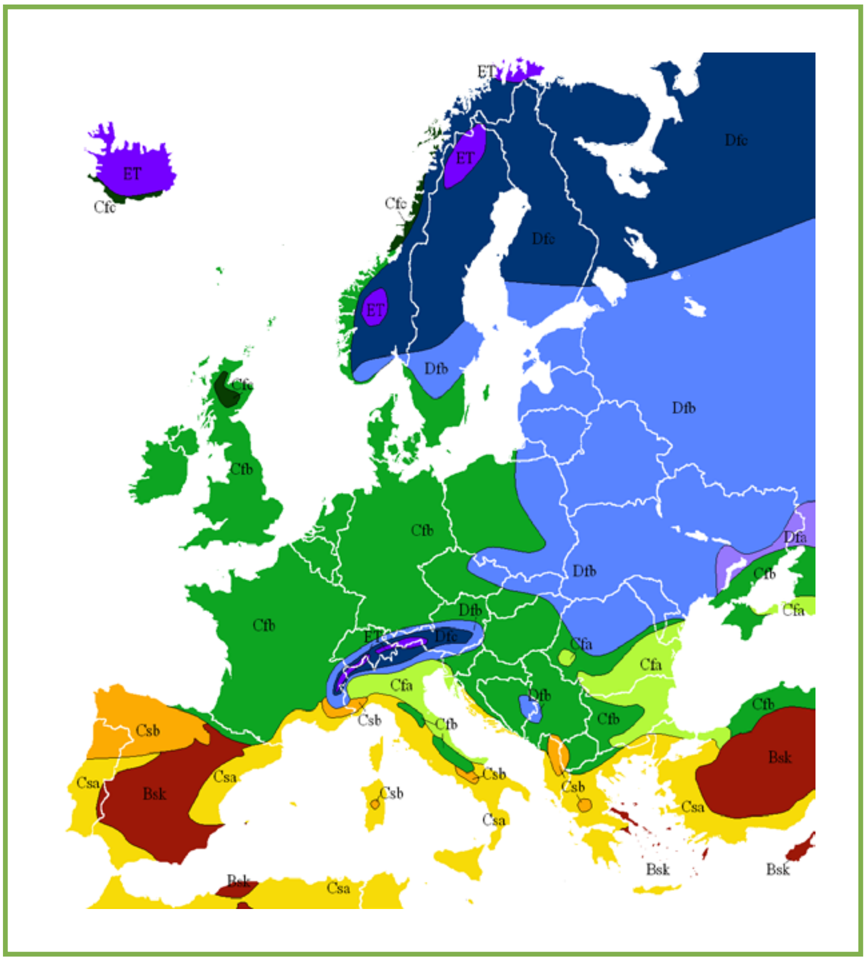


Figure 9: Climates in Europe according to the Köppen-Geiger climate classification[40]

Passive heating solutions are efficient in heating-dominated climates, passive cooling measures in cooling-dominated climates, while both are relevant in mixed climates.

5.1 The heat balance of a building

The heat balance of a building is basically the balance between heat losses and gains. In buildings, we would like to keep a certain temperature, which is called the set temperature in order to provide good thermal comfort for the residents. If heat losses are equal to heat gains, we do not need any heating. But if losses exceed gains, heating system will be needed to provide the missing energy.

40 Source: https://commons.wikimedia.org/wiki/File:Climates_of_Europe.png

Every building has heat gains. As heat gain covers a certain ratio of heat losses, we do not need to turn on the heating system immediately if the daily mean external temperature drops below 20 degrees. For example, in an average building in Hungary, most heating systems start to operate when the external temperature is below 12 °C for three consecutive days, which happens around the middle of October, because solar and internal gains cover the temperature difference. In a well-designed, low energy building, heat gains will cover a much higher ratio of losses, which leads to a shorter heating season and a lower heating energy demand. This can be achieved with a dual strategy: reducing heat losses and utilising as much solar energy as possible. Both are important in the design of an energy conscious building.

In the following chapters, we present passive heating and passive cooling solutions.

Heat balance of a building

Considering the case of heating, losses are due to transmission and ventilation, while the positive side of the balance is the sum of solar radiation and internal gains:

- Transmission losses arise as heat conduction and heat transfer through the structures surrounding of the building and thermal bridges
- Ventilation losses are caused by the exchange of warm internal air with external, colder air due to the need for fresh air
- Solar gains originate from solar radiation that enters the building through transparent (and non-transparent, opaque elements) elements
- Internal heat gains are the heat outputs from internal sources whose main purpose is not heating, such as people, appliances and equipment
- Furthermore, the actual heat balance is influenced by the change of stored heat stored in the mass of building elements: heat is either absorbed or released depending on the conditions. For a longer period, the change in the stored heat is zero if changes are periodic.
- If losses overpass gains, the missing energy is given by the heating system.

The energy balance is the algebraic sum of these items.

5.2 Passive heating solutions

Passive heating solutions reduce heating energy demand, which is especially important in heating dominated climates. In these climates, 'defensive' strategies are used to prevail: window sizes were kept small to reduce heat losses. Recognizing the importance of energy saving and the rapid technological development of glazing in the last decades has led to the advent of solar architecture: buildings are designed to harness the energy of the Sun through large, well-oriented glazed facades and heavy structures which can store a large amount of heat. While the heating energy demand of an average conventional building in Europe is around 200 kWh/m^{2}yr, for a low energy building that is around 50-70 kWh/m^{2}yr[41] and an extremely low energy building (passive house) can be as low as 15 kWh/m^{2}yr. The strategies to reduce the heating energy demand by cutting losses and increasing gains are summarised in the following sections.

In vernacular architecture traditionally, small windows were applied[42]

41 https://passiv.de/former_conferences/Passivhaus_D/Aufsatz_Passivhaus_1997.htm (last access in April 2021)
42 Source: https://commons.wikimedia.org/wiki/File:Szal_paraszth%C3%A1z%2Budvar.jpg (last access in April 2021)

a. Reduction of heat losses

The most important measures to reduce heat losses are the following: buil-ding shape, thermal insulation and airtight building envelope. It is essential to mention a very simple but efficient way to reduce heat losses: not setting the internal temperature too high. A one-degree reduction in the internal temperature results in an approximately 6-10% saving in terms of heating energy demand in a typical residential building in a moderate climate.[43] However, the temperature should be still high enough to provide adequate thermal comfort

Building shape

Shape matters. The majority of a building's energy quality is already determined when the architect draws the first sketches. A compact shape will have lower heat loss than the distributed, complicated forms. The shape of the building can be characterised by the so-called surface-to-volume ratio (A/V): that is the surface of the building envelope separating the heated interior space from outside, divided by the heated volume. A smaller surface-to-volume ratio is favourable, as the surface area in contact with the exterior is smaller for each unit of volume. An ideal building would have a spherical shape. Due to practical reasons, dome-shaped buildings are rare in terms of occurrence but cubic buildings without unnecessary protrusions are also beneficial. However, very deep floor plans should be avoided because the amount of daylight and natural ventilation may be insufficient in internal spaces. In Central Europe for example, the maximum depth penetrable by sunshine in the winter is approx. 6 m the window.[44] Slightly elongated rectangular forms work well both for heat reduction and for solar gains.

43 https://www.energy.gov/energysaver/thermostats (last access in April 2021)
44 Zöld, András; Szalay, Zsuzsa; Csoknyai, Tamás: Energiatudatos építészet 2.0

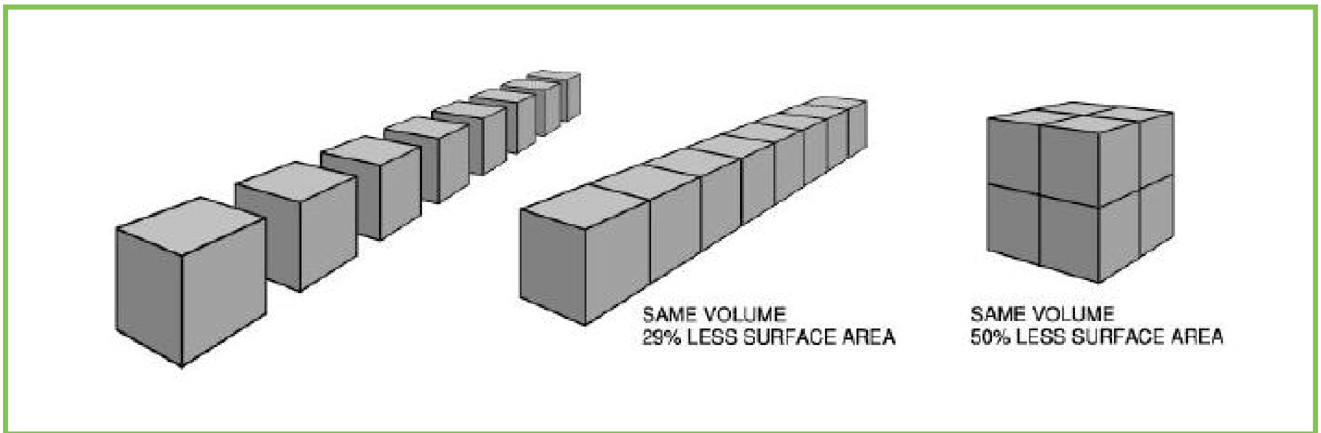


Figure 12: Compared to the first case, the second arrangement has the same volume but 29% less surface area, while the third 50% less surface area

Size matters. While the increase in surface area is squared, the increase in volume is cubed, hence larger buildings have a lower surface to volume ratio. A large multi-family apartment house has a much lower energy demand per m^2 floor area than a detached house with the same insulation level! The figure below shows the specific (primary) energy demand of a building sample, with each point representing one building (this energy includes space and hot water heating, multiplied by a so-called primary energy factor describing the efficiency of the energy carrier conversion). Each building in the sample is the same regarding the insulation level, thermal bridges, airtightness, building service systems, etc., with the only exception being the size and the shape of the building. Yellow dots represent one-storey buildings with an average energy demand of 100 while the energy demand of large, 10 storey buildings may be as low as 75 kWh/m^2yr. There is also a big difference between buildings in the same category: the energy demand of a compact detached house is about 20 kWh/m^2yr less than that of a complex shape.

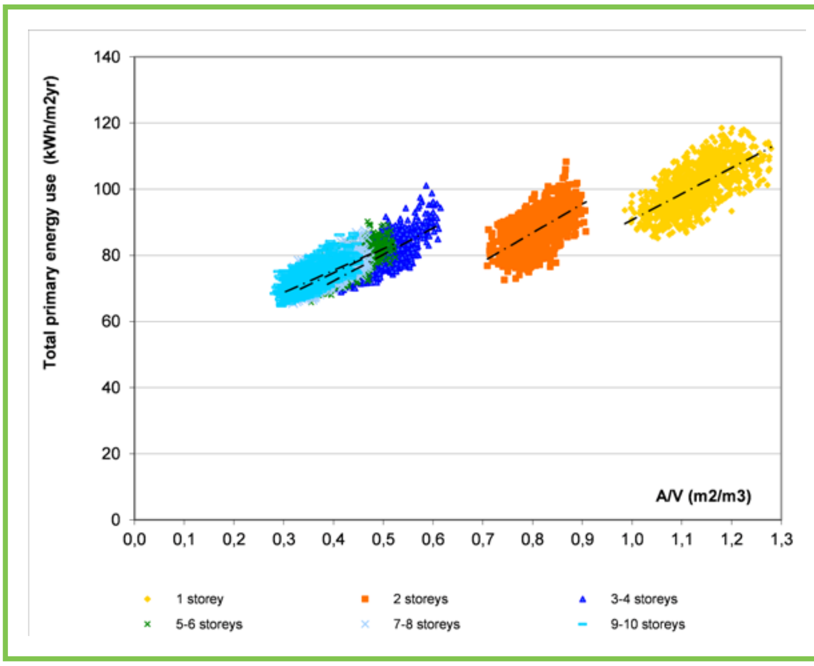


Figure 13: Total (primary) energy demand of a building sample with uniform insulation levels but different number of storeys and shape [45]

45 Source: Zsuzsa Szalay

Space matters. It should be noted that efficient space usage also contributes to energy savings. Even the most compact, very well insulated but oversized detached house consumes energy, and saving on space also saves energy. Consider the real needs of a family when deciding on the size of a house to be established. It's also worth noting, however, that this is a complex matter with several further aspects to be taken into account. For example, housing rights and subjective considerations. The size of the building also affects the amount of land occupied, which is also an environmental indicator.

Orientation matters. The orientation of the building should take into account the prevailing wind direction and should be favourable for solar energy utilisation (see chapter 5.2.b). The arrangement and zoning of the floor plan should follow the Sun: buffer spaces where lower temperature is acceptable or desirable, such as storage rooms, pantry or bathrooms should face North, while living rooms should open up to the Sun. In mixed climates, two terraces or balconies work well: one to the South and one to the North, to be used in hot weather.

Thermal insulation

The transmission heat losses of a building are reduced in the most efficient way by applying high levels of thermal insulation. Although thermal insulation manufacturing also causes emissions and energy needs, the environmental payback time is quite short in terms of time, for the common materials, i.e. the energy saving exceeds the embodied energy in a few years (see chapter 4.3.). Insulation leads to energy savings but also ensures good thermal comfort and protects the building fabric. A side effect of insulation is that the internal surface temperatures will be higher compared to a poorly insulated structure. That influences the so-called operative temperature, which is the result of the air temperature and the radiant temperature of the enclosing surfaces. This is the temperature that humans actually feel and it is used for describing the thermal comfort. As the radiant temperature is high, the air temperature can be lower for the same thermal comfort, which results in further energy savings.

Figure 14: Blowing of cellulose insulation into an attic

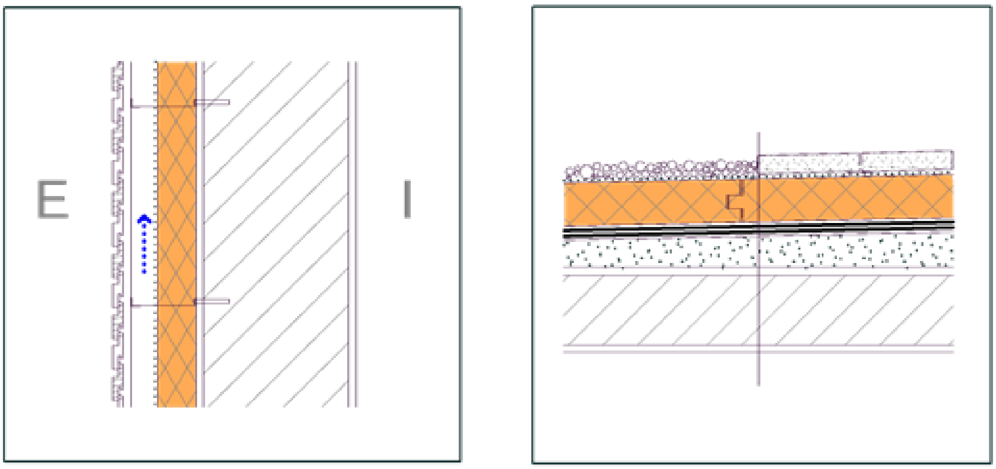


Figure 15: External wall and flat roof with insulation[46]

The thermal transmittance (U-value) shows how much heat is transferred through 1 m^2 of a building structure if there is a temperature difference between the two external surfaces, in W/m^2K. The lower the U-value, the better the insulation. The typical numeric values are rather low: a U-value of 1 or above indicates a poorly insulated structure, while well insulated elements have U-values of 0.1 - 0.3 W/m^2K. For example, in Hungary new external walls need to have a U-value of less than 0.24 W/m^2K, corresponding to an insulation thickness of approx. 14-16 cm if a conventional insulation material is applied.

A very important indicator of the insulation capacity in case of the building structures, is the so-called U-value or thermal transmittance.

46 Source: Zsuzsa Szalay

The U-values of windows are typically higher than the U-values of opaque elements (for modern windows 0.7-1.6 W/m^{2}K), but we should not forget that windows contribute not only to heat losses but also to heat gains: glazing transmits solar energy to the room behind and this reduces the heating energy demand (see chapter 5.2.b). For example, the overall winter energy balance of a south-oriented window in a moderate climate is positive: that means that more energy is transmitted through the glazing than the total heat lost through the window in the heating season. When selecting a window, it is essential to pay attention to the fact that many manufacturers indicate only the U-value of the glazing, which is usually better than the U-value of the frame. The U-value of the whole window is the surface weighted average of the frame and the glazing. In cold climates, triple glazing with special coatings and gas filling is required, while in warm climates double glazing may be sufficient.

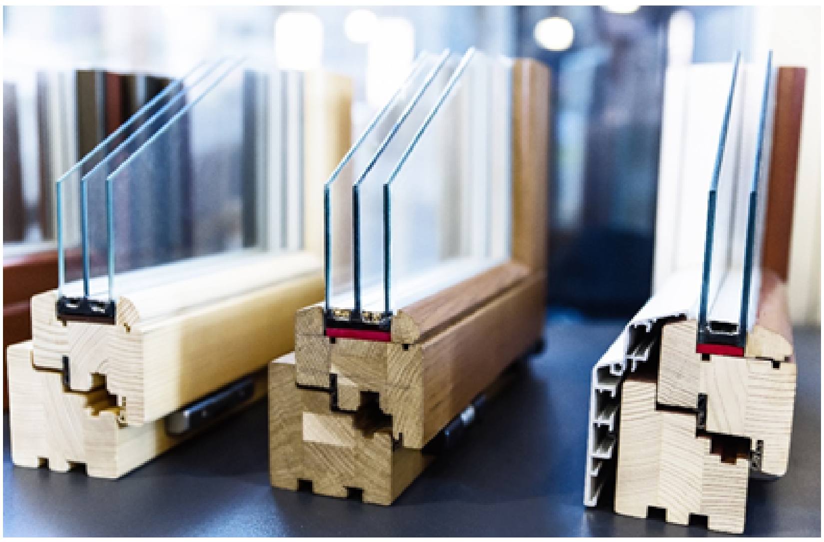


Figure 16: Wooden windows with double or triple glazing

Thermal bridges

Thermal insulation of the surfaces is very important but special attention should be paid to the details of the building. Additional heat losses may occur at every junction and at every change in the building elements. These are called thermal bridges. Let's think about the simplest thermal bridge that is present in every building: wall corners. When we look at the wall corner from the inside, we only see a line. From the outside, there is a large surface corresponding to this line, hence the heat losses at the 'line' are much larger than on the general surface.

This type of thermal bridge is called a 'geometric' thermal bridge. Geometric thermal bridges occur in every building and it is practically impossible to avoid them. Other types of thermal bridges are, for example, due to the change in the material use, e.g. load-bearing reinforced concrete pillars in a brick wall or the junction of a reinforced concrete slab with a brick wall. Even wooden rafters in a roof are thermal bridges compared to the infill insulation in a heated attic, as the insulation capacity of wood is about three times lower than that of the insulation. It is important to install additional thermal insulation at these types of thermal bridges not only to minimize the heat losses but also to avoid the reduced internal surface temperature. If the internal surface temperature drops below a critical value, the risk of condensation and mould growth significantly increases.

Figure 17: Mould growth after window change, due to thermal bridges and insufficient ventilation[47]

Handling thermal bridges is especially challenging when existing buildings undergo renovation, as it is often difficult to insulate some of the building elements and junctions. For example, insulating a slab on the ground would mean that the floor construction must be completely rebuilt and the change in the ground floor level would affect all adjoining structures. In this case, a perimeter insulation along the footing is effective for reducing the ground heat losses but this also requires a lot of groundworks. Even relatively small insufficiencies in the insulation layer may contribute to significant losses. For example, insulation should be turned in to cover the vertical soffit at the edge of the window, even if its thickness is limited by the window frame. The best option is if windows are installed in a way that they are connected to the surface insulation or they are in the plane of the insulation. Deficiencies in the insulation layer can be controlled with the help of infrared thermography.

47 Source: Martin Marosvölgyi

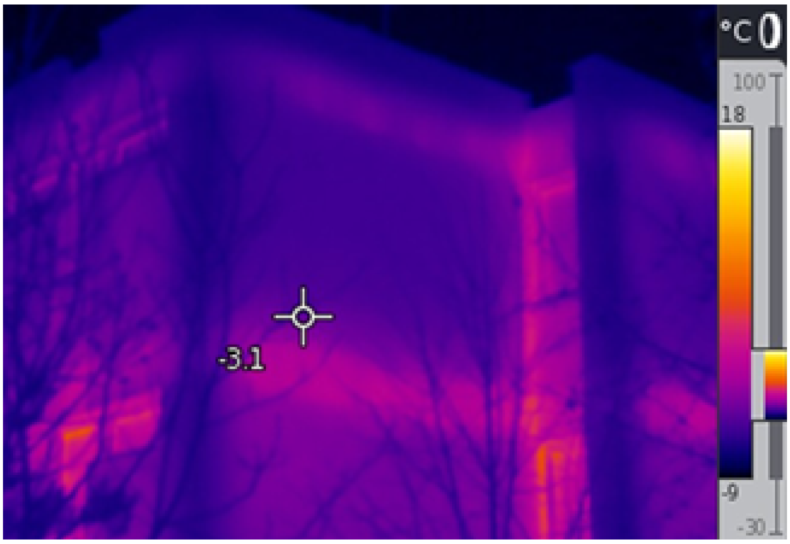


Figure 18: Thermal bridges can be detected with the help of infrared thermography[48]

People need fresh air for their health and comfort. However, it is important to distinguish between ventilation and infiltration. Ventilation is the deliberate movement of air to remove odours and contaminants, and it can be provided through opening the windows or a mechanical ventilation system. Infiltration, on the other hand, is an unintentional air exchange between inside and outside through the cracks in the building fabric. It is unwanted as it leads to uncontrolled heat losses. To minimise infiltration, an airtight building envelope is needed.

In general, the 'pencil rule' applies: if we take a look at the cross section of a building, we should be able to follow the airtight building envelope without lifting a pencil. It is easier to fulfil airtightness in solid masonry or concrete buildings, where the building envelope can be sealed through internal plastering. In lightweight constructions such as in a timber frame wall or a pitched roof, airtight membranes should be installed. Again, special attention should be paid to the details: even small holes, such as plug sockets or piping penetrations may contribute to very large air leakages. Through these gaps, moist internal air may penetrate the structure and may lead to serious damage in the fabric. While modern windows are usually very airtight, window joints are typical weak points: the joint between the wall and the window must be sealed with an airtight tape.

48 Source: Zsuzsa Szalay

Providing fresh air is still necessary in a very airtight building but this can be conducted in a controlled way. If ventilation is provided through a window opening, it is important to ventilate the apartment well at least twice a day or even more often depending on the use. In wet rooms, humidity-controlled trickle vents can be applied that automatically open if humidity levels exceed a certain level. Ventilation may be provided artificially as well. This has the advantage if a heat recovery unit is also installed that heat loss is reduced this way significantly. (see chapter 6.1).

Blower door test

The airtightness of a building can be tested with a so-called blower door test where a fan creates a pressure difference between the inside and outside. The airtightness of the building, indicated by the air changes per hour at 50 Pascal pressure difference (ACH50 or n50), can be calculated from the rate of airflow. Old buildings may have a value of n50 over 10, typical new buildings around 2-5, but the requirement for a passive houses is 0.6 h^{-1}. This test is compulsory for new buildings in some countries as this test can help filter construction errors.

b. Increase of heat gains

Heat gains reduce heating energy demand. The two main types of heat gains are solar gains and internal gains from residents, appliances and equipment. As the operation of appliances consumes electricity, it should not be wasted for heating purposes only, it is worth buying energy efficient machine with high efficiency. Solar energy, on the other hand, is ‘free’ and can significantly contribute to heating.

Solar gains

Every building with window uses solar gains in a passive way. Obviously, solar gains depend on the orientation of the surface. In the Northern hemisphere, surfaces oriented towards the south with an inclination roughly corresponding to the latitude, receive the maximum incident solar radiation. For example, in Hungary, the total solar radiation on a surface oriented towards the south with an inclination of 45° is about 450 kWh/m^2 in the heating season, while for a vertical surface it is around 400 on a South, around 200 on an East/ West surface and around 100 kWh/m^2 on a North facing surface. As heat gains exceed heat losses for a modern South facing window in the heating season, a high window ratio is beneficial on the South façade but steps must be taken to provide shading in the summer to reduce the risk of overheating. (see chapter 5.3.a)

The phenomenon of greenhouse effect

To understand how solar gain contributes to heating, it is important to remember first what the greenhouse effect is. The energy of the Sun is transmitted through the atmosphere and some of this energy is absorbed by the surface of the Earth. Heat then radiates from Earth towards space but some of this heat is trapped by greenhouse gases in the atmosphere and warms the Earth itself. Why is this heat trapped? Because greenhouse gases transmit most of shortwave radiation coming from the Sun, while they block most of the longwave radiation of the Earth. The same phenomenon is observed on a building scale: most of the solar energy is transmitted through the glazing, it is then reflected, absorbed and re-radiated by the surfaces until it heats up the whole room. It is trapped in the room, as glazing, similarly to greenhouses gases, has a very high solar transmittance for shortwave radiation but its transmittance dramatically decreases in the longwave range, which is radiated by the surfaces of the room. The solar transmittance value of the glazing is characterised by the g-value.

Thermal mass

Thermal mass helps reducing temperature fluctuations inside a building. This is beneficial both in winter and summer. In winter, solar radiation is absorbed by the thermal mass during the day and later released when the temperature drops. This results in a higher utilisation of solar gains and hence plays an important role in passive solar heating systems. Also, installing a heating system of lower capacity will be sufficient in such an instance. High thermal mass is an advantage in buildings that are continuously in use, such as homes, but it may be counterproductive in a rarely used holiday house where it takes longer to heat up the structure. The relevance of thermal mass in summer is explained in chapter 5.2.

Thermal mass is a function of the density and specific heat capacity of building materials. (The heat capacity describes the amount of heat to be supplied to a given mass of material to produce a unit change in its temperature.) Heavy materials such as concrete, brick and stone have a high thermal mass. The production of these materials require typically rather energy intensive procedure and this needs to be taken into account in the evaluation of their whole life cycle performance. The effective thermal mass of the building depends on the materials near the internal surfaces of the building elements. Heat absorbed in a single day does not penetrate into the deeper layers: the effective thickness for a one-day period is approx. 10 cm. However, insulating layers close to the internal surface will cut off the mass behind. For example, an internal insulation or even a carpet or a false ceiling could have an adverse effect on thermal mass.

In very well-insulated buildings, the role of thermal mass is less pronounced because the reaction time of the building to outside changes is in direct proportion to the heat capacity and indirect proportion to the heat transfer coefficient. As the heat transfer coefficient is greatly reduced in well insulated buildings, these will respond slowly to any weather changes (the so-called time constant will be high).

c. Innovative passive heating solutions

There are many other innovative passive solar solutions. Some of these have been around for 30-40 years but most of them are still in research phase and their practical usage is limited.

Sunspace

A sunspace is a glazed area outside of the heated building envelope facing South without any heating device. The sunspace collects sunshine during bright periods and due to greenhouse effect, it gets heated up. This heat is transferred inside by transmission through the common wall and by ventilation through vents, which can be opened. The heat storage capacity can be increased by implementing a rock store where heated air from the sunspace is mechanically channelled into and later heat is given off by radiation and conduction. If there is no sunshine, the sunspace functions as a buffer space, reduces heat losses and protects the building against wind and rain. In favourable weather conditions, it provides living space. As sunspaces can easily overheat in the summer, mobile shading is necessary. Placing operable vents to the exterior at the top and bottom of the sunspace will help remove heat by ventilation.

Trombe wall

A Trombe wall is a basically a dark-painted heavy wall facing South that absorbs solar radiation. The wall is covered with glazing from the outside, with a small air gap behind the glazing, which functions as a greenhouse. The heat from solar radiation is stored in the wall, and the room behind is heated by radiation and a controlled air exchange through small vents. The operation of the vents depends on the season and the time of the day: in winter, vents are open during the day to help solar-heated air enter the room but they are closed at night to avoid cooling the space. Summer overheating of the structure must be reduced with an operable shading device.

Figure 19: Trombe wall in France[49]

49 Source: https://commons.wikimedia.org/wiki/File:Trombe_Wall_by_Felix_and_Michel.jpg

Transparent insulation

Transparent insulation combines the function of glass and opaque insulation: it has a good insulation capacity but can also transmit solar energy and daylight. The typical construction is made out of glass or plastic, arranged into the formulation of a honeycomb or capillaries. Transparent insulation materials have been already been applied to windows, walls and solar collectors, among others. They can also be combined with a Trombe wall.

Figure 20: Transparent insulation for the retrofit of a façade (Villa Tannheim, Freiburg[50]

Phase change materials

Phase change materials help increasing the thermal mass of a building. These materials have a low melting temperature, around the thermal comfort limit of humans. When the temperature increases, the material changes from solid to liquid and this reaction absorbs heat. Later, when the temperature drops at night, the material changes from liquid to solid and releases the heat. These substances are already available in commercial products, for example in plasters and gypsum plasterboards but their use is not yet widespread.

Figure 21: Trombe wall with phase change material (Ebnat-Kappel, Switzerland)[51]

50 Source: https://commons.wikimedia.org/wiki/File:Villa_Tannheim_in_Freiburg -Vauban,_Sitz_der_International_Solar_Energy_Society_(ISES).jpg
51 Source: https://www.schwarz-architekten.com/project/solarhaus-iii/

Solar wall

In a solar wall, a perforated dark metal cladding is installed in front of a South facing wall as an external cladding. There is a ventilated air layer behind the metal, which rises as it heats up due to the incident solar radiation. The system is connected to the building HVAC system and ventilation fans are used to draw the warm air into the building and distribute it via air ducts. This is a relatively simple and inexpensive technology, which can be successfully applied, for example, in industrial buildings.

5.3 Passive cooling solutions

Passive cooling solutions may greatly reduce or totally eliminate energy demand of cooling in a building. It is possible to reduce or remove the cooling load by passive means., which is summarised in the following chapters.

a. Reduction of loads

While sunshine is desirable in winter, it should be blocked from the building when external temperatures are high in cooling dominated and mixed climates. Shading can be provided by vegetation, building elements, dedicated shading devices or special glazing.

Vegetation/Greenery

Planting trees in a clever way can help controlling internal temperature. Evergreen trees are recommended only on the Northern side to protect the building from wind. On the South side, deciduous trees function well. They shade the building in the summer months, but in winter, after the leaves fall, they do not obstruct sunshine from entering inside. Vegetation also has the advantage that it provides evaporative cooling (see chapter 5.3.c).

Vegetation can also be planted on the building such as, on the façade, on the roof or even inside the building. Green facades usually have a substructure mounted to the façade. Leaves will shade the façade and provide evaporative cooling if plants are regularly watered. Green roofs with a thick soil layer and larger plants (intensive roofs) have a similar effect but even if the thickness of the soil layer is limited and plants are smaller (extensive roof it will reduce the heat load due to its thermal mass.

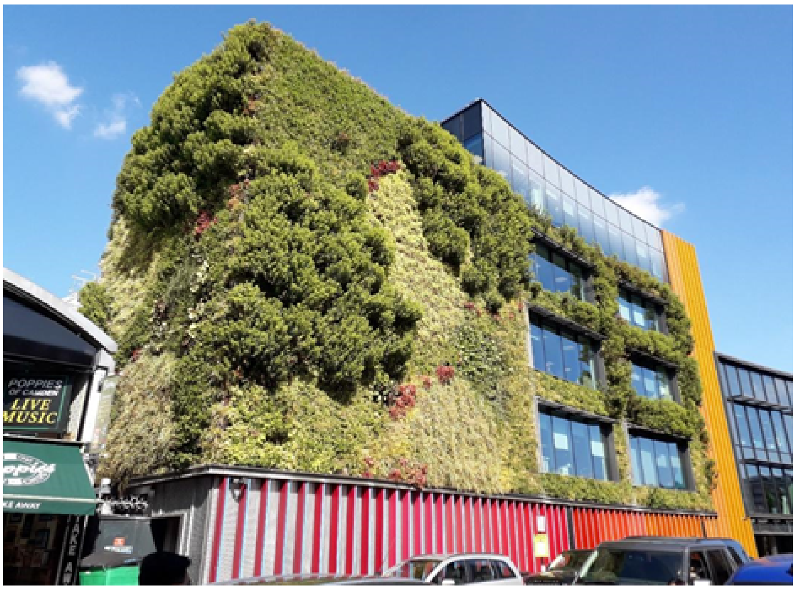


Figure 22: Green wall (London, UK)[52]

Shading

Protruding shading element elements work very efficiently if well designed. For south-oriented windows, horizontal elements such as roof overhangs or balconies above the window can be applied.

The movement of the sun and the change in temperature are not perfectly aligned in the summer, as the Sun is the highest in June but the strongest heat usually occurs in July/ August. Hence the shading should be designed so that it protects from the sunshine even in August. Overhangs possess an advantage as they do not block daylight, allowing it into the building even in the summertime. For East and West facing windows, horizontal overhangs are not very effective as the sun angles are low in the morning and afternoon. Vertical fins or separate shading devices work better in this case. These devices have an advantage that is they do not block entirely the light of sun, and therefore, natural lightning will be sufficient.

52 Source: Zsuzsa Szalay

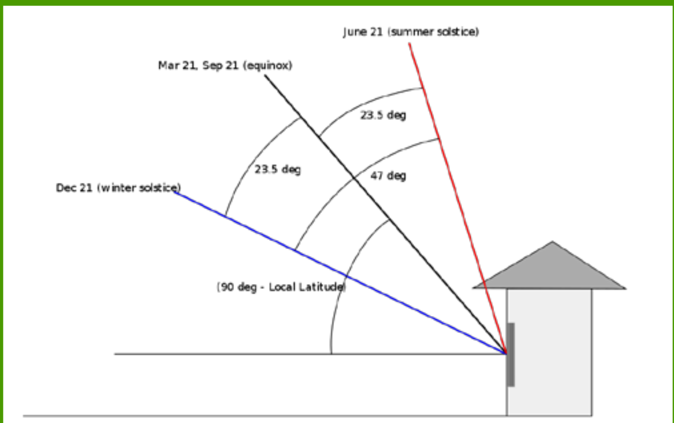
Designing the length of an overhang

The length of the overhang should be designed so that it provides shade during summer when the Sun is high but does not obstruct sunshine during winter at lower sun angles. For example, in Hungary at a latitude of 47° North, the sun altitude at exact noon is:

at the equinox (March 21/ Sept 21): (90° – latitude) = 43°

at summer solstice (June 21): (90° – latitude + 23.5°) = 66°

at winter solstice (Dec 21): (90° – latitude - 23.5°) = 20°



Source of the picture: https://commons.wikimedia.org/wiki/File:Solar_altitude.svg

For the protection of windows, there are several shading devices such as shutters, blinds, screens, awnings, roll ups, etc. In general, external shading devices are more effective as they block the sun before reaching the window. Heat that is transmitted through the glazing and absorbed by an internal shade is already inside the room and will contribute to warming the space. Internal shades are only effective if their solar reflectance on the side facing the window is high. There are also adjustable shades available that are placed between the glass panes. These shades are still quite effective and they are also protected from wind effects. Operable shades that can be opened or closed have the advantage that their use can be adapted to the changes depending on the position of the sun during the day and during the year. Shading devices are also beneficial against glare. The reduction factor indicating the percentage of solar gain that enters the room is shown for some mobile shading devices in the table below.

A common issue with shading devices is that most of them also reduce the incoming light and may increase the need for electric lighting. Shutters with adjustable slats are a good solution that enable lighting, visual connection with the exterior and ventilation, while shading the room.

Shading device	Reduction factor	
	if placed internally	if placed externally
Roller shutter	-	0,1
Venetian blind, light	0,45	0,15
Venetian blind, dark	0,80	0,35
Textile blind, light	0,55	0,35
Textile blind, dark	0,85	0,6
Aluminium-coated textiles	0,2	0,1
Curtain, light color	0,8	-
Curtain, dark color	0,95	-

Figure 23: Reduction factors for some mobile shading devices[53]

Special glazing

Shading may also be provided by the glazing itself. A large variety of glazing with different films and coating are available. The most important properties of glazing are the solar energy transmittance (g-value or SHGC) and the visible light transmittance (VLT). While a high VLT is always desirable, a high g-value is preferable in the winter and a low value in the summer. Normal glazing cannot adapt itself to the changing conditions, so in a residential building a combination of glazing and operable shading devices is more suitable than a non-adjustable solar control glass that may also change the colour of the light.

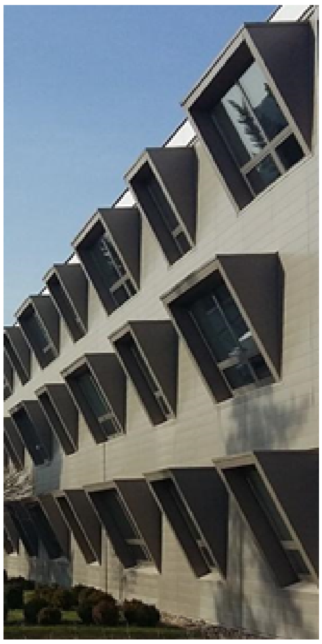


Figure 24: Shading with tilted windows (ÉMI, Szentendre, Hungary[54]

53 Source: MSZ EN ISO 13790: 2008
54 Source: Zsófia Deme Bélafi

There are also some innovative but rather expensive special glazing techniques available that can dynamically change their properties depending on the outside conditions. Photochromic glazing darkens under sunlight, similarly to automatically darkening sunglasses. However, as they adjust to light, they may darken even on a cold but sunny day when heat gains would be welcome. Thermochromic glass responds to heat and the tint of the window darkens with more intense sunlight. Thermotropic systems change their light-scattering properties depending on the temperature. Electrochromic glazing undergoes a reversible change if light falls on it. The advantage is that they can also be controlled manually.

Figure 25: Electrochromic glazing (Washington) [55]

Thermal mass

In summer, thermal mass leads to a reduction of temperature peaks and a time lag compared to the outside peak. Thermal mass accumulates the heat from the Sun and internal gains during the day and releases the heat towards the exterior by natural ventilation when the external temperature becomes lower than the internal one. For further details, see chapter 5.2.b.

55 Source: https://www.sageglass.com/en/article/what-electrochromic-glass

b. Removing heat loads

Ventilation/aeration

Heat loads and heat stored in the thermal mass can be most efficiently removed by ventilation when the external air has a lower temperature than inside. This is usually valid at night in summer. Ventilation rates can be increased via cross ventilation by opening windows on different façades and internal doors. During hot periods in the daytime, ventilation should be kept at a minimum to avoid further heat load. Simple fans can be used to create air movement instead of letting hot air inside.

Ventilation inside building elements helps decreasing the heat load on building elements. A ventilated air layer behind the external façade cladding or roof covering functions as an 'umbrella' against rain and as a 'parasol' against sunshine. Heated air moves faster in the air gap and this enhanced natural ventilation removes heat from the surface facing the air layer.

c. Innovative passive cooling solutions

Evaporative cooling

Evaporative cooling has been traditionally applied in hot and dry climates of the Middle East and in Mediterranean architecture, in order to cool the outdoor air. Air should be in contact with water on a large surface, for example a fountain or pool of water. In the process, air heats up the water, the water starts to evaporate and the temperature of the air is lowered without changing the amount of heat in the air. This type of cooling increases the relative humidity of air so it only works well if the outside air is dry enough.

Figure 26:
Evaporative cooling with plants and fountains (Alhambra, Granada)[56]

56 Source: https://commons.wikimedia.org/wiki/File:Alhambra_Generalife_fountains.jpg

Wind catchers

Wind catchers or wind towers have been traditionally used and built in hot and arid or humid areas such as the Middle East and Egypt. Their main role is to enhance natural ventilation and provide cooling by leading external air into the building. The wind catcher is on the top of the roof where wind velocities are higher with openings facing the prevailing wind. Air can be pulled through the basement or over water surfaces to precool the air before it enters the rooms. The extraction can be enhanced by installing a Venturi plate on the tower. Venturi effect is the principle that a velocity of a fluid increases and the static pressure decreases if it passes through a constricted pipe.

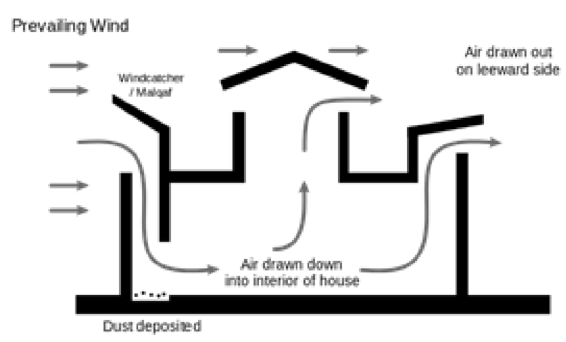


Figure 27:
Wind is forced down on the windward side and leaves on the leeward side in a pair of windcatchers[57]

Figure 28:
Venturi plate on the Hungarian nest+ project for enhancing natural ventilation and passive cooling[58]

57 Source: https://www.wikiwand.com/en/Windcatcher
58 Source: http://www.sde2019.hu/hungarian_nestplus.html

Solar chimney

A solar chimney provides natural ventilation and passive cooling. It is a dark-painted chimney with a glazing cover facing South, placed outside of the building while being connected to it. Upon exposure to solar radiation, the air in the solar chimney heats up and the large temperature difference causes air to lift up and out of the chimney (stack effect), pulling external air inside through the building and creating a draft inside. A staircase or multi-storey atrium may also work like a solar chimney.

References and further reading

- John R. Goulding (Author), J. Owen Lewis (Author), T. C. Steemers (Editor): Energy Conscious Design: A Primer for Architects, B T Batsford Ltd; Revised Edition (1993)
- Christian Schittich (Editor)Solar Architecture, Birkhäuser Architecture; 1st edition (November 24, 2003)
- Zöld, András ; Szalay, Zsuzsa ; Csoknyai, Tamás: Energiatudatos építészet 2.0, Budapest, Magyarország : TERC Kereskedelmi és Szolgáltató Kft. (2016) , 320 p. ISBN: 9786155445347 OSZK
- https://www.passipedia.org/
- https://energyeducation.ca/encyclopedia/Main_Page
- https://www.designingbuildings.co.uk/wiki/Home
- https://www.greenspec.co.uk/

Spread of Innovative Solutions for Sustainable Construction

Handbook

6 Active Solutions

IS-SusCon

Co-funded by the Erasmus+ Programme of the European Union

6 Active Solutions

Building technology system is a category that is made up of all mechanical, gas, electrical, sanitary, heating, air conditioning, ventilating, elevator, plumbing, life-safety, telecommunication and other service systems of a building.

There are essentially three ways to reduce the consumption of electricity and pipeline gas:

- When designing and building a house, we strive to ensure mini mum energy consumption - these are passive solutions.
- We use energy-saving equipment and household appliances, and we also operate them economically and consciously regarding the environment.
- We install and use renewable energy sources.

The latter two can be referred as building technology systems. These are not mutually exclusive solutions; the best option is to take advantage of all three options.

In the following chapter, we give a short overview of the most common building technical systems and their environmental relevance.

6.1 Heating, cooling, ventilation

a. Heating systems

A heating system is a mechanism for maintaining temperatures at an acceptable level by using thermal energy within a home. It is often part of an HVAC (heating, ventilation, air conditioning) system. A heating system may be a central heating system or distributed in each room.

Every heating system consists of two parts: the heat source and heat dissipator. In central heating systems the two parts are separated from each other. For example, in homes equipped with central heating system, heat is usually generated centrally by a gas boiler or a heat pump. This heat is then transferred as hot water in the pipes towards each room and it is dissipated by radiators or underfloor pipework.

In case of heat dissipators, the construction of radiators is usually simpler and therefore, faster and cheaper than that of surface heating. The cost of underfloor heating is much higher; however, it results in a much larger heating surface. On the one hand it is more comfortable, because there fluctuation in temperature is less temperature. On the other hand, it has lower operational costs as the heat generators (boilers, heat pumps) can operate more economically by needing lower water temperature.

In new family houses, the most common heat generators are condensing gas boilers, heat pumps and wood gasification or co-fired boilers.

Perhaps the most common heat generators are condensing natural gas boilers, which have an efficiency of at least 86% for new equipment according to standards. It recovers flue gas heat to preheat the cool water returning from the heating system. The cooler the returning water from the radiators, the better its efficiency. This is why condensing boilers work better with surface heating, such as floor, wall or ceiling heating. If this is not possible, at least efforts should be made to install radiators with a larger surface area than necessary, in order to lower the return temperature and thus more economical heating.

A co-fired boiler can be an economical choice in a rural location where cheap firewood is available. However, these boilers are being phased out as many people do not use them properly. The burning wet firewood or household waste results in the release of very harmful pollutants. Wood gasifiers require extra low moisture wood for proper operation. These boilers produce high temperature heating water - a good pairing for conventional radiators as heat emitters. If it is used for surface heating, the heating water must be mixed with the return water, so the efficiency will be reduced. Thus, installing an intermediate buffer tank between the heat generator and the heat emitter is absolutely necessary.

There is a growing interest in electric boilers among people who renovate their houses or plan to build new ones. These do not require complicated permitting processes for natural gas use, nor do they generate flue gas, which should be removed, and they are also suitable for radiator heating. Here, however, the main disadvantage is that electricity is the most expensive energy source.

In addition, there are heating systems where both the heat generator and the heat dissipation unit are located inside one single unit, for example air conditioners with heaters or oil-filled electric radiator space heaters. These are more common in places where the heat demand is small or casual such as cottages or regions with mild winters. Open fireplaces and heating fans usually serve only as complementing units.

More recently, low-cost heating cables, heating foils and infrared panels have also been introduced to the market. As they use electricity for heating, the user has to pay a much higher energy price than for natural gas or firewood. On the other hand, combined with renewable energy systems that generate electricity such as photovoltaics the operational costs can be competitive.

Heat pumps also use electricity but they are 3-4 times more efficient than other electric heating options. This is because heat pumps collect heat from the soil or the air, and concentrate it for use inside.

Condensing gas boilers

With some countries as exceptions, natural gas boilers are the most common heating systems in Europe. Now, only the most efficient condensing boilers are now used. It is also one of the best choices in terms of comfort and air pollution, and it is also one of the most economical solutions with adequate thermal insulation. Due to its low cost and reliability, other heating systems are almost only economical, if the installation of the gas boiler is not possible for some reason or requires very expensive renovation (e.g. a new chimney). A serious disadvantage is that natural gas is not a renewable energy source and, in addition, most of it must be imported from outside Europe. Its carbon footprint is higher than those of wood-fired or heat pump systems. Expecting a possible future rise in gas prices and for climate protection reasons, more and more people are choosing other heating systems instead. With regard to other pollutants, however, gas combustion is relatively clean compared to conventional coal or wood burning, as neither particulate matter, nitrogen oxides nor sulphur oxides are produced in large quantities.

Environmental impact during the life cycle

Production and installation include not only the manufacturing and installation of the boiler, but also other equipment required for the operation such as the chimney, combustion air supply and so on. Still, this section represents only a very small environmental impact compared to the operational phase. The operational phase includes the extraction, transportation and combustion of natural gas, maintenance and possible replacement of parts. From an environmental point of view, the most important part is the combustion of natural gas itself, as it generates high CO_2 emissions. Burning one cubic meter of natural gas releases approximately 2 kgs of carbon dioxide. In addition, natural gas has to be made available in our homes, and during the extraction and transportation of natural gas, some of it inevitably leaks into the atmosphere. This is a significant problem as one of the main components of natural gas is methane, which is about thirty times stronger gas in terms of greenhouse effects than carbon dioxide. At the end of its life, the disposal of equipment does not pose a major risk to the environment: most boilers and other ancillary equipment consists of easily recyclable materials, mostly metals.

Heat pump / air conditioner

Any machine that extracts heat from a colder place and transports it to a location with higher temperature is called a heat pump. This is how our everyday refrigerator and air conditioners work. When used for heating, heat pump acts as a “reverse” refrigerator: it draws heat from the outside environment and transports it to the inside of the house.

Depending on the design, some heat pumps can only be used for heating but there are also types available that are suitable for cooling in summer and for producing domestic hot water as well.

In a heat pump, the refrigerant liquid evaporates in a heat exchanger while absorbing the heat of the environment (e.g. from the water from pipes laid in the ground or from the outdoor air). It then releases its heat while condensing and returning to a liquid state. Then the cycle starts all over again.

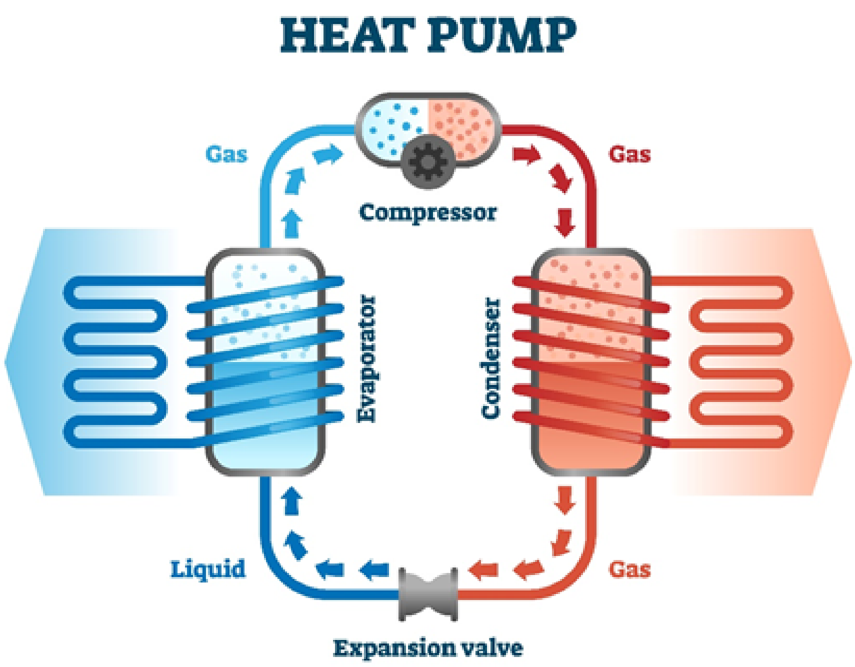


Figure 29: Schematic of a simple heat pump

The source of heat can be external air, soil or, if available, even surface waters such as a river or lake. A common feature of water-to-water heat pumps is that they utilise the heat of groundwater or surface water, and the heated medium is also water. Similarly, ground-to-water systems extract heat from the ground and air-to-water heat pumps extract the heat from the outdoor air. The heated medium can be water if the hot water is fed into a central heating system or the temperature can be set directly by blowing hot air in the rooms. In this latter case, we are talking about air-to-air, water-to-air or ground-to-air systems.

Several types of heat pumps are distinguished depending on the location of heat removal and its medium. There are three types of heat pumps: air-to-air, water source, and geothermal. They collect heat from the air, water, or ground outside your home and concentrate it for use inside. The most common type of heat pump is the air-source heat pump, which transfers heat between a house and external air.

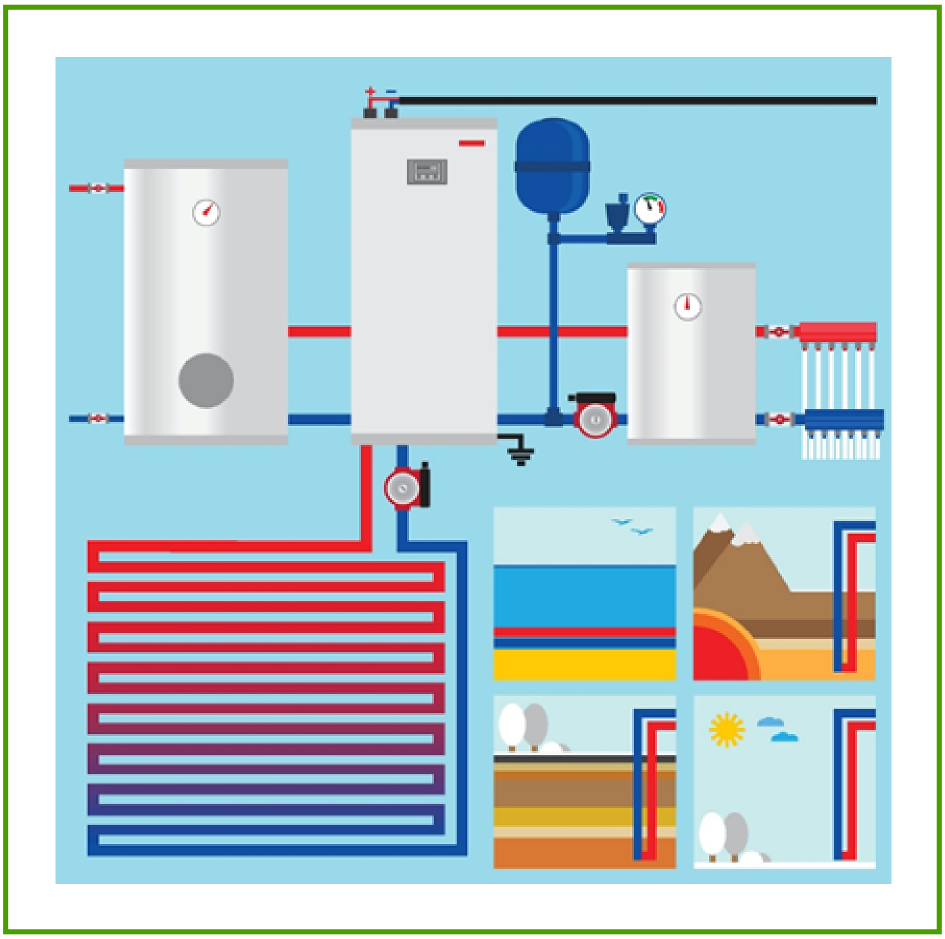


Figure 30: Diagram of a typical heat pump system, including buffer storage, pressure valve and electric pump. Source of the heat can be various, such as the air, the ground or a lake

Air-to-water systems are the most common today due to their relatively low investment costs.

Electricity is required for the heat pump to work. All heat pumps available on the market are given a COP ("coefficient of performance") value, which presents how much heat energy is produced by consuming a unit of electricity. The COP value is not constant throughout the year, as the larger the temperature difference it has to overcome, the worse the efficiency will become. For example, ground probe systems consume less in winter than an air source heat pump with the same heat output because the deeper layers of the soil never cool as much as the ambient air. Similarly, efficiency is higher if a lower temperature is sufficient for proper heating, such as in the case of underfloor heating.

Therefore, it is better to look for the SCOP ("seasonal coefficient of performance") value, which gives the efficiency for the entire heating season. This can be found on the energy efficiency label of heat pumps together with the SEER (" seasonal energy efficiency ratio") if the heat pump is capable of cooling as well. Both values are very important when selecting a heat pump, as the higher these numbers, the better the efficiency of the machines are. Production of heat pumps is also the most relevant in terms of mineral resource depletion because these machines contain a large amount of stainless steel, copper and other valuable materials.

Environmental impacts of heat pumps

Production and installation

The production of heat pumps and the refrigerant liquid is a material- and energy-intensive process, so it can be accountable for up to half of its the environmental impacts during its entire life cycle. The production and installation of ground-water systems that use more materials and involve more installation work are more harmful to the environment than air-to-water heat pumps, but they put less load on it during operation because they use less electricity.

Operation

Although no smoke is generated when using heat pumps they still present indirect emissions by using electricity. Although these emissions might not be apparent electric power still has to be produced in one way or another. Indirect emissions are highest in countries where most of the electricity comes from fossil fuels (such as coal or natural gas). In such cases, the overall environmental load of using a gas boiler may be less than heat pump. In contrast, where a large proportion of electricity is generated by renewable energy sources, such as solar, wind, or hydropower, the heat pump emits much less than a gas boiler. For this reason, if financially possible, heat pumps can be well paired with solar photovoltaic systems that provide renewable energy for the operation of the equipment. As the proportion of the renewables are expected to grow everywhere in the future, along with improvements of the heat pumps efficiency, it will certainly become one of the most environmentally conscious heating methods.

Refrigerant leak

All heat pumps are filled with approx. 1-2 kgs of special refrigerant. These refrigerant leaks very slowly over the years, so it may need to be refilled. Unfortunately, these refrigerants are powerful greenhouse gases, so a leak of only a few kilograms equals to hundreds or thousands of kilograms of carbon dioxide. Since, on average, half of the refrigerant leaks over the life of the equipment, this entails a very significant environmental impact, reaching up to a quarter of the total carbon footprint.

Dismantling and waste management

The main equipment of the heat pump is almost completely recyclable. Exceptions to this are plastic pipes, fittings, components that are either incinerated or disposed of at the end of their life cycle. Unfortunately, during disassembly and disposal, the remaining refrigerant may leak, so this can only be conducted by licensed companies.

Sources

1. Viral P. Shah, David Col Debella, Robert J. Ries (2007): Life cycle assess ment of residential heating and cooling systems in four regions in the United States.

2. Simona Marinelli, Francesco Lolli, Rita Gamberini, Bianca Rimini, Life Cycle Thinking (LCT) applied to residential heat pump systems: A critical review,Energy and Buildings, Volume 185, 2019, Pages 210-223, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2018.12.035.

Wood gasifier boilers

Wood gasifier boilers provide heating by burning pelleted biomass, such as sawdust and other woody waste depending on their design. Compared to other heating systems the disadvantages may be that the quality of pellet varies and in some cases it has a more difficult controllability compared to other heating systems. In addition, it can be inconvenient to constantly refill the equipment with pellets and dispose the resulting ash. An environmentally important advantage is that the carbon content of the fuel has plant origin, i.e., it only emits as much carbon as the plant has sequestered over its lifetime. Thus, by burning pellets, it contributes much less to climate change than by burning natural gas. Yet it cannot be called "climate neutral" because timber extraction, pellet production and transportation all involve emissions. Furthermore, burning biomass results in the removal of valuable nutrients from forests and other agricultural areas. Combustion of pellets also produces other air pollutants: flue dust, sulphur oxides, nitrogen oxides, hydrochloric gas, etc. These emissions are significant because they occur in residential areas and thus have a detrimental effect on human health. Compared to conventional wood burning, on the other hand, it has better efficiency, lower emissions and it is a more controllable, more convenient system.

Electric heating

Direct electric heating is also possible, although it is most often it is only installed additionally to other heating systems. This is because operation costs can increase with three to four times compared to other heating methods. In return, however, it is easy to regulate, convenient, investment costs are low, and its construction is simple, if sufficient power is available from the grid. Maintenance needs are also minimal. It is often used outside the main heating season, for example in late spring, when only moderate additional heating is needed. In mild climates and well-insulated houses, it might as well supply the entire heat demand.

There are many types of electrical heating, e.g. infrared panels, oil filled radiator heaters, heating foils and heating cables for floor and wall heating, hot air blowing fans, electric boilers and stoves etc.

An apparent advantage of these is that no harmful air pollutants are generated at the place of use. The production of electricity, evidently, involves emissions but these occur far away from residential areas and are usually strictly controlled. Environmental impacts are thus largely determined by how electricity is produced. In contrast, the production and waste management of the heating equipment itself is of little importance. It also does not generally matter the type of system used (e.g. radiator, infrared panel, etc.) selected, the amount and source of electricity used is much more important in this aspect.

District heating

Modern district heating systems can be one of the most environmentally friendly solutions in densely populated urban environments. Its main environmental advantage is that heat can be obtained from a variety of energy sources, such as waste heat from power plants, waste incineration or natural gas or even using geothermal and solar energy.

Another important advantage is that large central heating plants can be controlled and its emissions can be reduced more easily than many small individual boilers.

For this reason, many major European cities are intensively developing their district heating systems. Much like electricity, the environmental impact of district heating is determined by the source of the heat.

Summary

It is a main characteristic of all presented heating systems that the production of heat generating equipment (boiler, heat pump, etc.) is almost negligible from an environmental point of view. It is a more important aspect how much heat should be generated during the use and from what source. Firewood and pellet combustion are beneficial from the viewpoint of climate protection, but unfortunately, they contribute greatly to local air pollution. It would be more appropriate to use them in district heating, as it is much easier to clean flue gases properly in large heating plants.

Natural gas combustion does just the opposite: it burns much more cleanly, so it makes only a small contribution to air pollution, but it is a non-renewable resource and its lifecycle involves significant CO_2 emissions.

Electric heating is relatively expensive to operate and beneficial only if the electricity comes mainly from renewable sources. Heat pumps are very efficient at converting electricity into heat, but unfortunately the escape of refrigerant partially offsets this, so they only compete with other energy sources in terms of environmental impact if the electricity used is largely produced by renewables.

It is important to remember – the best type of energy is the one that is not needed to be produced.

b. Ventilation

Nowadays, when it residential buildings are renovated and modernised, usually doors and windows are replaced, the roof and the facade are both insulated, and sometimes the old heating system is updated. There is little talk of ventilation, and many times it is not even planned.

Old wooden doors and windows let in some air even when closed, providing some sort of ventilation. New doors and windows are however completely air-tight. That is why we need to pay more attention to ventilation in case of renovated buildings.

Also, it is well known that nowadays, people spend much more time indoors than in the old days. 90% of the time we spend working, resting and leisure are usually spent indoors, in closed buildings from where we take the air we breathe. Therefore, the quality of the inhaled air has become very important. If a building is not properly ventilated - for example, if the windows are new but not opened frequently - the humidity in the air and the amount of pollutants can increase greatly indoors.

Depending on the habits of the occupants, the pollutants generated in an average dwelling can be of:

- water vapour from exhalation, kitchen activities, bathing, etc.
- carbon dioxide from exhalation
- other gases and vapours (e.g. smoking)
- other combustion products e.g. in the case of a gas stove,
- decomposition products of organic materials, evaporation products of building, materials,
- dust, suspended matter, pollens,
- viruses, bacteria, fungi and their spores in the
- odours from kitchen and restrooms.

Humidity is an essential component of air quality. For a healthy adult, humidity between 40 and 60 percent is optimal. By exhaling, in addition to the vapor, a fairly large amount of carbon dioxide is released into the air. Indoor air can be considered good if carbon dioxide levels remain below 1 ppm (parts per million).

Fungal spores are always present indoors, no matter what the conditions are. If other conditions are met (no ventilation, the wall corner or other thermal bridge cools below the dew point, condensation is present, the internal relative humidity rises above 75% - high internal moisture development), the appearance of mould is inevitable. With adequate ventilation, though, the chances of this can be reduced.

According to standards, the minimum fresh air requirement of a resting person performing sedentary or light physical work is 30 m3/ h / person. It can be higher in case of medium or heavy physical work. An average ventilation with a few minutes of window opening two to three times a day, calculating average for 24 hours equals to approx. 4 m3/ h air circulation. It is easy to see that if new doors and windows are installed, it is not possible to provide the right amount of fresh air just by opening the windows - especially if there are several people in the room. The new and renovated buildings nowadays, therefor need to be ventilated more, and mechanical ventilation is becoming more and more widespread.

Another argument in favour of mechanical ventilation is the following, by simply opening windows, we are often unable to improve air quality as external air is very polluted. In addition, there are more and more people living with allergic, asthmatic and other respiratory diseases, which also prohibits allowing simply external air of entering to their homes.

One possible way of ventilation is to build an air duct network with a central ventilation system. Ducted systems simply use ductwork. If a home already has a ventilation system or the home will be newly constructed, you might consider this system.

On the other hand, ductless applications require minimal construction as only a hole of three inches is required through the wall to connect the outdoor air vent cover and the indoor ventilator. Ductless systems are often installed in addition, when the ventilation of each room can be created separately.

Simpler, fresh-air mechanical ventilation systems provide only the necessary air exchange and air filtration but result is significant in terms of heat loss in cold weather. For this reason, the so-called energy recovery ventilation (ERV) systems are now often used. These use a heat exchanger to heat the incoming cool fresh air with the warmth of the indoor air, so that their use involves much less heat loss.

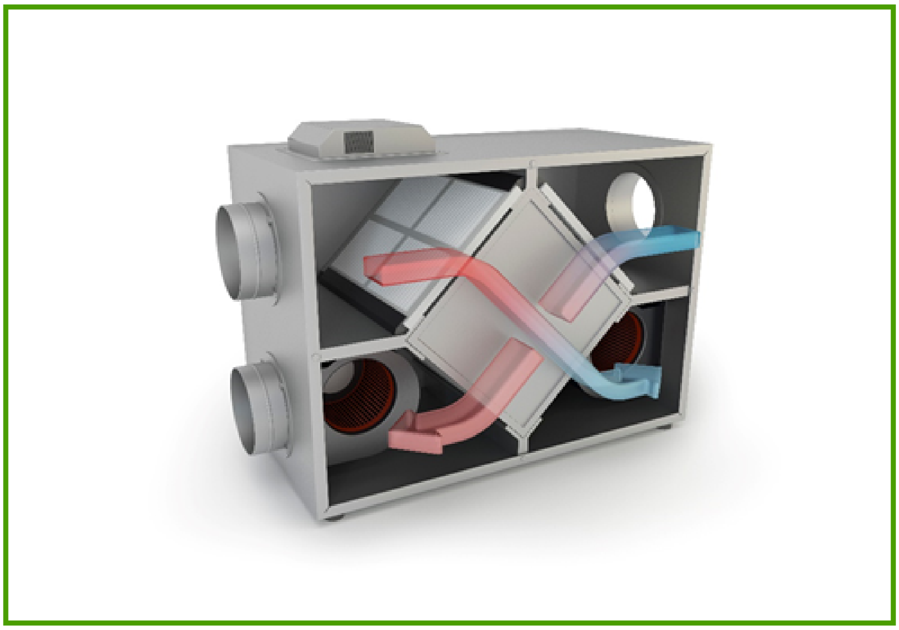


Figure 31: Ventilation system with built-in heat exchanger

Environmental impacts of ventilation

The production and disposal of ventilation systems are generally negligible compared to the energy required during usage. The only exception is mineral resource depletion as ventilators contain valuable metals such as copper, aluminium and stainless steel.

During the phase if use, energy consumption is the most important part. Energy consumption comes from two aspects: the electricity consumption of the equipment, and the thermal energy that is needed to offset heat loss during ventilation. For example, even if no electricity is used when we open windows, we still lose heat or cold that has to be replaced. In case of ventilation systems with energy recovery, heat loss is lower but in return some extra electricity must be invested in the operation of the heat exchangers.

6.2 Lighting

The design of lighting in an apartment is highly dependent on the style of the occupants. Many people want to determine the style and atmosphere of the interior lighting themselves. We would not want to take this beautiful, creative work away from anyone. However, in order for all the spaces in the apartment to receive optimal lighting (neither more nor less), it is also worth asking for advice of a lighting specialist or an interior designer. If you we wish to provide an environmentally friendly lighting, here are some tips to share and follow.

14% of the electricity consumption of an average European household is spent on lighting. This also means a significant burden on the environment. If we can reduce this with modern light sources and with the right design, it will be economically beneficial to the residents and the environmental impact of the house can be reduced as well.

Some lighting system quantities that are useful in choosing a proper light source.

We do not provide the adequate textbook definitions as they can be accessed with a few clicks. Rather, we would only show the buyer information worth knowing, the meaning of the data on the boxes, so that when we make a purchase, we can make a more informed decision.

- Luminous flux
- Efficacy
- Average lifespan
- Colour temperature
- Colour rendering index (R_A)

	Incandescent	CFL (Compact Fluorescent Lamp)	LED (Light Emitting Diode)
Efficacy (lm/W)	10-15	50-70	80-200
Lifespan (hours)	1000	8-12000	10-50000

Figure 32: Comparing light sources[59]

Luminous flux: All radiation emitted by a light source per unit time that can be perceived as visible light. Its calculation also takes into account the sensitivity of the human eye in the middle range of the visible spectrum (yellow - green). Unit: lumen [lm] (A 75 watt incandescent lamp emits approx 1000 lm.) (Spectrum: white light resolved by color or wavelength.)

59 Source: György Gröller

Efficacy:

The lamp converts electric energy into useful light radiation, and the rest into heat, sometimes invisible UV (ultraviolet), or IR (infrared) radiation. The efficacy shows how much luminous flux the lamp provides from 1 W of electrical power. This is the most important feature in the use phase of the life cycle.

Average lifespan:

It is also important from an economical and environmental point of view. Here we understand the concept "life" differently, LEDs do not suddenly break, their luminous flux decreases slowly. Life expectancy is defined as the luminous flux decreases to 70% of the original and is given as L70. The lifespan of LEDs can be significantly reduced if operated at higher temperatures.

Lamp comparison should be based on the quantified function, which also implies "for how long" the function is provided. For example, if we have to choose a 10,000-hour compact fluorescent lamp and a 20,000-hour LED we have to compare the price and production load of two fluorescent lamps with that of an LED. If we look at the lifespan of an LED for 20,000 hours, we have to buy about 20 incandescent bulbs during this time, and their energy consumption is about 10 times higher than that of an LED. That is why we cannot even buy a light bulb in the EU.

Color temperature (Tcc):

To put it simply, when a material is heated, it emits light at a higher temperature, and its color changes with temperature. It is initially red and the higher the temperature shifts towards blue. Thus, we can use temperature to characterize the shade of white that light sources shine with.

- warm white (T < 3300K)
- neutral white (3300K < T < 5500K)
- cold white (T > 5500K)
  This called "daylight" also, because the color temperature of the Sun is about 6000K.

It is recommended to use warm white inside the apartment, it is good to use neutral white at most in the bathroom and work areas. It is especially annoying when light sources with different color temperatures are mixed within the same room

Color rendering index (RA): It shows how faithfully a light source reproduces or distorts colors that are perceptible in natural light. Incandescent lamps are the best in this field (RA = 100), but RA values above 80 are already acceptable within the apartment. For LEDs, the price of better color rendering is slightly lower efficacy.

The features listed above shall be applied to light sources that can be found on the boxes of bulbs. In order to enjoy the right lighting in every part of the apartment, we need to place them well, we have to plan the general, local, direct, indirect lighting, the regulation (dimming) of the light sources. In other words, the right illuminance needs to be implemented. It is advisable to seek help of a specialist, as poor lighting makes the eyes unreasonably tired and impairs the feeling of comfort. Excessive lighting can also be annoying, but it is definitely a waste of energy and a burden on the environment.

Figure 33: Information on packaging. (The efficacy is: 1100lm/12W=91lm/W)

Illuminance

With our eyes we see the density of light, which means the rays of light projecting from a given object in the direction of the perceptual eye. Measuring and controlling this in a given space is quite difficult, therefore, we determine the light conditions indoors by measuring the amount of light falling on the objects. This is the illuminance, i.e. the luminous flux per unit area (lm/m^2 = lux [lx]). Lighting standards and recommendations - in parallel with several other lighting quantities - provide this to different areas. Within the apartment e.g. 100-300 lux in the living room, 300-500 lux for reading, 750-1000 lux for kitchen worktops or meticulous work. In addition to the given levels, the uniformity of the lighting is also important. Good and economical lighting can be combined with a combination of general and local lighting: e.g. in the living room with general lighting supplemented with a reading lamp, in the kitchen with counter lighting, desk lamp on the desk, etc.

Uniformity is easier to achieve if indirect lighting is used, if this is achieved with more light sources with less power, and if the reflection of the walls is higher. In well-lit areas, we can see the fine details of objects more accurately, work more efficiently, and we are less tiring of our eyes. Illuminance is not automatic, it depends on the luminous flux of the lamps, the light distribution of the light sources, the reflection of the surfaces and the natural light. Therefore, it is advisable to seek the help of a specialist for planning, as poor lighting unreasonably tires the eyes and reduces the feeling of comfort. Excessive lighting can also be annoying, but it is definitely a waste of energy and a burden on the environment.

Lighting 101

Daylight

It is the cheapest and the least environmentally damaging. If it is possible to let natural light in with proper orientation and the use of reflective, shading surfaces, we can save significant lighting energy. A sunny, bright apartment has a positive effect on our mood but even on our ability to work. Of course, if it is too much, it causes glare, so it is important to think about its regulation and shielding. Also, one should keep in mind that the thermal insulation of the windows is 2 to 3 times weaker than that of the walls, so we gain from lighting with windows that are too large but heating energy demand may increase.

With the solution shown in the picture, natural light can be introduced into the less illuminated spaces of buildings, even a few levels down. Through the chimney with a reflecting wall inside, the sunlight reaches the apartment with little loss. Due to its price, it is used even more in public buildings today, but in a newly built apartment it can help if you have to place a study or kitchen on the north, shady side of the house. At present prices, investments of around € 500 - 1000 are unlikely to reduce significantly the electricity bill but due to the lower environmental load and the aforementioned freedom of arrangement, it may be an interesting alternative.

Figure 34:
Solar tube, part on the roof

Light sources

There are three types of lamps for home lighting: incandescent, compact fluorescent and LED. From the listed types, incandescent lamps can no longer be marketed in the EU due to their economic, technical and environmental parameters. The efficacy of compact fluorescent lamps is already significantly better but no more serious development is expected and its marketing will be banned in the near future due to its Hg content. LED is the only option left, and anyone planning new lighting for their home today is not worth looking for anything else. The rare convenient situation is that we do not have to compromise because of our environmental goals, LED is not only the most environmentally friendly but also the best from an economic and technical point of view. It also gives designers more freedom to implement beautiful, interesting, and unique solutions.

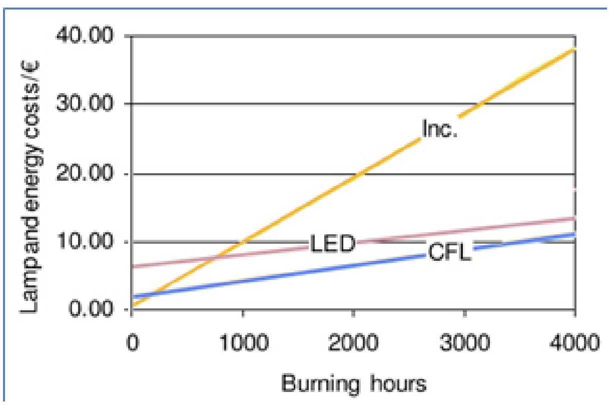
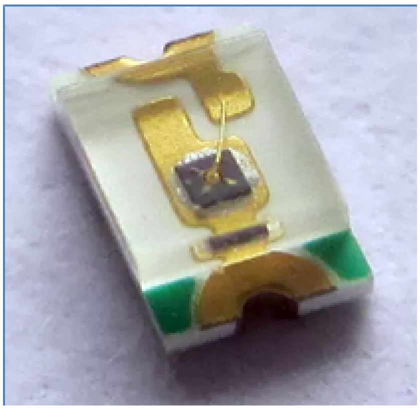


Figure 35: The cost of purchasing and operating a 500 lm light source as a function of time. (1 kWh ≈ 0,2€)[60]

60 Source: György Gröller

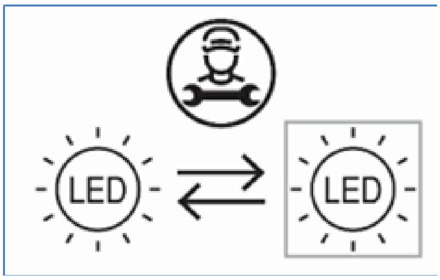
In order to confirm the above, the top diagram shows the evolution of lighting costs over time. The incandescent lamp produces an increasing energy bill after the low cost. The starting price of the other two light sources is higher but due to lower consumption, the total cost in a few hundred hours is less than that of a light bulb. The switching time between an LED and a compact fluorescent lamp depends on the efficacy of the LED. With today's 150 lm / W lamps, this happens after just a few thousand hours.



LED itself is a few mm diode by connecting several of them we can get an effective light source. The diodes operate on low voltage (12 - 24 - 48V) DC. It can be connected to the mains voltage via a power supply. There are separate and integrated power supplies with LEDs. So, when calculating the environmental impact of LEDs, the power supply should always be included in the calculation as well.

Retrofit lamps

These bulbs are similar in appearance and usage to conventional incandescent bulbs, they can be screwed in a place, and have a similar luminous flux to 25 to 100 W incandescent bulbs. The power supply is also clamped in the socket. This is a weaker solution in terms of both circuit and heat dissipation, so the efficiency and lifespan of these lamps are both also less than compared to a good LED lighting. In practice, this means an efficacy of 80 to 110 lm/W and a lifespan of 10 -20 000 hours. Its advantage is that it can be screwed into old chandeliers and sockets, and it does not require further investment.



Integrated LED

The potential of a new light source can be best exploited if the luminaire, LED panel, drive electronics and cooling are designed together and made up in a single unit. This refers to the design, many beautiful, elegant solutions are visible and also to efficiency, 130 - 180 lm / W and a service life of 50,000 hours are available today. So, it is designed for 20 to 30 years, so more noble, time and corrosion resistant materials have to be used which makes it more expensive. The disadvantage is that it is difficult to repair, the components are rarely replaced. Unfortunately, consumers have to count with the most failures regarding the other types. Many poorly designed, carelessly executed dumped goods that break down after a few weeks or months cannot be repaired. In principle, it would be possible to replace the panel or power supply but it is very difficult to persuade manufacturers to use standard components. The EU recommends using pictograms or similar on the packaging to indicate the interchangeability of components.

LED stripes

Ideal for indirect lighting of rooms and extra lighting of work areas. Coloured ribbons are suitable for unique decorations. It can also be a challenge for those who consider electricity their hobby. For long-term use, an aluminium rail with a plastic cover is required, so the environmental effects of it must also be added to the load on the power supply and the LED strip.

Lighting and the environment

The environmental impact of most light sources is significant during the use phase of the life cycle. Due to the small weight of the lamps, the production, transport and end of life (waste scenario, recycling) barely reach 10% of the total load.

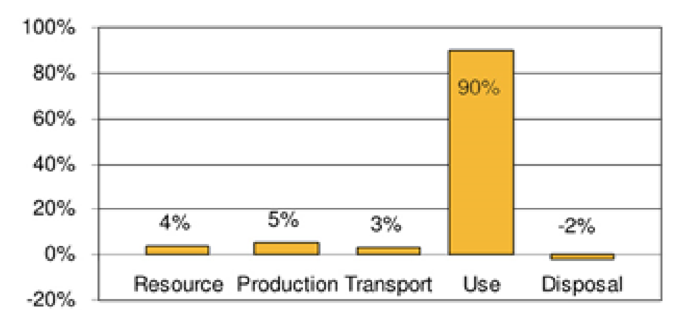


Figure 36: Greenhouse gas emission of a retrofit LED at major stages of its life cycle. The other impact categories (e.g. Eutrophication, Ecotoxicity, Resource depletion, etc) also give similar results.[61]

What can the customer do in order to reduce the environmental impact of lighting?

Choosing light source

LED technology is still in the rapid developmental stage, the efficacy, lifespan and stability are still spectacularly improving. So, we need to know that new products are not only more expensive but are indeed better in the above-mentioned terms. When buying, it is definitely worth paying attention to the luminous flux, efficacy, colour temperature and lifespan of the lamp. The above parameters are usually found on the box of retrofit lamps, less often on integrated LEDs.

Use

We plan general and, if necessary, local lighting for our rooms. It is not a problem if we also have some scarcely used light sources, as it is not the production, but the use that presents the greater burden on the environment. General lighting should be dimmable/adjustable. The controllability of the lighting is important, on the one hand, as different lighting levels are suitable for different tasks, and on the other hand, individual people have different needs. In old age, higher illuminance levels provide the same level of visual comfort. Around the age of 40 approx. twice, over 60 approx. we require three times higher levels of illumination than in younger ages.

61 Source: György Gröller

Luminous flux control can be solved with individually dimmable (e.g. rotary knob) switches but there are control systems that automatically adjust the lighting for the lighting conditions and presence. The best known is the DALI system (Digital Addressable Lighting Interface). This can be part of smart home solutions. With this and similar systems, we can control the lighting in our home, remotely, or as a function of natural light or according to a specific program. Installation requires some extra wiring as well as dimmable light sources - this is usually marked on the packaging.

A long life of the LED is guaranteed if the lamp is not permitted to overheat. Therefore, LED chips are mounted on a good thermal conductive surface and they are not placed in a tight, non-ventilated space.

The environmental impact of the use phase depends to a large extent on the sources of the electricity consumed. Where the proportion of fossil fuels is high, the load is higher at the same consumption. That is why it is useful to cover as much of our energy needs as possible from our own solar source or from the other green energy.

The rebound effect

Switching to LEDs can also reduce the environmental impact and cost of lighting by 30 to 50%. Cheaper operating costs can lead to a more careless use, and it makes it easier to leave lights switched on in empty rooms, over illuminating rooms, which can neglect the environmental benefits of better light sources. In addition to conscious use, good planning and automatic control help. Then one must just pay attention to the money saved this way should not be spent on hobbies that are not environmentally friendly (referred to as an indirect rebound effect).

The end of life

According to the EU WEEE Directive, used light sources are classified as electrical waste to be collected (except for incandescent light bulbs). Therefore, it is essential and we kindly ask the reader to return waste lamps to one of the collection points. With today's technology, they can process the metal content of LEDs, especially aluminium, glass and plastic parts. For the time being, phosphors and semiconductor materials are being deposited. Compact fluorescent lamps will be in use for a few more years, although they will no longer be available for sale in the EU after 2021. Because of their mercury content, it is even more important that they are processed in a professional recycling plant at the end of their life.

Figure 37: Global rebound effect

6.3 Renewable energy sources

A national or European electricity mix includes some mixture of renewable and non-renewable sources. In most countries, the proportion of natural gas, oil and coal is still close to 50%. As can be seen in the diagram - and it is well known - their impact on the climate is more than an order of magnitude greater than that of renewables, and the trend is similar in other environmental impact categories. If we can decouple our house from this, it is a serious step towards an environmentally friendly, carbon-neutral home.

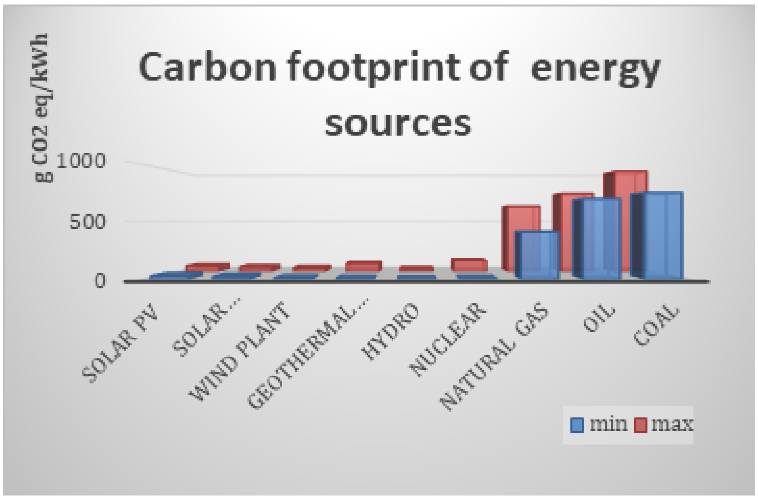


Figure 38: Carbon footprint of energy sources[62]

In the size of a residential building, solar panels, solar collectors and heat pumps using geothermal energy are the possible, suitable solutions, therefore, we summarize the characteristics of those.

a. Solar Thermal collectors

Solar collectors/ panels convert the radiant energy of the Sun into thermal energy that can be used to produce hot water and heat in homes. In a simple installation, we can obtain heat energy economically and with good efficiency. The downside is that it produces less energy in winter, when we also want to heat homes with it, and the surplus generated during summer cannot be stored. Otherwise this is referred to as a sizing problem, it is not worth installing more panels than the summer hot water demand because we cannot use the heat energy produced. Thus, in winter, we cannot expect heating assistance. Some might be able to equilibrate this energy variation of extra summer energy by heating their swimming pool but we do not wish to analyse the environmental impact of such a scenario.

62 Source: György Gröller

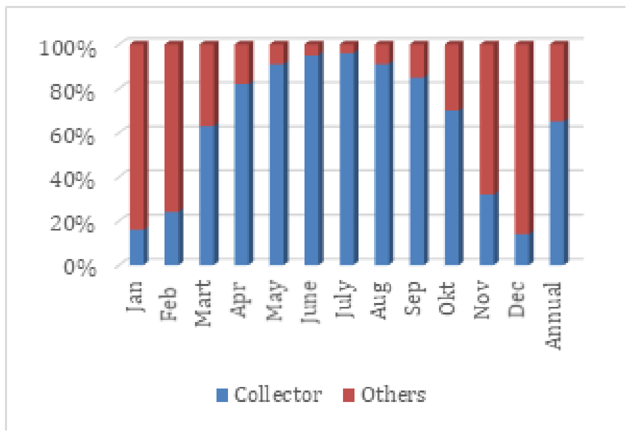


Figure 39: Distribution of energy sources required for the production of domestic hot water in one year[63]

Flat plate collector:

Under the cover glass run liquid-filled tubes that are in close contact with the absorber, which is a dark-surfaced metal (copper or aluminium) for good heat transfer. Below this plane is a thicker thermal insulation layer that prevents the liquid from cooling.

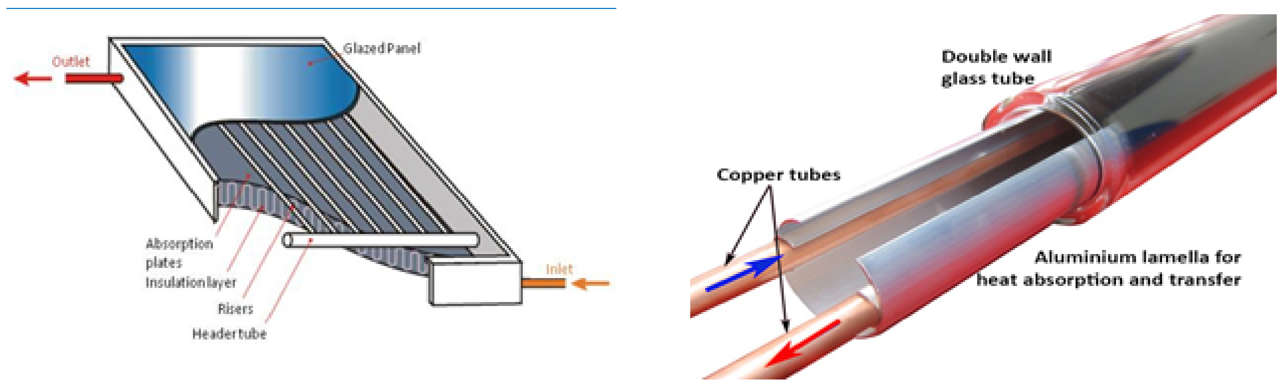


Figure 40: Structure of the flat plate and vacuum tube collectors

63 Source: György Gröller

Vacuum tube collector:

The heat transfer fluid here flows inside a double-walled glass tube (jacketed pipe), and the absorber is located within it. The thermal insulation of this construction is better than for flat plate collectors, therefore, they can efficiently heat water, even in winter cold. Their price is also higher, approx. we can count with an increase of one and a half times as of investment, but the price depends a lot on the particular construction.

In both types, the outermost protective layer is glass, but it is a hard borosilicate glass that has very good mechanical resistance, good light transmission, excellent heat and radiation resistance, so it has a good chance of protecting our collector for the expected 20-30 years.

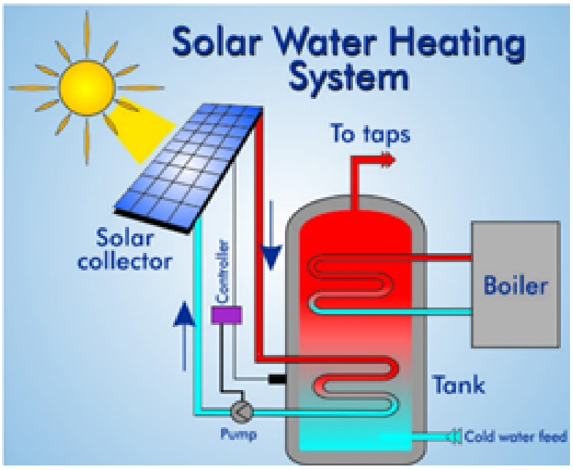


Figure 41: Schematic of the solar water heating system

Both types convert solar energy with good efficiency, although here efficiency cannot be given as exactly as e.g. for solar cells because it is very dependent on outside temperature, irradiation angle, etc. Some manufacturers promise 80 - 90% efficiency, this is also valid for the optimal case, but depending on the time of day and season, it can go down to 30% (unfortunately, it works with less efficiency in winter, energy-poor times).

A person uses approximately 50-60 liters of hot water per day. It requires 2.5 kWh of thermal energy. With a solar collector of 1 square meter, 2-3 kWh of solar energy can be utilized daily in half a year (summer) and 0.5-1.5 kWh in winter. Thus, with a solar collector of 1-1.5 square meters per person, a significant part of the required amount of hot water can be produced.

In case of detached houses, it is advisable to install 2-3 solar collectors for the production of hot water, and 4-5 solar collectors for larger water consumption. If we supplement it with heating, we can count on a collector surface of 2 - 3 m^2 / person. There is also a need for a relatively large hot water tank, usually 200-500 liters. The larger and well-insulated hot water tank is suitable for storing hot water produced by collectors during the day for evening and morning water consumption.

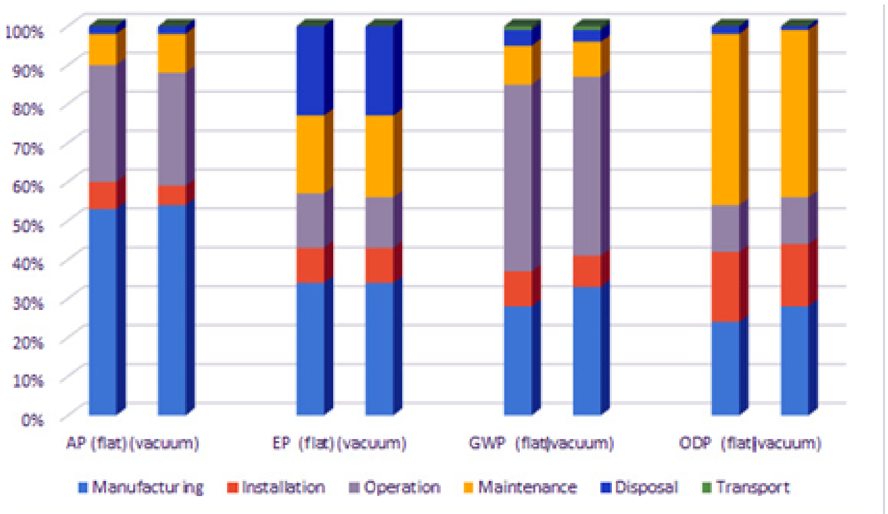
The average price of household-sized collectors is 300 – 900 €, depending on the size and manufacturer. The entire system is around 900 – 1800€, but this does not include the costs of installation.

Environmental assessment

The environmental balance of the collectors is clearly positive.
Following the life cycle:

- Raw materials: iron / steel, copper, aluminium, glass. Their production has a significant impact on the environment but not more than many ordinary industrial products. Fortunately, no special rare earths, precious metals, or severely toxic substances are needed. However, there is not much chance of finding other, more environmentally friendly substitutes.
- Production: The production technologies of the components do not include special steps with a serious impact on the environment. The elements contribute to the load on the system roughly in proportion to their weight, so the two most significant effects are the solar panel and the water tank, to a lesser extent the control electronics, the pipeline, the circulating pump and the mechanical fasteners.
- Transport, packaging: Much of the transport comes from the Far East - therefore, it is beneficial also for the environment, to choose a domestic, European-made product.

- Usage: During the use phase, the electrical energy consumption of the circulating pump must be taken into account, which is on average between 10 -45W depending on the load.
- End of life: At the end of life, practically all of its components can be recycled if they are dismantled separately. They do not contain hazardous substances, with the exception of the controller and the pump, these must be collected separately as E-waste, but most of them can also be recovered.



AP:
Acidification-Potential
EP:
Eutrophication Potential
GWP:
Global Warming Potential
ODP:
Ozone Depletion Potential

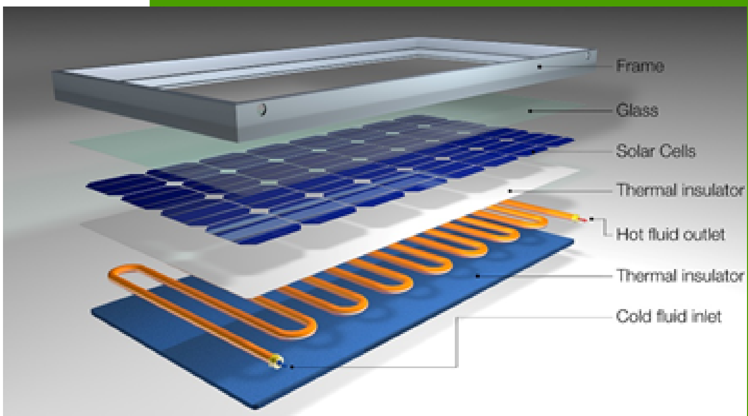
Figure 42: The environmental impact of different stages of life cycle in the light of four impact categories. The comparison only can be interpreted within a pair of columns, here we see the contribution of each stage to the overall environmental impact.[64]

64 Source: György Gröller

Some directions for development

We present two solutions that improve the usability and environmental values of the collectors.

a, Hybrid solar collector system: solar cells can only utilize a certain range of solar radiation, reflect a smaller part and transmit a significant part. This second part can be saved with a solar collector, which has a double advantage. On the one hand, we can produce more energy on the same surface, plus heat and electricity together, so that some conversion losses can be avoided. On the other hand, the collector cools the solar cell, which, being a semiconductor device, works better at lower temperatures. These devices are also available in the market but still at quite high prices.



b, Operation of a cooling system from a solar collector. It is known that the rapid increase in summer energy consumption is largely due to the use of air conditioners. In the absorption type air conditioner the cooling liquid is heated by electricity. This can be done in the same way with a heat exchanger from a solar collector, reducing electricity consumption to a fraction. Another advantage is that energy is produced almost in sync with the need for air conditioning. Thus, not only do we use the collector to produce hot water, we can cool it from the larger capacity in summer, and this capacity can contribute more to heating in winter. They are hardly available in the market yet but more skilful users can even make it at home.

https://www.youtube.com/watch?v=wzcfYVZ7G3w&pp=wgIECgII-AQ%3D%3D&feature=push-fr&attr_tag=0GqRi6YEmvqgXHLX%3A6

b. Solar panel

It produces electricity directly, making it the most popular and researched renewable energy source. Several semiconductor materials are capable of the so-called photovoltaic (PV) effect. Many of them are also available in the market as products, but in practice four varieties are present to a considerable extent. The important types:

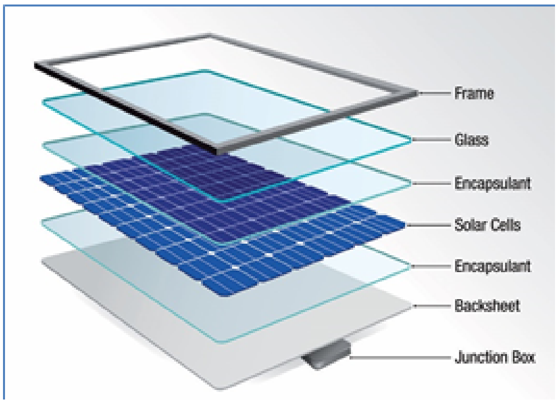


Figure 43: Structure of a crystalline Si solar PV panel

- **Monocrystalline silicon** (monocrystalline, mc Si), the most efficient (18 - 20%) and also the most expensive. Suitable for use in residential buildings.
- **Polycrystalline silicon** (poly Si), only a few% less in terms of efficiency and proportionally lower in price.
- **Thin-film solar cells:** several materials can be used here
  - **amorphous silicon (a Si), microcrystalline (μ-Si)**
  - Other semiconductor compounds: **cadmium telluride (CdTe), copper-indium diselenide (CIS) and copper indium gallium diselenide (CIGS).** Their efficiency can be between 8 and 16%, but eg μ-Si can reach 20%, however, their lifespan is shorter than that of crystalline Si panels. Therefore, they tend to occur in larger solar parks.

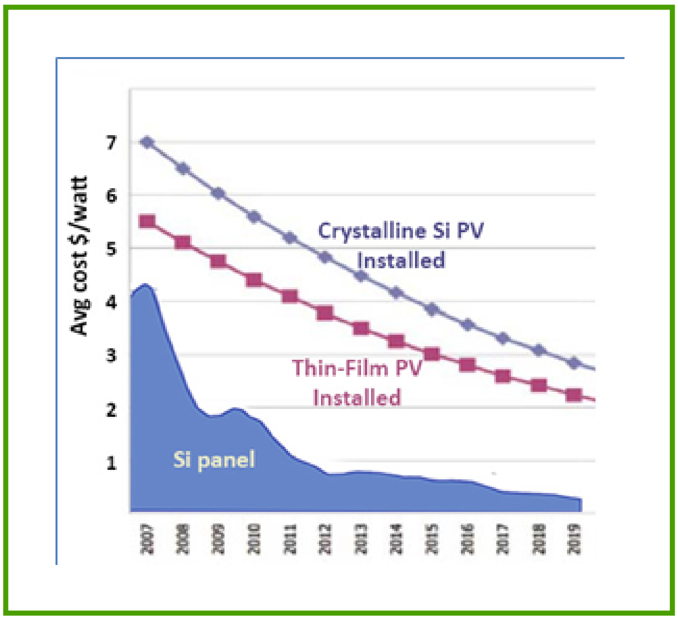


Figure 44: The decline in solar cell prices over the past decade[65]

There have been two main directions of development in recent decades. One of them is the improvement and simplification of silicon technology, as a result of which the price of the panels has greatly decreased, the service life has increased, and their efficiency has improved slightly. The other direction is to develop new, cheaper or more efficient materials. For the most part, the success of the first direction slowed the second one a bit. There are promising candidates, but these products are not seriously market-competitive products. The most interesting developmental directions that are already on the market:

Dye-sensitised solar cell: you can select the utilised wavelength range, which can be infrared, so it transmits most of the visible light and can be mounted on a window.

Polymer/organic solar cell: light, flexible, portable, their efficiency is relatively low (5 - 10%), but the panels are not proportionately cheaper

Perovskite: only a few years of development behind it, fast-improving results, efficiency already above 20% (measured in the laboratory).

All three can be made on flexible substrates, layers can be applied with cheaper printing methods, thus providing greater flexibility in both technology and use. For now, they have a few % of market share.

65 Source: György Gröller

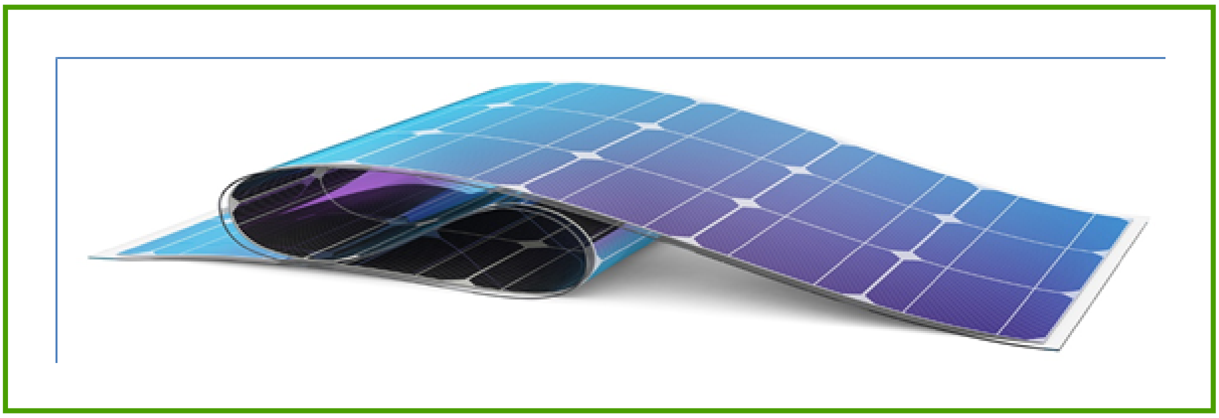


Figure 45: Solar cell on a flexible substrate

Elements of the household solar system

In a slightly expanded list, we present the supplementary elements needed to make the system function, primarily to see what else is needed to be considered in our environmental assessment of solar panels. For more information on the elements of the system, e.g. you can read here:

Panels: The voltage and current that can be obtained from an elementary cell are also very small. Therefore, several are connected in series (strings) and the strings are connected in parallel, from which a separate mounting unit, the panel, is built. The standard size of the panel is 1.5 - 2 m^2, weight 17 - 20 kg. The weight is mainly given by the glass and metal frame, the silicon itself is only a few tens of g.

Inverter: The solar cell provides a direct current (DC) of around 30 - 70 V, which is converted by the inverter to the standard 230 V alternating voltage (AC). This is how we can use it for our household appliances and thus export the surplus to the network. Its performance and size must be matched to the performance of the entire system. The inverter is also the central unit of the system, usually including the measuring unit and providing the possibility to access the data remotely.

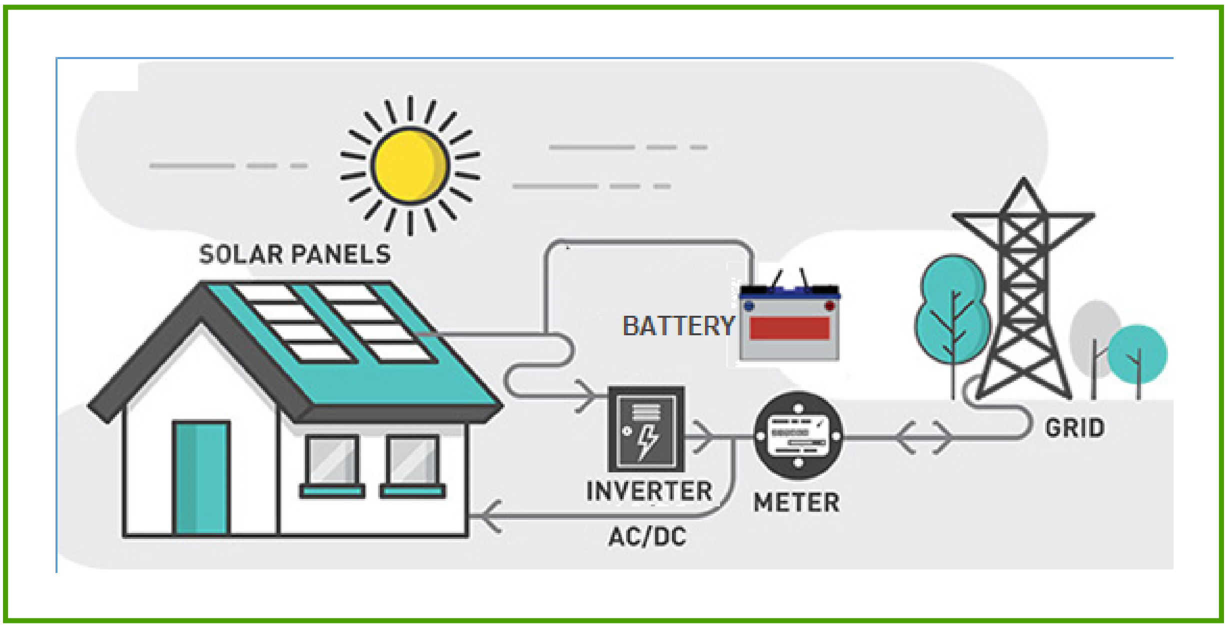


Figure 46: Elements of a household solar system

Measuring meter: If our solar system is connected to the grid, the exported- and imported current must be measured. In many cases, it is also necessary to log at what time of day the feedback occurred.

Battery: The unused generated electricity can be stored in batteries. In a networked system, this is an option but it is essential to use it in island systems.

Fasteners/Fixture: Mechanical elements made of iron or aluminium are required for fastening to the roof. On a flat roof, it comes with a sloping scaffold and concrete weight. All of these should be made of a material that will serve the solar cells for approx. 30 years lifespan.

Environmental assessment of solar panels

Let's review the life cycle of solar panels and the environmental loads worth mentioning at each stage.

- **Production of raw materials:** Silicon is made from quartz sand. It is abundantly available but the production of high-purity silicon requires a great deal of energy and special - often harmful - chemicals. Of the thin-film solar cell materials, cadmium (Cd) is very toxic, and tellurium (Te) and indium (In) have very low reserves on Earth. These all cause significant environmental load in different impact categories. Although the mass of the cells is only makes up of a few % of the total mass, it makes the largest contribution to the environmental impact of the entire system. In addition, the vast majority of the panels are made in China, where the source of energy needed for production is largely coal and oil.
- **Copper and silver** are used for **electronic interconnections**, tin and lead for soldering. (The use of leaded solder is exceptionally permitted in this area for long-term reliable operation.) In case of metals, especially precious metals, mining and metallurgy cause environmental damage. Lead is harmful to human health and the ecosystem, so its use in most electrical and electronic products is prohibited.
- **Inverter and other electronic components:** The main environmental loads in these are PCBs, copper conductors, precious metals, and rare earth metals in the iron core of transformers.

  Most of the mechanical structures are made of aluminium, the production of which also has a significant environmental impact, but it is well recyclable.

- **Transport, packaging, distribution:** Altogether, they account for only a very small proportion of the total load, we could almost say insignificant. From another point of view, however, it is by no means negligible, as it is important to reckon that millions of panels arrive in Europe every year, and transporting them already means serious fuel consumption, CO_2 emissions and seawater pollution. We know that this is not specifically a problem of solar panels, but stems from the current structure of the world economy.
- **Usage:** The service life is approx. In 30 years, there is almost nothing to do in terms of maintenance with solar panels, possibly sometimes to clean the surface but all in all, there is no environmental impact.
- **End of life, recycling, disposal:** The life expectancy of silicon solar cells is 25-30 years that of thin film panels is 10-15 years. Slightly different recycling methods have been developed for the two types. In all of them, the recycling of metal parts and the supporting structure can be considered simple, this can be practically be entirely solved. It is much more difficult to process the panel itself, as here it is needed to disassemble a sandwich structure that has been glued together to last for 30 to 40 years. The glass is almost completely recyclable, the conductor, contact and solder metals (Al, Cu, Ag, Pb, Sn) can be separated. There is no industrial-scale technology for the economical and environmentally friendly recovery of silicon, but the dismantling of the first panels is only just beginning. There are several possibilities for recycling, it depends on the purity of Si. Nowadays, this is an important research topic. One interesting solution may be that, given in the anode of the Li cells, it improves the capacity of the battery. Recycling technology is also available for semiconductor materials in thin film cells.

https://www.pv-magazine.com/2020/05/27/solar-panel-recycling-turning-ticking-time-bombs-into-opportunities/

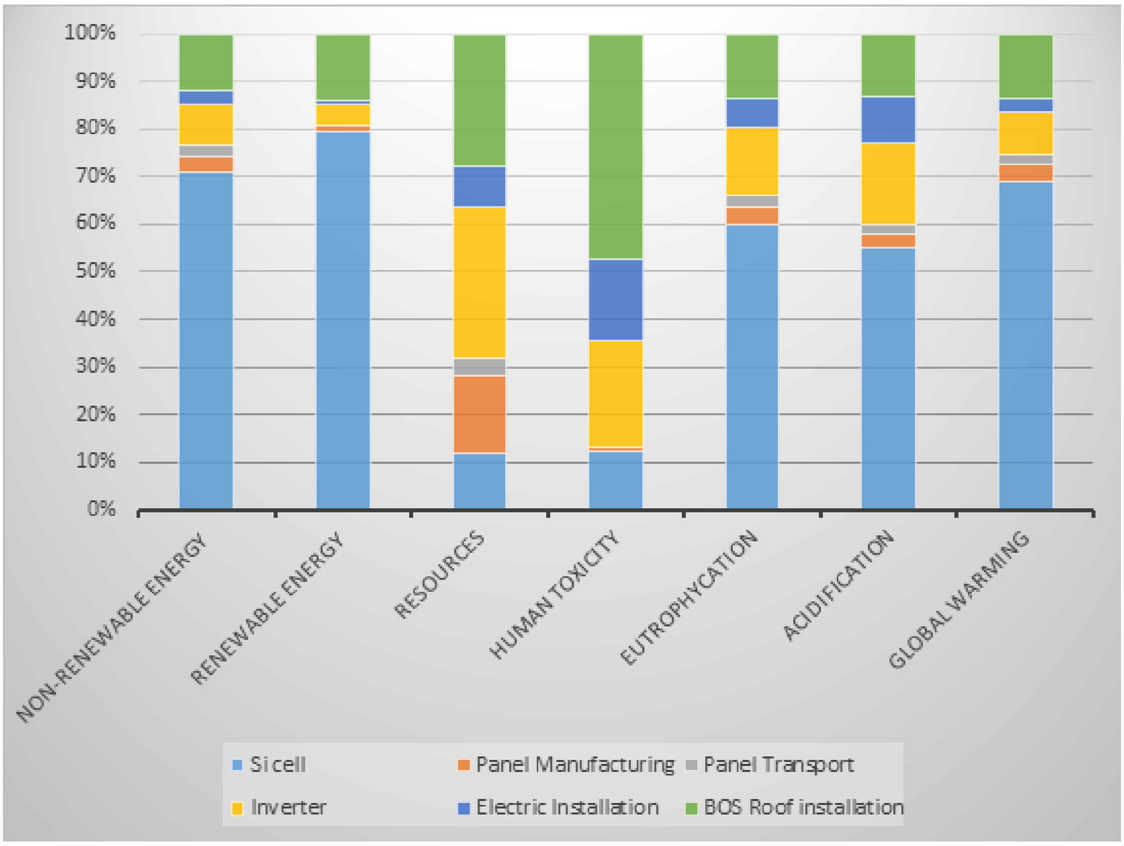


Figure 47: Environmental load of the elements of a crystalline Si solar system in seven different impact categories. The biggest effect is the production of the Si cell, followed by the inverter and the support structure. (BOS: Balance of System) In this representation mode, comparisons can only be made within each effect category, not between categories, because each is normalized to 100%.[66]

Important technical, environmental and economic characteristics

- Power, efficiency
- Spectral sensitivity
- Lifespan
- Energy payback time, cost payback time

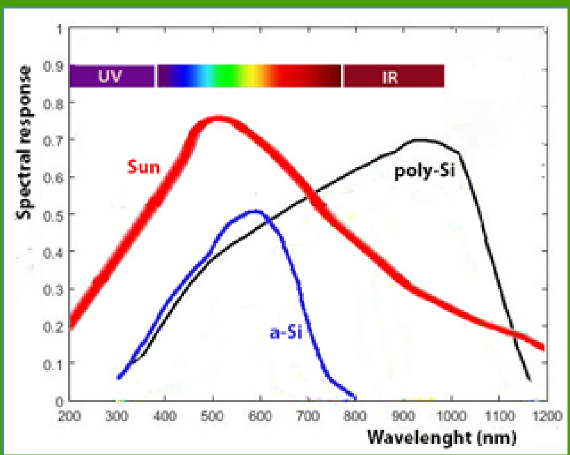
66 Source: György Gröller

Power, efficiency: The performance of the panels is measured under standard conditions and the peak power is given (Wp) This varies between 260 and 400 Wp, which is not enough to power an apartment. Therefore, multiple panels are connected into one system (in both serial and parallel connection, the power is simply added together). The current system output depends on several factors:

- the material of the cell, which determines the efficiency,
- the intensity of the radiation and its angle of incidence,
- temperature (higher at lower temperatures),
- the success of technological solutions to improve efficiency.

We can scale our system to be installed based on performance and average daily radiation. It is worth calculating in order to ensure our expected annual consumption with solar panels. Thus, the overproduction during the sunny days and the energy taken from the grid at other times will be almost the same. It is advisable to oversize the inverter by 30 - 50%, if one wants to expand the capacity of the system later, one does not need to replace the inverter.

Efficiency is calculated in the usual way: transmitted electrical power/absorbed radiated power. The special factor in this case is getting useful energy from a free and unlimited source, so the efficiency decides how much surface area one can get from the required output. If the panel is cheaper (and its production is not very environmentally harmful), it is not a problem if the efficiency is slightly lower, we can safely choose that one as well. In other words, that is why it was a good direction of development over the last 10 years, when the main goal was price reduction. The price has indeed has decreased to a third, while efficiency has increased by only a few percent (a threefold increase in efficiency had no realistic chance).



Spectral sensitivity: The semiconductor materials used here can only utilize a certain wavelength range (= spectrum) of the light falling on them and convert its energy into electrical energy. The figure shows the sensitivity curves for amorphous and crystalline Si. According to this, the utilisation (sensitivity) of **crystalline Si** cells is best between 700 and 1000 nm and is already decreasing in the visible range. The sensitivity of the **a-Si** in the thin layer cell is lower, but it covers the visible range better, so these cells perform better in cloudy weather. If we want to broaden the utilized spectrum, we can make a so-called tandem cell with two active layers of different materials with different sensitivities. With these, an efficiency of 45% was achieved in the laboratory.

Lifespan: The lifespan of these devices usually does not end with a one-time failure, but rather presents a slow decrease in efficiency. That is half to one percent each year, and when performance drops below 70 to 80 percent, it's worth thinking about replacement, perhaps expansion. Essentially, due to a manufacturing defects or accidents, it occurs that panels are damaged earlier but with a very limited instances. Crystalline Si panels have a life expectancy of 25 to 30 years, while thin-film solar cells have a life expectancy of only 10 to 15 years. Inverters are less long-lived, typically operating for 10 to 15 years. If a battery is included with the system, it may be replaced after 5 to 15 years.

Energy Payback Time (EPBT): Suitable for expressing energy gains. It calculates how long all the energy used in the pre-use stages of the life cycle is "repaid" by the solar cell. (Consumption of all additional energy is also included here.) This is a rather reassuring figure, approx. after a year and a half of operation, the "debt" is already settled by the solar cell, from where we really get the electricity cleanly. On a similar principle, we can calculate a **Cost Payback Period**, i.e., how long it takes for the cost of ownership to be recovered from unpaid energy bills. It depends on several factors, e.g. current state support, the price of residential electricity, the number of hours per day in the given area, the orientation of the roof, the amount of electricity exported to and imported from the network. Such an estimate can usually be obtained from the installation company or calculated by automatic calculators, the result can be between 5 and 10 years. The uncertainty significant due to the above variables.

Recommended sites:

https://www.solarguide.co.uk/solar-panel-payback-time#/ (last visited: 2021 April)

https://energyinformative.org/solar-energy-pros-and-cons/ (last visited: 2021 April)

6.4 Smart home

Today it is unimaginable to have a new or renovated home without any level of automation, electronic monitoring system. Almost every function of the flat has an existing control equipment measuring, and controlling systems that are controlled by an integrated IT and remote monitoring system. A detailed environmental analysis would go beyond the scope of our handbook. There are only a few LCA study in the literature, they do not examine complete systems, only a few details. We try to draw attention to some important aspects related to their installation and use.

Somewhat arbitrarily, we divide the devices used in smart house technology into three groups.

- Elements of the measuring and control system used for the energy management of the apartment
- Security systems
- Comfort and luxury solutions

Tools for energy management

By function, they belong here

- Thermometers, temperature controllers, switches required to control the heating and cooling system.
- Operation of the renewable energy sources belonging to the house, control of storage and recharge.
- Smart connectors connected to different consumers, which measure the consumption data of the devices (display, store, transmit) and switch the device on / off based on the received signals.
- Light meters, presence detectors and luminous flux controllers required for the operation of the lighting system.

Essentially, each can be implemented in different stages, from installing a couple of thermometers and heating controlled by those, to using smart meters and transmitting their data to a computer, processing them to control the heating, cooling, ventilation, lighting, shielding and any other functions. By solving all this with the help of the Internet, it can be ensured that residents can also send instructions for operation from a mobile phone, adapting to their current needs.

If we look at the environmental impacts, it is expected that the production, continuous operation and, finally, the waste management of many electronic devices, computers will mean significant energy consumption and environmental impact. In contrast, energy savings achieved in the household with these are the same in value. The life cycle analysis carried out on the topic showed that only in the case of the simplest construction can we achieve a load reduction of around 2-3% in the various environmental impact categories. If we build a complete sensor, monitoring and automatic control system, we can expect an increase in the environmental load between 6 and 16%. It improves the negative overall picture a bit with the fact that we are able to manage the operating time of large household consumers with smart systems so that we can smooth out the fluctuations in the load on the power supply system. This means that during low-load periods of the day, mainly basic power plants operate (e.g. nuclear) with minimal environmental impact, while during peak hours, gas, oil and coal-fired power plants also have to be started up. So, if we can divert the water heating, heat storage stove heating, electric car charging, possibly washing, and washing dishes to the time of the deep valley, it is both environmentally and economically advantageous. Smart systems can solve this with finer tuning, taking advantage of smaller valleys during the day.

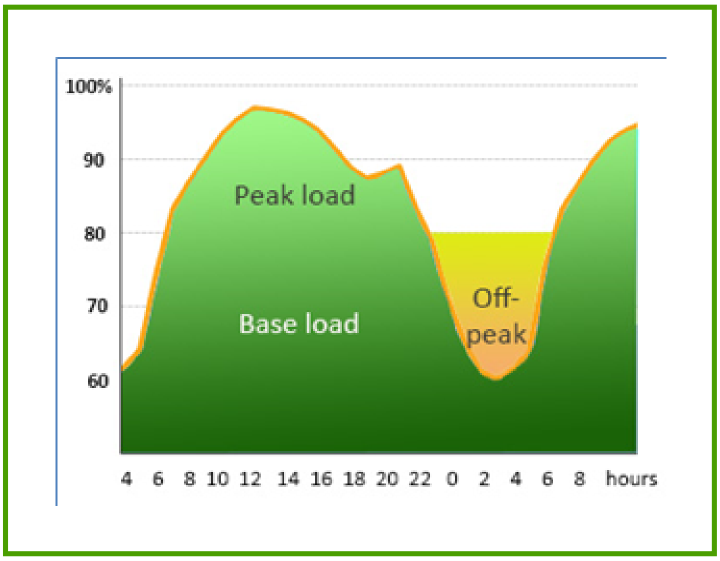


Figure 48:
Daily fluctuations in power consumption on an average summer day[67]

Another invaluable benefit of these tools supporting our house's energy management is to better focus our attention on energy conservation. Instead of 1 - 1 electricity and gas bill a year, we can have hundreds of data on our consumption every day. It is worthwhile to analyse these data from time to time, and based on this, to think about how we can operate our home in the most ecological way, based on our way of life and the characteristics of our house. One of the templates one can set up may not be the best. It is important to involve our family members, and especially our most environmentally sensitive children, in the analysis.

67 Source: Mavir, Portfolio.hu

Security systems

This includes security equipment, alarms, cameras, security power supplies, etc., and even in terms of cost and environmental impact, the proportion of the security company that operates the security system of our house provides remote monitoring. In addition to these, it is also worth installing fire, smoke and carbon monoxide detectors, safety lights for the safe night movement of our older family members.

It is acceptable that safety considerations will be a priority in this area. Environmental considerations can come from choosing between several systems with similar capabilities.

Convenience and luxury tools

These are not specifically environmentally friendly equipment. For those who have the need and opportunity and wishes to reconcile the usage with their environmentally friendly approach, we can suggest two things: to solve the energy supply from their own renewable source and to ensure the professional recycling of end-of-life equipment.

Spread of Innovative Solutions for Sustainable Construction

Handbook

7 Legal Regulations

IS-SusCon

Co-funded by the Erasmus+ Programme of the European Union

7 Legal Regulations

The aim of this chapter is to outline the legal framework related to construction and renovation in each country who has participated at the compilation of the handbook (Hungary, Italy and Finland). Although we mention some legislation and authorities, they provide a framework in force at the time of writing this handbook (2020-21), and without claiming to be exhaustive.

7.1 Legal regulation in Hungary

a. General legal framework for construction in Hungary

In Hungary the so-called **Building Act**[68] defines the basic requirements, tools, rights and obligations related to the shaping and protection of the built environment, as well as the related duties and authorities. We can call it as the general legislation of construction.

This Building Act contains, among other things, the duties and competences of state-, municipal- and authorities related to construction and town planning, as well as the basic regulations of the construction process (e.g. general requirements towards construction works, building authority approval, construction authority inspection, the construction fine). We can also find some rules about the protection of the architectural heritage in the Building Act.

The other important legislation is the **OTÉK**[69], which contains, among other issues, the range of buildings and structures that can be placed in the areas, the conditions for the construction and placement of buildings within the site, the requirements for the placement of buildings and public utilities, the conditions for the construction of buildings and existing buildings.[70]

68 1997 LXXVIII. Act on the Shaping and Protection of the Built Environment
69 253/1997. (XII. 20.) on the national settlement planning and construction requirements
70 https://epitesijog.hu/magyarazatok/epitesugyiengedelyezes/140-az-epitesugyi-igazgatas-jogszabalyai

The capital and county government offices perform the tasks regarding general construction authority, construction supervision and heritage protection. The local governments/municipalities perform settlement development and settlement planning tasks in order to create and protect the built environment.

Building permissions

The new system of building authorities has been in force since 2013, and at the same time the Code of Conduct for Building and Construction Supervision Procedures has also entered into force. Based on that the in general construction activities can be carried out either:

a) without a permit (legally),

b) on the basis of a simple notification,

c) on the basis of a building permit,

d) on the basis of a verified notification (corona virus outbreak norm in 2020)

Construction without a permit

Since January 1, 2017, the range of construction works that can be performed without a building permit has significantly expanded. Of these, the areas relevant to our handbook are:

- Modification, renovation, restoration, modernization, change of the facade of a building (except in the case of a closed or twin-built building, if these activities also affect the foundation or supporting structure of the adjoining building)
- Subsequent thermal insulation of an existing building, replacement of facade doors and windows, painting of the facade surface, modifying the surface of the facade
- Construction of a new chimney in an existing building
- Construction of a new, independent (fixed to the facade wall or free-standing) chimney with a height not exceeding 6.0 m
- Construction of the canopy, protective roof, umbrella structure connected to the facade of the building, or renovation, transformation of the existing one
- Changing the number of functional units in a building
- Construction of private garden water source, swimming pool, garden pond
- Fence, garden structure, terrain staircase, sidewalk and slope, household furnace, meat incense, ice stack and vegetable stack construction, plant support qualifying as a structure, construction of a plant-raising grid, or renovation, transformation of the existing one
- Solar collector, ventilation, air conditioning, alarm system, lightning protection equipment
- Construction of a utility connection and utility replacement structure within the plot
- Construction, renovation, restoration, conversion of a cellar with a depth of up to 2.0 m and an air space of up to 20 m^3

Constructions with simple notification

The construction of residential buildings not exceeding 300 m^2 of total useful floor area has been possible since 2016 with a simple notification.

The construction supervisory authority remains responsible for handling and verifying the simple notifications. They are checked by the authority and in case of incomplete documentation they inform the builder and the Chambers of Architects and Engineers within 8 days. It is worth noting, however, that the authority sends a notification only about the incompleteness of the notification, but it does not necessarily check the content of the documentation.

Building permit

Where a construction cannot be subject to simple notification, the construction or expansion activities can begin only with a definitive building permit. The main rule is that the permit must cover all construction activities carried out on a plot at the same time. Various documents have to be attached to the application.

During an on-site inspection the construction authority checks whether the planned construction complies with the legal and professional requirements and the submitted documentation.

Source:
https://epitesijog.hu/8874-2014-oktober-24-teljes-atalakulason-esett-at-az-egyszeru-bejelentes
https://epitesijog.hu/8874-2014-oktober-24-teljes-atalakulason-esett-at-az-egyszeru-bejelentes

b. Energy performance requirements

The minimum energy performance requirements of buildings are regulated by the 7/2006 (V.24.) TNM regulation[71] in Hungary. The requirements are compulsory for all new buildings and there are also requirements for retrofits aimed at saving energy. The regulations have been gradually strengthened in recent years, any new construction must be "nearly zero energy building". Six types of requirements exist:

71 7/2006. (V. 24.) Ministerial decree about the determination of the energy performance of buildings

1. The maximum thermal transmittance of the envelope components determines how much insulation shall be applied on external walls, roofs or cellar floors etc. The requirements are around 0.17 – 0.24 W/m^2K, i.e. approx. 16-24 cm insulation is necessary (see chapter 5.2).

2. The *specific heat loss coefficient* shows the energy quality of the building itself without the technical systems. This includes the heat losses of the whole building envelope and also the incident solar gains in the winter. The shape, size and orientation of the building matter. An average, relatively compact and well oriented building generally complies with this requirement with minimum insulation thicknesses. However, a very complex building with unfavourable orientation may need additional insulation.

3. The *total primary energy use* of the building includes the energy use of the space and hot water systems, cooling and mechanical ventilation if these exist, but does not consider household appliances nor lighting systems in a residential building. This indicator is expressed as non-renewable primary energy, which is different from the delivered or final energy use specified on the electricity or gas bill. Primary energy also considers the efficiency of energy transformation, for example the weighting of electricity is 2.5 in Hungary, while natural gas is 1. For nearly zero energy buildings, the maximum allowed primary energy use is 100 kWh/m^2yr.

4. The indicator of *summer overheating* describes the risk of the overheating in the building. The requirement can be usually fulfilled if the building has effective external shading devices. Also, night ventilation has a favourable effect.

5. The requirements on the *technical building systems* define the quality of boilers, control systems etc.

6. The *minimum renewable energy share* is 25%. This requirement is usually fulfilled if heating is supplied with heat pump or biomass boiler, and in many locations also with district heating. In case of gas heating, installing photovoltaics or solar collectors is necessary for compliance. An alternative compliance path is

enhanced energy efficiency if the possibilities for renewable energy utilization are limited. In this case, max. 76 kWh/m^{2}yr primary energy use is allowed. For example, in a densely built city, solar energy utilization or biomass heating is usually limited or not possible, but energy efficiency can be increased with heat recovery ventilation or improved insulation.

The architect and the building service designer must ensure that the building complies with the energy requirements and prove this with a calculation. The energy certificate of the building shall be issued based on this calculation before the building gets the permit for occupancy. Nearly zero energy buildings belong to category BB or better.

When existing buildings undergo energy renovation or get an extension, the requirements depend on the extent of the intervention. In case of a major renovation when more than 25% of the surface undergoes renovation and in case of large extension when the floor area of the extension exceeds the floor area of the existing building, several requirements must be met. Obviously, components undergoing renovation must comply (e.g. part of the building envelope where insulation is added or part of the technical system being exchanged). Beyond this, also the specific heat loss coefficient and the primary energy demand requirement of the whole building must be met, but the latter is less strict than for new buildings. These encourage thorough, deeper renovations with several interventions applied at the same time and with high energy saving. Renewable energy utilization is not compulsory for renovation but it is expected that funding schemes will prefer renovated buildings reaching the level of nearly zero energy buildings.

Related literature

https://epitesijog.hu/magyarazatok/epitesugyiengedelyezes/140-az-epitesugyi-igazgatas-jogszabalyai

https://epitesijog.hu/8874-2014-oktober-24-teljes-atalakulason-esett-at-az-egyszeru-bejelentes

https://epitesijog.hu/185-az-epitesi-es-egyszer-sitett-epitesi-engedelyezesi-eljaras

7.2 Legal regulation in Italy

In Italy, in order to proceed with construction works, to ensure that construction works are performed in compliance with national and local regulations and to provide local administration with detailed information or main reference for compliance check, different administrative procedures exist. The administrative procedure to be followed depends on the type of construction works. More in details, construction works can be performed either:

1. Building permit
2. Certificated notification of activity start (SCIA)
3. Simple notification (CILA) or without notification

This section provides a brief description of procedure in place in Italy and related steps for each of them. Type of cost and procedure time are also described. Guide is provided on which procedure it has to be followed, based on the type of construction works.

DISCLAIMER: This section is intended to provide a general overview, without claiming to be exhaustive. Thus, it is suggested to local administrations and/or professionals for a completer and more updated guide.

a. Building permit

When:

- New building
- Building renovations affecting:
  - o Volumes and/or shape
  - o Functional destination (only for building in the old town area)
  - o Elevations, in case of building subjected to “protection” in the frame of Culture and Landscape protection code
- Recovery of attic (under roof) space

The applicant and the person submitting the document:

Building permit is released to the building owner or to the one entitled to receive it. It can be presented even by the representative of a company of the professional (architect, engineer) as far as that person is delegated to perform as such by the owner.

In practice, owners or delegated persons are the formal applicant, whereas the physical submission of the request is always performed by the professionals.

Content and validity:

The building permit is realised in max. 60 days from the day of the request submission. In case of no answer from the receiving local administration, the request is intended as “approved”.

It has to include the date of start and end of the construction works. The former, no later than 1 year from the date of the permit release, the latter no later than 3 years. After 3 years from the date of permit release, it expires unless an extension is required before the expiring. The extension last 1 year and extension request has to be motivated.

Costs

The building permit is not free of charge. Indeed, it requires the payment of the following:

- Infrastructure costs
- Construction contribution.

Infrastructure costs are intended as contribution to the costs of construction and maintenance the local administrations have to afford. The cost depends on the specific location and is calculated per m^2

Construction costs are calculated as % of the whole construction works. The % is in the range of 5 – 20%.

Information and references to calculate costs are often accessible at the website of local administrations, at the section on buildings and construction.

The payment has to be done by the applicant.

Other costs associated to construction works to be done under the frame of a building permit are:

- Costs of professionals
- Costs of construction companies, namely of materials, processing and labour
- Costs of administrations fee and secretariats

b. Certificated notification of activity start (SCIA)

When:

- Extraordinary maintenance affecting structural parts of the building or elevations
- Restoration
- Renovations different from those one requiring the building permit
- Variations to the building permit, within certain limitation and in compliance with prescriptions stated in the building permit

Examples of works which can be done under SCIA: roof renovation, floor substitution and renovation, placement of new windows, new external doors or skylights

The applicant and the person submitting the document:

As for the building permit, the SCIA is released to the building owner or to who is entitled to receive it. It can be presented even by the representative of a company or by the professional (architect, engineer) as far as the one delegated to this by the owner.

In the practice, owners or delegated persons are the formal applicants, whereas the physic submission of the notification is always performed by the professionals. The SCIA has to be submitted on paper, it cannot be submitted online.

Content and Validity:

The SCIA does not require the answer/response of the receiving local administration. Indeed, does require a notification. The notification submission gives the right to start the works. However, the local administration has 60 days to verify the compliance of declared works to the national and local regulations and in case of not compliance or missing information it can ask for the works interruption. If the interested building is subjected to special protection, e.g. under the frame of Culture and Landscape protection code, the owner (or the delegated) has to acquire the authorization from the body responsible for the related protection program.

The SCIA is valid for 3 years. If construction works are not finished within this time-frame, a new SCIA has to be submitted and justifications provided.

Costs

Costs associated to the SCIA can include or not the infrastructure costs. Indeed, is not due for all type of construction works which can be implemented under the frame of a SCIA.

Other costs associated to construction works to be done under the frame of a SCIA, as in the case of the building permit, are:

- Costs of professionals
- Costs of construction companies, namely of materials, processing and labour
- Costs of administrations fee and secretariats

c. Simple notification (CILA) or without notification

When:

CILA

- ***Extraordinary*** maintenance not affecting structural parts of the building or elevations
- Restoration not including structural works
- Works to satisfy temporary needs, to be removed when needs finish and in any case within 90 days

Works without notification

- Ordinary maintenance, which means all construction works concerning only repair, renovation and substitution of finishings or needed to integrate and maintain the efficiency of existing technic systems (e.g. heating systems)
- Installation of heat pump with power until 12 kW
- Works to eliminate architectonic barriers (e.g. installation of elevators) as far as they do not affect building volume and/or shape
- Finishing (e.g. tiles) of external area
- Installation of solar and PV panels, if outside from the "old town".

For CILA, the owner or the delegated party is the formal applicant. It can be submitted online by a professional. It is valid from the submission date and has not an expiring date. As for the SCIA, the local administration has 60 days to verify the compliance of declared works to the national and local regulation and to ask for work interruption in case of missing information or not compliance.

Costs

CILA requires the payment of the administration fee and secretariats, whereas no fees are due for works not requiring the notification. As for SCIA and building permit, the cost of construction works have to be considered by the owner, i.e.:

- Costs of professionals
- Costs of construction companies, namely of materials, processing and labour

d. Legal requirements – Energy rating

In Italy, in compliance to the EU Directives (2002/91/CE first and 2010/31/UE concerning the energy performance of buildings), the Energy Performance Certificate of buildings has to be developed and provided in each buying/selling operation as well as in renting operation.

The Energy Performance Certificate (APE), which in the past was called Energy Certificate (ACE), as said by its same name, overall reports the information on the building performance, its energy consumption during the operation stage, the energy efficiency of systems and the possible improvement options which can be implemented to further save energy and improve the performance. Italian national guidelines on APE have been recently revised, with major aims to fulfil the new and more stringent objectives established at EU level (Directive 2010/31/UE and its amendment) and to foster a more homogeneous application and implementation on the national territory.

In the following lines the classification scale and the main content of the APE used in Italy is briefly described.

At a general level, the energy performance of buildings is defined on a scale running from G (less performing) to A4 (highly performing), as represented in the figure 26.

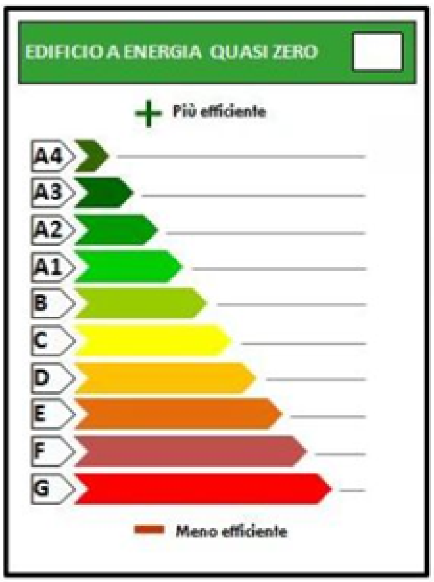


Figure 49: Energy performance scale for building classification in Italy[72]

72 Source: National guidelines for Energy Performance Certificate of Buildings, Annex I

The classification of such scale is based on a parameter which is called Index of energy non-renewable global performance ($EP_{gl,nren}$). The parameter, with specific reference to the residential buildings, takes into account the non-renewable primary energy demand for the following energy services: heating, cooling, hot water and ventilation[73]. It is measured in kWh/m^2year and the surface to be taken into account for the calculation is basically the net floor area heated, cooled and ventilated.

While the $EP_{gl,nren}$ is the parameter used to classify the building and is the main parameter reported in the APE, the APE, for sake of transparency, has to report also the contribution of the different energy services installed in the buildings as well as additional information on building characteristics affecting the final demand of the primary energy, namely:

- The envelope capacity of limiting the energy demand for winter heating and summer cooling (e.g. the ratio S/V)
- The performance of the heating system and of the cooling systems (i.e. the yield of the systems).

As far as the calculation method is concerned, the is calculated in compliance to the standard UNI/TS 11300. More in detail, the calculation method in the UNI/TS 11300 has to be applied to new buildings and can be applied to all buildings (new and existent). However, simplified calculation method can be also applied for existent buildings.

As far as the rating method, the scale is defined with the reference standard building method. The reference standard building, against which the real building is scored, has:

- The same location and context of the building to be scored as well as the same S/V
- Predefined Heating, cooling, air conditioning and ventilation systems, compliant to the minimum requirements defined for the year 2019/2021 by the so-called "Minimum requirements decree" (D.Lgs. 192/2005 and following integrations/modifications)

73 Other two energy services are included in the calculation of the EPgl,nren , which however are mandatory only for non-residential buildings.

- Predefined characteristics of the building envelope (U-value) according to the minimum requirements defined for the year 2019/2021 by the so-called "Minimum requirements decree" (D.Lgs. 192/2005 and following integrations/modifications). Such requirements are different according to the specific climatic zone

Based on the above bullet points, the $EP_{gl,nren,rif,\ standard}$ (i.e. the $EP_{gl,nren}$ of the reference standard building) is calculated and the classification scale (from G to A4) defined. In the second step, based on the comparison between the $EP_{gl,nren}$ and the $EP_{gl,nren,rif,\ standard}$, the energy class is assigned.

	Energy class	
	A4	≤ EPgl,nren,rif, standard (2019/2021) 0,4
0,4 EPgl,nren,rif, standard (2019/2021) <	**A3**	≤ EPgl,nren,rif, standard (2019/2021) 0,6
0,6 EPgl,nren,rif, standard (2019/2021) <	**A2**	≤ EPgl,nren,rif, standard (2019/2021) 0,8
0,8 EPgl,nren,rif, standard (2019/2021) <	**A1**	≤ EPgl,nren,rif, standard (2019/2021) 1
1 EPgl,nren,rif, standard (2019/2021) <	**B**	≤ EPgl,nren,rif, standard (2019/2021) 1,2
1,2 EPgl,nren,rif, standard (2019/2021) <	**C**	≤ EPgl,nren,rif, standard (2019/2021) 1,5
1,5 EPgl,nren,rif, standard (2019/2021) <	**D**	≤ EPgl,nren,rif, standard (2019/2021) 2
2 EPgl,nren,rif, standard (2019/2021) <	**E**	≤ EPgl,nren,rif, standard (2019/2021) 2,6
2,6 EPgl,nren,rif, standard (2019/2021) <	**F**	≤ EPgl,nren,rif, standard (2019/2021) 3,5
	G	> EPgl,nren,rif, standard (2019/2021) 3,5

Figure 50: Energy performance scale and values for building classification in Italy[74]

74 Source: National guidelines for Energy Performance Certificate of Buildings, Annex I

The APE has basically a validity of 10 years.

As required by the Directive, starting from January 2021, all new buildings have to be Nearly Zero Energy Building (NZEB). Such performance corresponds to the separation value between the class B and A1.

7.3 Finnish building regulations and upcoming alignment with the Finnish climate policy

In the Finnish government's climate policy, it is stated that Finland is to be carbon-neutral by 2035[75], which drives the construction sector along with other sectors to decrease their emissions drastically during the oncoming years. As a part of the national climate targets, Finland has developed a roadmap to low-carbon construction. The roadmap to low-carbon construction has put in place the general guidance to the regulations under development[76]. The road map was published in 2017 and it stated that the whole carbon assessment of buildings must be incorporated in the building regulations by the mid-2020s.

In Finland, the regulatory framework for construction sector is driven by the Environmental Ministry of Finland. The regulatory framework does not yet recognize the need for climate impact assessments. However, the regulation for land use and construction is bound to change during the oncoming years and the proposal for the new regulation is expected to come out by the end of 2021[77] in order to drive construction into a more carbon neutral direction by providing limit values for different building types.

75 https://ym.fi/en/carbon-neutral-finland-2035
76 https://ym.fi/vahahiilisen-rakentamisen-tiekartta
77 https://mrluudistus.fi/wp-content/uploads/2021/01/MRL_ilmastovaikutusten_arviointi_raportti_taitettu_150121.pdf

According to the upcoming regulation, a climate impact assessment for a new building project is needed to get a building permit. This includes calculations done by the Finnish Environmental Ministry Methodology. These requirements are not likely to impact small scale buildings, such as row houses and detached houses.

The roadmap and the Finnish methodology are currently concentrating on new buildings and refurbishments and are not taking a stand on the impacts of larger infrastructure projects. The building life cycle assessments are done using the Environmental ministry's method for the whole life carbon assessment of buildings. The methodology is heavily based on the European Commission's Level(s) methodology and the EN -standards.

The view the methodology[78] brings out is that a low carbon building has a small carbon footprint and a large carbon handprint and its whole point is thus to bring about the whole life cycle of a building under assessment. In the methodology the carbon footprint includes the whole lifecycle of the building, whereas the carbon handprint considers the net benefits that wouldn't be happening without the building being built, including for example the carbon sinks and storages (e.g. carbon stored in wooden materials) and the benefits given by recycling. Still, the Finnish government is expected to update this methodology in 2021.

Finnish regulation on energy performance of buildings

Today buildings are responsible for approximately 40 % of the Finnish total energy usage[1]. The aim of the regulation around energy usage in buildings is to improve the energy efficiency of buildings, to enhance usage of renewable energy and to decrease the amount of energy used and the emissions that come from energy usage[79].

78 https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/161796/YM_2019_23_Method_for_the_whole_life_carbon_assessment_of_buildings.pdf?sequence=1&isAllowed=y
79 https://ym.fi/rakennusten-energiatehokkuus

The Finnish legislation is based on the European Union's Energy performance of buildings directive. The legislation for land use and construction brings out the requirements for nearly zero-energy buildings and energy performance certificates[80]. The new regulations ensure the implementation of Directive 2010/31/EU.[81]

Where the energy performance certificate is mandatory for all the new buildings as well as old ones that are being sold or rented out, the nearly zero-energy building regulation affects all new buildings with some exceptions such as buildings under 50 m^2 and residential buildings that are not used as permanent residencies[2].

In terms of energy efficiency, the project owner must account to the building being designed as energy efficient as possible, and so that energy and natural resources are used as little as possible. The energy efficiency must be proved by performing calculations on the energy performance of the building. In order to get a building permit, the energy performance certificate is often needed and needs to be presented whenever asked for.

The National Building Code of 2017 specifically sets maximum values for total energy consumption, which vary by building type and, for single-family houses, also on the area of the building. The new building code encourages the use of district heating and renewable energy sources. Calculations also account for thermal comfort, indoor-air quality and infiltration, thermal bridges and shading devices.[41]

On the monetary side, according to national report that was submitted to the European Commission in 2013, the cost-optimal level of energy efficiency is in average 7% more efficient than the regulations set in the Ministry of the Environment Decree 2/11 (2011), and, for existing buildings, 8% more efficient than requirements set by Ministry of the Environment Decree 4/13 (given in 2013) [41]

80 https://finlex.fi/fi/laki/ajantasa/1999/19990132#L17P117g
81 https://epbd-ca.eu/wp-content/uploads/2018/08/CA-EPBD-IV-Finland-2018.pdf

Additionally, the Finnish government has introduced a range of incentives to encourage energy-efficient renovations, including financial subsidies for investments regarding energy efficiency and energy auditing for both public and private sector. For households, some renovation works are tax deductible, motivating so private house owners to engage professionals to support them to improve energy efficiency [41].

Spread of Innovative Solutions for Sustainable Construction

Handbook

8 Summary

IS-SusCon

Co-funded by the Erasmus+ Programme of the European Union

8 Summary

We have come to the end of our handbook. At the beginning, we didn't promise an easy and quick read, and the reader will surely agree with us that we kept our word. We are aware that the handbook contains a lot of new information and technical terms, seemingly complicated or really complicated professional excursus, but we hope that we have managed to present all this in an understandable, readable format.

In the handbook, we introduced the concepts of environmental impact, sustainability, life cycle, life cycle approach and life cycle analysis, their meaning and several professional background information behind them. We could get a brief insight into the different building rating systems, read about their meaning and usability. We took a look at the issues, opportunities that we may encounter during use, maintenance and renovation of buildings, and which also have a significant impact on the sustainability of our built environment.

We looked at different structures and materials, passive and active solutions, and different building systems. At the first reading, many of the solutions described in the handbook may seem to be futuristic, but we reassure the reader that all these technologies already exist and are available to everyone. Moreover we hope that in the near future not only new technological solutions but also their price will also make them attractive.

We are confident that as reading through the book, the reader's environmentally conscious thinking and commitment to sustainable construction has received additional perspective. We hope that during the construction of your new home or the renovation and transformation of your existing one, you will be able to utilize the information obtained from our handbook and the knowledge based on them.

At the beginning of the handbook, we drew your attention not to apply everything automatically, so study and think carefully about the content of the book, as everyone has to make their own decisions. We recommend that if you have any doubts or questions, do not hesitate to consult a specialist. Feel free to ask the help of your designer or another professional with in-depth knowledge of the subject.

We believe that the issues discussed in this handbook are vital, as they are about our future and the future of our descendants. If you found the topic useful, the options and solutions suggested in the handbook, please pass it on to others, especially your children and grandchildren.

Spread of Innovative Solutions for Sustainable Construction

Handbook

9 Annexes

IS-SusCon

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9 Annexes

- info sheets of the building materials
- Realized best practice examples of innovative and sustainable buildings