HI-SMART

HI-SMART: HIGHER EDUCATION PACKAGE FOR NEARLY ZERO ENERGY AND SMART BUILDING DESIGN

MODULE #2

CHAPTER 2: HIGH PERFOMANCE WINDOWS FOR NEARLY ZERO ENERGY BUILDINGS

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1.1 WINDOWS IN THE BUILDING ENVIRONMENT

Near zero energy buildings are meant to respect very high energy performance requirements. These buildings will typically encompass a high level of insulation, very energy efficient windows, a high level of air tightness and balanced mechanical ventilation with heat recovery to reduce heating/cooling needs. Although the nearly zero or very low amount of energy required should be covered to a significant extent by energy from renewable sources, the quality of built materials and elements plays the most important role to conserve the energy supplied to the building.

No doubts that for the energy savings a right selection of window type can be crucial. Therefore choosing high-performance windows with appropriate properties can dramatically decrease building´s energy use and operational costs. Windows, or window systems represents an important integral part of the building´s thermal envelope, which also directly impacts other mechanical systems. The key properties that should be observed are as followed:

- energy properties : - U values ($W.m^{-2}.K^{-1}$)

  - g value (-) also known as solar heat gain coefficient (SHGC)

- optical properties: - LT – light transmittance

  - Rt – light reflectance

Nowadays an early design stage building simulation can tell us if the desired ratio between opaque and transparent constructions can lead us to the energy effective design or not, parallel with maintaining the requirements for visual tasks or hygienic criteria. Modern simulation software tools enable us to change this ratio as a parametric input and therefore give an important piece of information for architects to define the shape and architectural expression.

As modern buildings that find inspiration in nature through organic architecture rely in large content on transparent constructions, not only the proper selection of the materials but also fabrication of these systems are very important.

The following issues can affect the performance of the windows systems:

- Thermal Bridging

- Thermal and Visual Comfort

- HVAC and Lighting

- Acoustics properties

- Water intrusion

Where thermal bridges are connected mostly with right composition of each window element and its installation, they must also include the thermal breaks in the installation of window frames, the absence of which can lead not only to energy loss (linear thermal bridges) but also to condensation and maintenance issues.

Thermal comfort is mostly connected with radiative heat that penetrates building which needs to be balanced with interior heating and cooling loads. Heat that comes through windows is favorable when it is needed during heating period, but in excessive measures can hugely impact cooling loads and also produce the discomfort for occupants.

Design for daylighting is an effective strategy which cannot be neglected. Large glass areas are chosen to maximize the visible light to penetrate, but needs to be tinted in the final steps in many cases. The lack of or inappropriate shading devices can cause glare. Therefore an optimal balance needs to be achieved between visual comfort and light transmittance. A minimum of LT=60% is required in Slovakia.

Proper design in terms of daylighting can save on artificial lighting needs and can reduce the size and energy need for HVAC systems since high-performance windows and glazing system affect building´s peak heating and cooling loads.

Acoustic properties are becoming crucial when building is located close to the source of noise such as busy traffic areas, technological facilities or airports. Right composition of glazing system including different thicknesses of panes needs to be calculated, often with combination of additional ventilation units, since these windows are designed to be operated without being opened.

Water intrusion is a problem in all building structure components and is mostly the matter of proper detail design. While glazing system itself have a high resistance to vapors in general, the framing design and its connection to adjacent envelope elements can produce weak spots enabling rainwater channels. The result is not only a deterioration of internal finishes, but it also decreases indoor air quality and affects the energy performance of affected adjacent structures.

Windows are part of passive energy efficiency solutions that include:

- the building envelope solutions – all the elements such as walls, roofs, etc.

- passive strategies for cooling, such as natural ventilation, shading, etc.

This passive solutions present the core of the building structure and equipment. Since their lifespan is designed along the economical usage of the building they need to be selected also with the aim of easy maintenance and not to be replaced in near future.

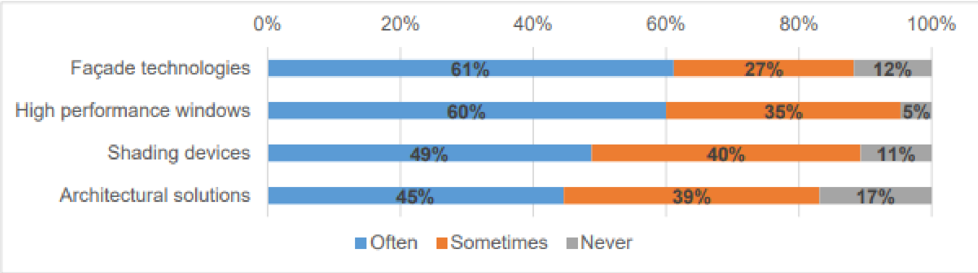


Fig.X Percentage of passive solutions used in nZEBs. (ZEBRA 2020)

According to surveys the professionals used mostly the façade technologies and high performance windows in realization of nZEBs. The architectural solutions such as natural lighting and passive cooling was less selected among the options.

1.2 WINDOWS IN EUROEPEAN UNION

An overview about EU producers

1.3 SOLAR RADIATION AND WINDOWS

Solar radiation is a general term for the electromagnetic radiation emitted by the Sun. As the sunlight passes through the atmosphere, some of it is absorbed, scattered or reflected by water vapors, dust, pollutants and other components of the atmosphere. This results in diffuse solar radiation.

The solar radiation that impacts Earth´s surface without being diffused is called direct solar radiation. The sum of direct and diffuse radiation is called global solar radiation. The atmospheric conditions can reduce the radiation that impacts building in various amounts. The spectrum of solar radiation is close to that of a black body with a temperature of about 5800K. About half of this radiation (43%) is in the visible part of the electromagnetic spectrum (400-700nm) and the rest is mostly (52%) in the near-infrared part (700-2500nm) with some (5%) in the ultraviolet (300-400nm) part of the spectrum.

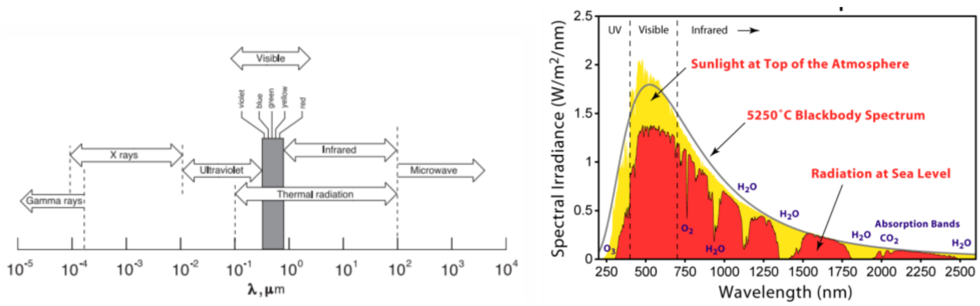


Fig. X Electromagnetic spectrum and solar radiation spectrum

As the solar energy from invisible part of the spectrum comprises more than 50 % of the solar energy, controlling the invisible solar spectrum using different glazing materials and coatings can play a significant role for nZEBs design.

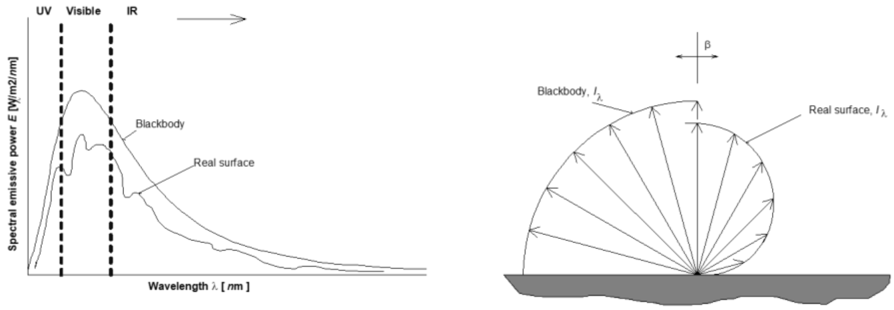
When hitting the Earth's surface the radiation in dependence of its wavelength and direction, and also the nature of the material, to which it is incident, gets reflected, transmitted, or absorbed by it. In semitransparent materials (e.g. glass pane, water) all three phenomena occur, i.e.

$$\rho\,\text{(reflection)} + \tau\,\text{(transmission)} + \alpha\,\text{(absorption)} = 1 \qquad (1)$$

In opaque materials the transmission drops out and applies that

$$\rho\,\text{(reflection)} + \alpha\,\text{(absorption)} = 1 \qquad (2)$$

The absorbed radiation raises the temperature of the material (mass), which in turn removes the excess heat energy by radiation. The amount of emitted energy is dependent on the emissivity (surface radiation), ε, which is one of the characteristics of material. The emissivity is defined as the ratio of the radiation emitted by the surface of the material to the radiation emitted by a black body at the same temperature. Black body is a perfect absorber and issuer of radiation, whereas the spectral distribution of the intensity of solar radiation according to wavelengths is approaching the spectral distribution of the intensity of blackbody radiation at a temperature of 5800 K.



(a) (b)

Fig. 1: Comparison of blackbody and real surface emissions. (a) Spectral distribution, (b) Directional distribution (I_λ = radiation intensity, β = radiation angle) (Incropera & DeWitt, 1996)

The emissivity of a given material depends on the temperature of its surface and the wavelength of the emitted radiation. But also depends on the direction of the radiation. The spectral distribution of the absorbed radiation and subsequent emission may differ, e.g. in the case of glass (ordinary glass “converts” the absorbed shortwave radiation into longwave radiation).

Opaque materials and structures are characterized by thermal conductivity factor (λ). In case of transparent materials we focus on the properties connected with transmittance of solar radiation. We distinguish two main types of these properties - solar and visual. The solar properties integrates, more or less, the entire spectrum of sunlight and are intended mainly for energy simulations. The visual properties refers to the visible part of spectrum only and are intended mainly for daylighting calculations.

In addition to the characteristics listed above a global characteristic of the solar properties in form of the total solar energy transmittance coefficient, so-called solar factor (solar heat gain coefficient (SHGC)), or the g-value is widely used.

The solar factor (SHGC), g, is defined by EN 410:1998 as the sum of the direct solar transmittance, τ_{sol}, and the secondary heat transfer factor, q_i, of the glazing towards the inside. The secondary heat transfer factor is caused by convection and long-wave infrared radiation of that part of the incident solar radiation, which has been absorbed by the glazing. The respective equation for the g-value is then:

$$g = \tau_{sol} + q_i \tag{3}$$

The solar direct transmittance, τ_{sol}, is a glazing property. It is the portion of incident solar radiation that passes through the glazing layer and can be described as primary heat gain, g_1, divided by the total incident solar heat flux, φ_e . The secondary heat transfer factor, q_i, is dependent on the absorption factors of glazing layers, their emissivities (long-wave infrared radiation), ε, and thermal conductance, Λ, including the cavities and surfaces heat transfer. It is the absorbed portion of incident solar radiation that is converted into conductive and radiative heat flow towards the inside, and can be described as secondary heat gain, g_2, divided by the total incident solar heat flux, φ_e. Hence, another equation for the g-value is:

$$g = \frac{g_1 + g_2}{\varphi_e} \tag{4}$$

The solar factor is one of the most important characteristics of glazing systems because it allows an immediate and reliable assessment of the future performance of the glazing system in terms of solar heat gains.

Modern glazing systems are equipped with highly modified glass panes. The most frequently used treatment of glass in terms of improving solar properties is so-called coating or plating. This method is based on reducing the emissivity of the glass by applying an extremely thin layer of metal oxides. The producers adopted different technologies of manufacturing, mainly:

- **CVD** (chemical vapor deposition) – "hard coat" an on-line process where the coating is applied in the bath. This type has limited ability to achieve high-perfomance solar control levels.

- **Spray Pyrolysis** – an on-line process where coating of metal oxides is sprayed on surface where the reaction creates a durable layer. This type may influence the color of substrate glass and increase reflecivity, thus reduce light transmission.

- **MSVD** - Magnetron Sputter Vacuum Deposition – an off-line process where coating is applied in vacuum chamber to ready-made pre cut glass panes. This type enables lower emissivity and better solar performance. Since the nature of the coating layer most of them should be sealed inwards or laminated to avoid its damage. Most of solar control low-e glasses are made using this technology.

Using these methods we can reduce the glass emissivity from about 0.95 (clear glass) to 0.2 or less. This group of glazings is called low-emissivity or "low-e"glazing.

The position of low-e layer is very important. A typical low-e glass can work as:

-**Solar control low-e**: blocks solar radiation to reduce solar gains resulting in reduction of cooling costs.

-**Passive low-**E: transmits solar radiation

Only one low-e coating should be installed in one airspace for best performance. Besides those two basic types, there is also tinted, reflective, anti-reflective or other types of special glasses.

Besides coating technology, there is also a possibility of application of reflective films with special desired spectral properties (also known as spectral selective films). The main advantage of this technique is, that this films can be also applied after window installation, or during retrofitting of the older buildings.

Disadvantage of these treatments, aimed at the solar properties of glazing, is, that it also affects the visual properties of glazing systems. And therefore the huge reduction in solar factor (reduction of external heat gains) can result in reduction of light transmittance which can lead to increased use of artificial light (increase of internal heat gains).

1. Understanding LOW-e Coatings – Vitro architectural Glass,2018

These buildings will typically encompass a high level of insulation, very energy efficient windows, a high level of air tightness and balanced mechanical ventilation with heat recovery to reduce heating/cooling needs.

The European Union's energy policy is strategically conditioned by the sustainable development of civilization, in particular the mitigation of climate change due to global warming. In the period 2010-2020, the following energy efficiency targets have been set:

- Achieve energy savings of at least 20%,
- Reduce greenhouse gas emissions by 20%,
- Increase the share of energy from renewable sources to at least 20% of total energy consumption.

These percentages are a comparison with the situation in 1990.

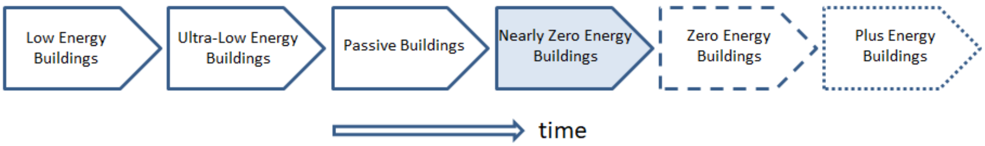
By 2030, a 27% share of energy from renewable sources should be achieved, energy efficiency should increase by 27% and greenhouse gas emissions should fall by 40%. Prospectively, goals were also formulated until 2050:

- Cover at least 85% of final energy consumption with renewables,

- Reduce greenhouse gas emissions by at least 90% compared to 1990.

These are extremely ambitious goals. Their fulfillment has several accompanying effects, such as reducing the EU's dependence on fossil fuel imports, reducing air pollution or modernizing the economy. It can be said that we have been gradually approaching these goals in small steps for several decades. The respective steps and concepts are illustrated in Figure 1.1. In the process of setting the criteria for assessing the high energy efficiency of buildings, their various names emerged, e.g. passive buildings, zero energy buildings, net zero energy buildings, zero carbon buildings, "green" buildings, sustainable buildings and so on. In principle, they are the same type of building, with a specific name indicating the characteristics that indicate the type of building in question. In Figure 1.1 the outlines of the terms "zero" building and plus-energy building in dashed lines, resp. dotted lines to indicate that these terms are not yet internationally clearly defined.

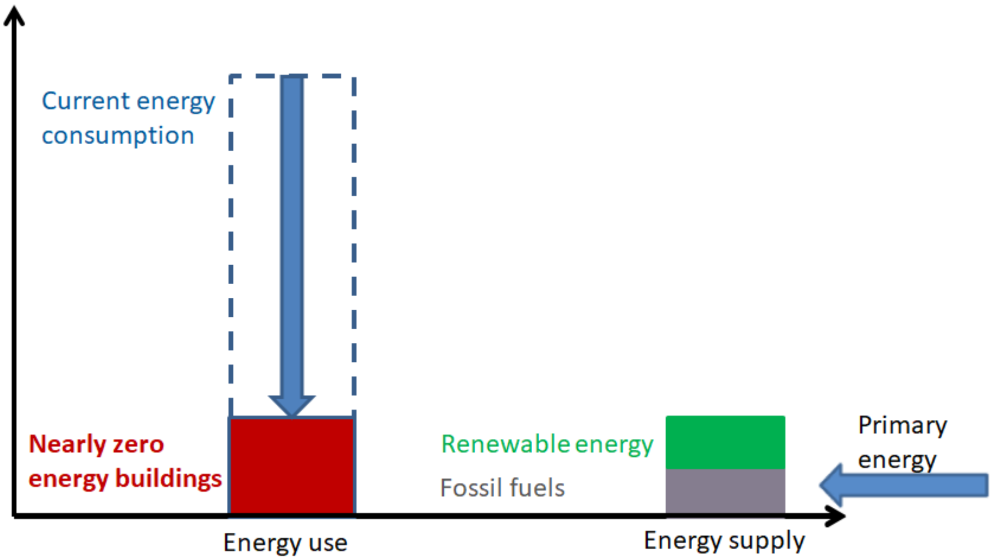
In this context, it should be noted that many experts doubt whether the declared policy objectives are achievable. One of the many reasons for skeptical voices is the steady increase in population and consumption. Reducing energy prices and their availability is accompanied by an increase not only in energy consumption, but in almost everything.



1.1. figure - Gradual steps in the strategy of reducing the energy performance of buildings

The concept of "nearly zero energy building" (nZEB) was introduced by the Energy Performance of Buildings Directive (EPBD) 2010/31/EU (Directive, 2010; Directive, 2012). According to the EPBD, nearly zero energy building means *"a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby".*

According to this vague political directive, new public buildings are to be built in the states of the European Union from January 2019 and other buildings from January 2021.



1.2. figure - The principle of nearly zero energy buildings as defined in Directive 2010/31/EU

Specific criteria for nZEB are set by individual EU Member States. The principle of nZEB, which expresses the essence of their definition according to Directive 2010/31/EU, illustrates Figure 1.2. Each EU country determines the energy consumption of a nearly zero energy buildings, which renewable energy sources are allowed, at what distance from the building and how they are included in the energy consumption. It is also important to determine how to quantify the relationship between energy consumption and carbon (or water) footprint.

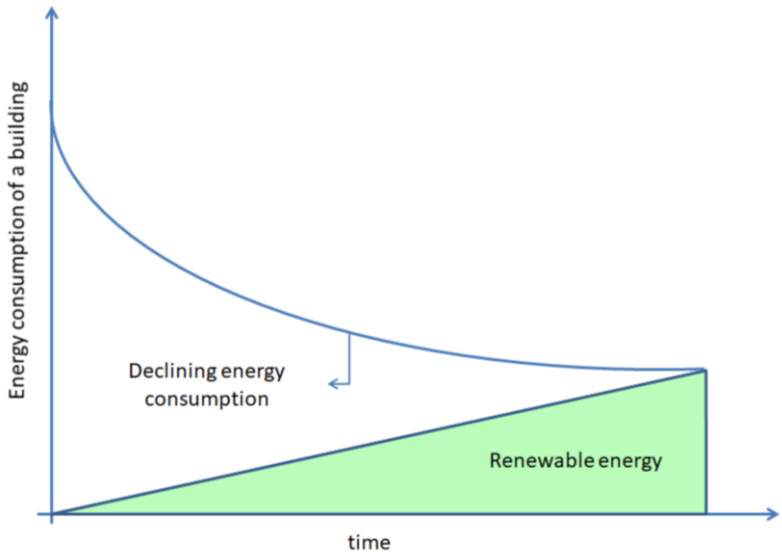
Differences in "national" definitions of nearly zero energy buildings and the criteria and methods for determining them cause problems in comparing them. In general, nearly zero energy buildings in a given country have relatively very low energy consumption. For example, in Slovakia, according to (Decree 324, 2016), nZEB are included in energy class A0. Annual energy needs for the operation of various types of buildings in individual energy classes expressed in primary energy per 1 m^2 of floor area are in Table 1.1. If a nearly zero energy building deliver or stores energy, it will be included in subclass A0$^+$ in Slovakia (Decree 35, 2020).

1.1 table - Range of energy classes of the global indicator expressed in primary energy in kWh/(m^2.a) in Slovakia (Decree 324/2016)

Global indicator - primary energy	Categories of buildings	Energy efficiency classes of buildings							
		A0	**A1**	**B**	**C**	**D**	**E**	**F**	**G**
	family houses	≤ 54	55-108	109-216	217-324	325-432	433-540	541-648	> 648
	apartment houses	≤ 32	33-63	64-126	127-189	190-252	253-315	316-378	> 378
	office buildings	≤ 61	62-122	123-255	256-383	384-511	512-639	640-766	> 766

	school buildings and school facilities	≤ 34	35-68	69-136	137-204	205-272	273-340	341-408	> 408
	hospital buildings	≤ 98	99-197	198-393	394-590	591-786	787-982	983-1179	> 1179
	hotel and restaurant buildings	≤ 82	83-164	165-328	329-492	493-656	657-820	821-984	> 984
	sports halls and sports buildings	≤ 46	47-92	93-181	182-272	273-362	363-453	454-543	> 543
	buildings for wholesale and retail	≤ 107	108-213	214-425	426-638	639-850	851-1062	852-1275	> 1275

More ambitious then nZEB are purely energy-neutral buildings, whose annual energy balance is neutral. This means that they supply as much as energy to the grid that they take from it per year. An illustration of the concept of a purely energy-neutral building fully supplied with renewable energy is shown in Figure 1.3 logically, although still too futuristic, energy-positive buildings follow in energy policy. Technically, energy-plus buildings are already feasible today, but it is extremely costly.



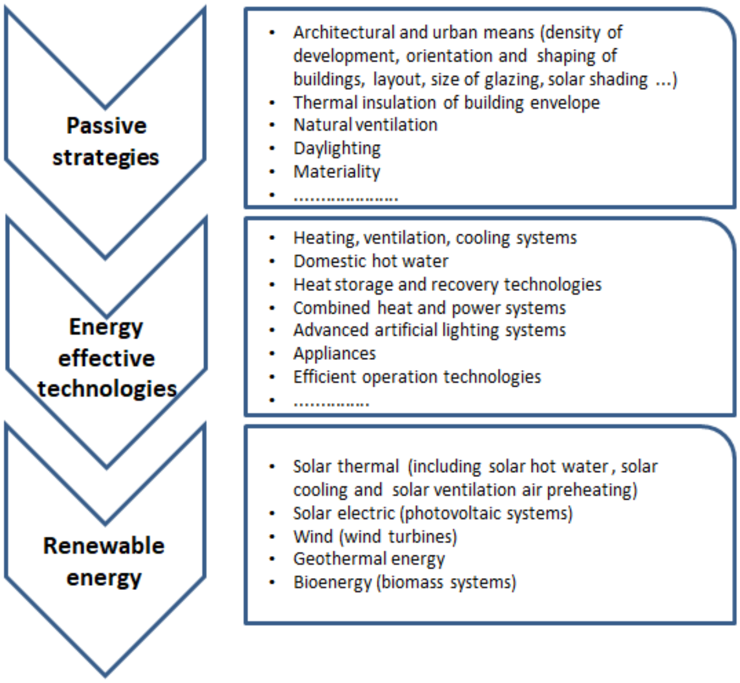
1.3. figure - The concept of a purely energy-neutral building supplied with renewable energy

At present, it can be said that the trend of nZEB realization is almost global. In different climatic, economic and also cultural and social conditions, the target parameters of nZEB differ considerably. In this publication, we will deal with selected issues of the nZEB constructions in the conditions of Central Europe. Although the issues concern renovated buildings, the information presented will deal mainly with new nearly zero energy buildings. Considering that very low energy consumption and decarbonization of the building stock is not possible without insulation and renovation of older buildings; we also pay brief attention to this issue.

1.4 BASIC STRATEGIES OF NEARLY ZERO ENERGY BUILDINGS DESIGN

Nearly zero energy buildings design strategies are conditioned by several factors. It is necessary to take into account urban structures, local climate, type of building and requirements for its indoor environment and method of its use (including expected changes in its functional use), expected life, wider environmental, economic and socio-cultural context etc.

It is necessary to respect the well-known fact that every building is unique. At the same time, however, there are several rules that have proved their worth in the design of low-energy buildings in certain regions. In the project preparation of buildings is the greatest potential for reducing energy consumption for the operation of buildings, especially for heating, cooling, ventilation, hot water and lighting. In general, passive strategies are preferred, complemented by flexible low-temperature heating, natural ventilation (mechanical with heat recovery during winter) and high-temperature cooling. In simple terms, we can summarize the basic strategies for designing nZEB into 3 steps, Figure 1.4.

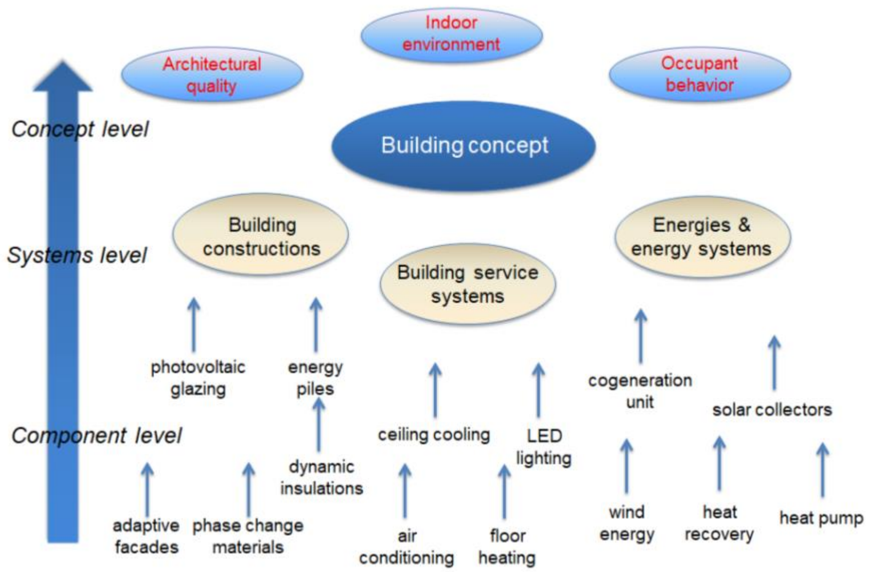


1.4. figure - Basic conceptual strategy for designing of nearly zero energy buildings

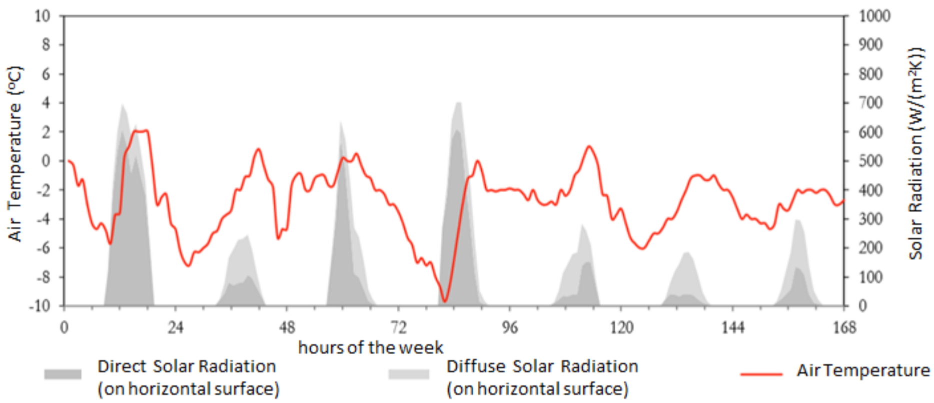
When designing nZEB, the emphasis is on an integrated approach to their design, in which all designers communicate and look for the best possible solutions. Participants in the designing of the building, in addition to meeting the requirements of the builder and the relevant legal requirements, also deal with broader environmental and social issues, maintenance and operation requirements within the entire expected life of the building. This approach requires a change in the traditional way of thinking. An integrated approach requires thinking in a broader context and integrating the individual components and systems into a whole in a mutually balanced way, Figure. 1.5 (inspired by (van der Aa et al., 2010)).

For example, if we focus on the high thermal resistances of individual components of building envelope and neglect the consistent insulation of thermal bridges, we will not achieve the desired goals. The use of renewable energy sources for heating without high airtightness of building envelope may mean that the nZEB energy standard is not met. Different climatic conditions and modes of operation in a building require different project strategies. In the temperate climate zone, it is energetically advantageous to use solar energy, daylight and natural ventilation in buildings. In Central Europe, climatic conditions are changing dynamically throughout the year, Figure 1.6.

In recent years, various systems of adaptable facades with integrated HVAC have been intensively developed, which have an increased ability to respond to the current weather and mode of operation in the building (Shen et al., 2018; Shady et al., 2015). Such an approach to building design is expected to have the potential to increase their energy performance. The terminology in this area is not stable, the names climatically active facades, interactive facades, dynamic facades and others are also used.

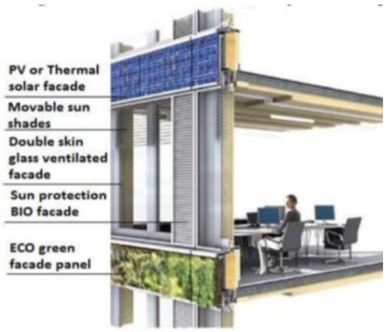


1.5. figure - The concept of the building - from the level of components to a balanced whole



1.6. figure - Typical changes in air temperatures and solar radiation in January in the Central European region

An example of an external wall in which elements of adaptable building envelopes are applied in combination with ecological ones is shown in Figure 1.7. The design of modern buildings must seek to strike a balance between passive and active means of achieving energy efficiency, while meeting all requirements for the quality of the indoor environment.



1.7. figure - The concept of an adaptable facade with ecological elements

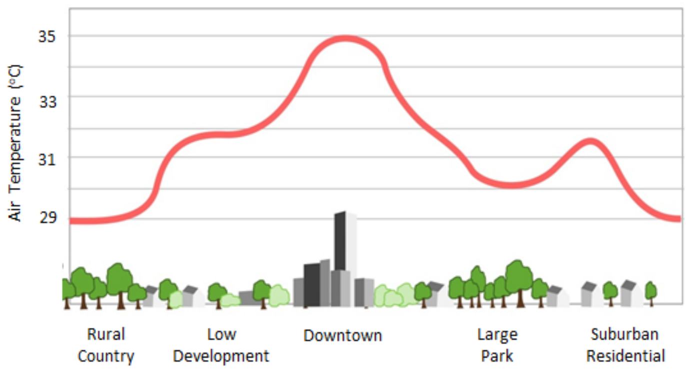
In this publication, we deal only with passive strategies, which we divide into architectural-urban and constructional-physical.

1.2.1 Architectural and urban strategies

The architectural and urban concept of the settlement unit creates a basic framework for the application of passive strategies to reduce the energy consumption of individual buildings and the settlement as a whole. The high density of buildings reduces the availability of direct solar radiation and diffused daylight in buildings, Figure 1.8.

1.8. figure - Dense development reduces the availability of solar energy in buildings

Solar energy and daylight are renewable energy sources, the judicious use of which reduces energy consumption from non-renewable fossil sources. The high density of urban development also creates significant heat island effect, Figure 1.9.

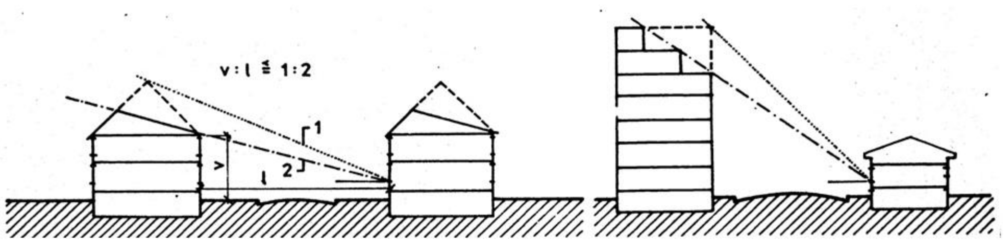


1.9. figure - Typical profile of an urban heat island effect

In such conditions, urban structures of this kind are overheated not only during the day, but especially at night, when the air temperature in them can be up to 7 K higher than the air temperature in the surrounding open areas. Such urban solutions increase summer overheating, and at the same time cause thermal discomfort in both outdoor and indoor environments. The result is an increased use of cooling of buildings, or cooling of the external environment (e.g. watering roads, sidewalks and other areas), which increases the energy costs for the operation of buildings, respectively built environment.

Other urban strategies that have an effect on reducing the energy consumption of buildings are:

- Design of the street network so that it is possible to orient the main facades of buildings to the south,
- Planting high and low greenery in urban settlements (dampens the wind around buildings, shades the building and evaporates water from greenery to cool the air),
- Creation of larger water areas, which contribute to the stabilization of temperatures in settlements,
- Avoiding exposed positions, e.g. do not design tall buildings on hills where increased wind speeds increase heat loss in winter,
- Zoning settlements to create conditions for natural ventilation of urban structures (especially from the point of view of the prevailing wind directions in summer) and to maximize daylight availability in exterior and interior spaces.



1.10. figure - Examples of shaping new buildings that improve the availability of solar energy and daylight in neighboring buildings

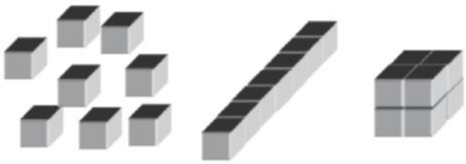
Architects can significantly influence the design of nZEB. Through their work, architects create the basic preconditions for achieving high energy efficiency of buildings, they propose:

- Placing of the building in the territory and existing urban development,
- The shape of buildings (Figure 1.10), and affect their compactness, especially the ratio of the surface of buildings to their volume, Figure 1.11,
- Layout of buildings and orientation of different types of interior spaces to the cardinal points,
- Plan of facades (size of glazed parts, fixed shading (balconies, loggias, cornices …), use of green roofs and green facades etc.,

- Atriums, glazed areas and other spaces attached to or incorporated into the building, Figure 1.12,
- Applications of systems using renewable energy sources which create parts of the building envelope,
- Color of surfaces and they influence the choice of many materials.

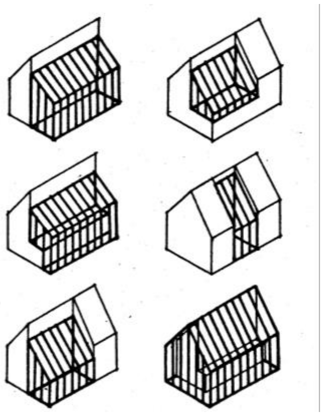
1.2.2 Constructional and physical strategies

In Central Europe, in the context of reducing energy consumption for the operation of buildings over the last three decades, solutions have been preferred that have reduced, in particular, energy for heating. In cold climates and in older types of buildings, energy consumption for heating represents more than 50% of the total energy needed for operation of buildings.



1.11. figure - Compactness of buildings

Significant progress has been made in this area with radical thermal insulation. However, energy performance needs to be assessed comprehensively and energy consumption must be considered throughout the year, even with a long-term perspective. In passive residential buildings, today the energy consumption for preparing hot water is greater than for heating. Hot water is consumed all year round, while in passive buildings the heating season is shortened with low heat demand.



1.12. figure - Examples of glazed spaces in buildings

However, extreme thermal insulation and sealing of buildings, increased demands on thermal and visual comfort in buildings, growing internal heat gains and, in part, the increasingly evident global warming increase the energy consumption for cooling buildings. Even when choosing constructional and physical strategies for designing nZEB, it is necessary to take into account the overall view of the building in its entire life.

In addition to the technical side, the holistic view also assesses the economic costs within the life cycle and the social aspects of construction. Improving thermal, visual comfort and air quality in buildings has significant non-energy benefits, such as increased labor productivity, improved quality of life, which can be associated with reduced healthcare costs. On the other hand, too wide a scope of nZEB assessment may over-relativize the importance and weight of the constructional and physical side of such buildings. In this section, we focus only on the technical side of nZEB design.

From a constructional and physical point of view, the design of nZEB is based on the concept of passive buildings. The passive building is actually a consistently improved low energy building. From a conceptual point of view, it is essential that the thermal comfort in a passive house is achieved only by preheating or precooling the fresh air in the amount necessary to achieve the required indoor air quality.

The constructional and physical design strategy for low energy buildings in Central Europe typically includes the following basic measures:

- High thermal resistances of the building envelope,
- Windows with very high thermal insulation parameters,
- Consistent elimination of all thermal bridges,
- High tightness of building envelope,
- Air exchange with heat recovery during the winter.

In the case of passive houses, in the late 1980s, criteria were set for these measures. The criteria were tested at a passive house in Darmstadt (Germany), which is considered to be the first passive house, Figure 1.13. Some physical criteria have been slightly modified over time, their current values are given in Table 1.2.

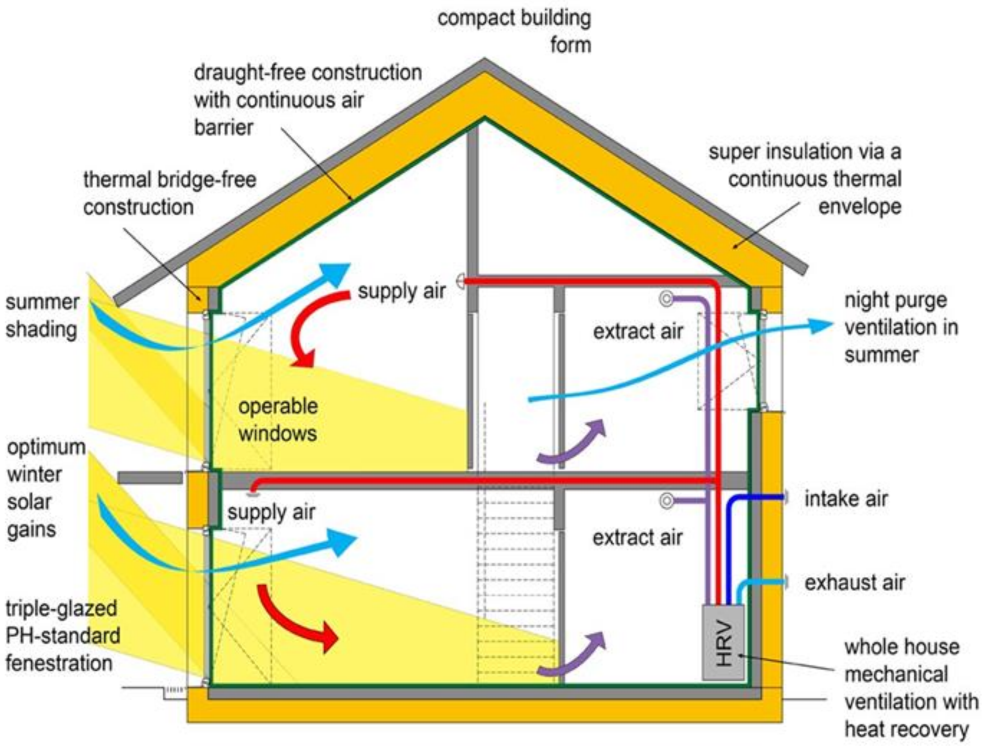
Passive buildings have become popular in Central Europe to the extent that they are now considered the standard. It has been confirmed that this is a technically and economically justifiable strategy from the point of view of the whole life of the buildings. Passive techniques generally have lower maintenance requirements and reduce the operational performance of environmental technology.

Demands for the maintenance of various specific elements of active low energy buildings (solar thermal systems, photovoltaic systems, heat pumps and others), and their low service life increase energy costs and emissions throughout the life of buildings. The application of these technologies in passive houses is not necessary, in contrast to nZEB, where their use is essentially necessary due to the accepted energy criteria of their design.

Of the key factors in the design of passive buildings, the most important is the thorough thermal insulation of the entire building envelope with the consistent removal of all thermal bridges. Initially, thermal insulation windows were a problem when designing passive buildings, especially window frames of low thermal insulation quality. Considerable progress has been made relatively quickly in the area of the thermal insulation properties of glazing and window frames. Their thermal resistances have increased more than fivefold compared to windows commonly used in the 1980s. Similarly, the design in the field of elimination of thermal bridges has led to the fact that the thermal resistances of the various joints between the structural elements are almost indistinguishable from the thermal resistances of the characteristic fragments of the individual building envelope elements.

In passive buildings, special attention is paid to their airtightness. The heat consumption for heating is substantially increased by the heat required to heat the infiltrating cold air. Heat losses due to natural ventilation of buildings cause energy losses of 20 to 30 kWh/(m^2.year).

1.13. figure - **Southern view of the first passive house in Darmstadt from 1991 (Feist and Bott, 2007)**



1.14. figure - Typical passive house ventilation system with heat recovery (Bátora and Baloga, 2015)

By mechanical ventilation with heat recovery these energy losses can be reduced to values of 2 to 7 kWh/(m^2.year). Mechanical ventilation cannot function reliably and efficiently without high airtightness of the building envelope. Mechanical ventilation of passive buildings is standardly solved with heat recovery, Figure 1.14. Heat recovery efficiency of at least 80% is required.

1.2. table - Physical criteria for designing passive buildings

Parameter	**Criterion value**
Primary energy demand	< 120 kWh/(m^2.a)
Net heating and cooling energy demand	< 15 kWh/(m^2.a)
Maximum heating load	< 10 W/(m^2.K)
Thermal transmittance of facade, U_{facade}	< 0.15 W/(m^2.K)
Thermal transmittance of roof, U_{roof}	< 0.10 W/(m^2.K)
Thermal transmittance of whole window, U_{window}	< 0.75 W/(m^2.K)
Linear thermal bridge transmittance, ψ	< 0.01 W/(m.K)
Efficiency of mechanical ventilation with heat recovery	> 80 %
Specific input of a fan, P^*	< 0.4 W/(m^3/h)
Airtightness of building envelope, n (at 50 Pascal underpressure)	n_{50} < 0.6 / h

Limit of the internal comfort in summer	< 10% of the year air temperatures can be higher than 25 °C
Note: *P* is the specific fan input, which is the ratio between the effective input (in W) and the reference flow (in m^3 / h).*	

In this way, the heat demand for heating can be reduced by about 30%.

On the one hand, mechanical ventilation ensures a constant supply of fresh air that can be filtered. On the other hand, the operation of the ventilation equipment consumes electricity and its production is not only energy intensive, but also produces CO_2 emissions. Improperly designed ventilation system can be a source of noise, or even unpleasant air flow in the room. From an economic point of view, the necessary frequent replacement of filters cannot be overlooked either. A more complex solution of mechanical ventilation with heat recovery in combination with a heat pump and hot water preparation (Figure 1.15) increases the energy efficiency of the ventilation system.

The high thermal resistances of the envelope of passive buildings, the large fenestration on the sunny sides and the high tightness increase the tendency for overheating. Although it is possible to solve this problem by cooling, for example by reversing the heat pump, it is associated with considerable energy costs.

The problem of overheating of passive houses is not only during the peak summer, but can also occur during the transitional seasons when the days are sunny. At this time, warm indoor air can easily be replaced by colder outdoor air and thus the problem is not as considerable as in summer, when outdoor air temperatures are often much higher than 26 °C, which is the limit temperature in terms of thermal comfort in the building. In passive houses, it is highly recommended to design effective shading devices.

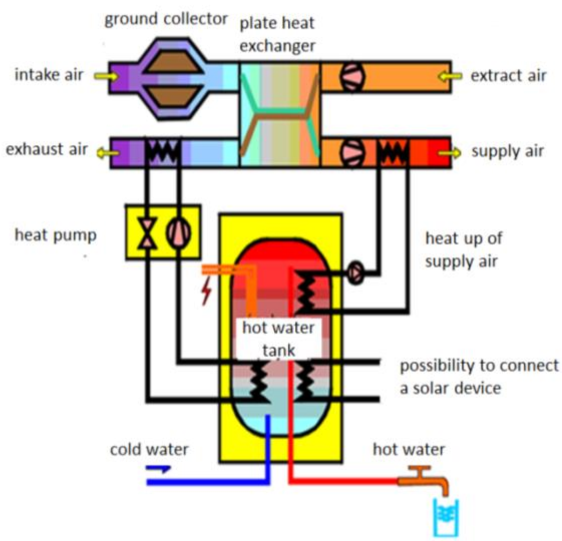
At a time when the outside temperature is higher than 30 °C, the shading technique alone cannot ensure that the air temperatures in the room are lower than 25 to 26 °C. In Central Europe, air temperatures above 30 °C are not common, so even in the criteria of a passive house, exceeding the indoor air temperature of 25 °C is tolerated for a certain time of the year (see Table 1.2). The time when there is a risk of summer overheating can be shortened by designing heat storage building structures that are in direct contact with indoor air, night cross ventilation, minimal ventilation during the day, not using equipment that generate much heat and the like.

The basic principles of nZEB design are summarized in Table 1.3. The very low energy demand in a building is largely achieved by passive building design techniques. The difference between a passive building and nZEB lies in the rate of use of renewable energy.

1.3. table – Principles of nearly zero energy buildings design

Principle	Very low energy demand	Use of renewable energy	Primary energy and low CO_2 emissions
Characteristics of the principle	The energy demand for heating, ventilation, cooling, hot water and artificial lighting and possibly other equipment (e.g. lifts, emergency lighting) must meet the highest standards.	Renewable energy should cover at least 50% of the total energy consumption. Renewable energy systems must be located on or in buildings, or close to them. In perspective, renewable energy sources should cover up to 90% of the energy consumption of buildings.	The energy demand for the operation of buildings is expressed by primary energy, while it is necessary to quantify the CO_2 emissions of individual energy carriers by the factors of primary energy. Prospectively, CO_2 emissions should be lower than 3 $kgCO_2$ / (m^2.year)

An overview of the ways for achieving the nZEB standard in Europe provides (Paoletti et al., 2017). This reference analyzes in particular the influence of climatic conditions on the choice of means for achieving the nZEB standard. The emphasis on the wider use of renewable energy in nZEB and thus the reduction of CO_2 emissions is correct from the perspective of the sustainable development of civilization. However, it is questionable whether this goal is realistic from a socio-economic point of view.



1.15. figure - Passive house ventilation system in combination with heat pump and hot water preparation

European energy policy guidelines emphasize that cost effective measures to reduce energy consumption should be used when designing nZEBs. Despite the financial demands of nZEB, the design of "zero" or plus energy buildings is increasingly being talked about. Visions that "zero" homes will be CO_2 free and buildings will use only renewable energy, or that surplus electricity produced by buildings will be sold, seem over ambitious.

1.5 CONSTRUCTION OF NEARLY ZERO ENERGY BUILDINGS

The design standard for passive buildings forms a proven basis for the construction of nZEB. This standard has been largely reflected in current standards and regulations, and the number of practical implementations of passive houses provides guarantees of achieving a high design standard. Virtually all types of buildings can be based on the passive house standard. Today, there is a rich material and construction database, which allows planning envelopes of nZEB with the required properties.

1.5.1 Non-transparent parts of the envelope of nearly zero energy buildings in the climatic conditions of Central Europe

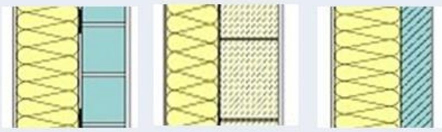
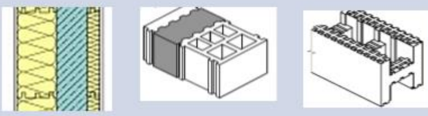
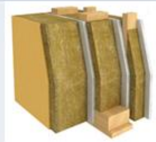
The external walls of nZEB should have the following basic properties:

- Thermal transmittance less than 0.15 W/(m^2.K),
- Practically excluded thermal bridges - linear thermal bridge transmittance less than 0.01 W/(m.K),
- High airtightness.

Single-layer external walls meeting the requirements of nZEB can be made of various masonry elements, but these walls are about 500 mm thick. The high volume of such walls takes away from the usable space of the buildings; in practice, single-layer external walls are used to a lesser extent. The walls with external thermal insulation composite systems have been widely used, see Table 1.4.

Walls made from monolithic reinforced concrete, lime sand bricks and from similar materials are relatively subtle and at the same time sufficiently thermal storage and, even with thick high efficiency thermal insulation, generally do not exceed thicknesses of 400 mm. External thermal insulation composite systems increase the laboriousness of walls of this type. To some extent, the laboriousness of the walls can be reduced by casting them in thermal insulation fittings made of polystyrene or other thermal insulation material (known as ICF, insulated concrete forms). In such processes, the thermal storage capacity of the walls is almost lost due to the thermal insulation on the inner surface. The various elements connecting the inner and outer parts of the thermal insulation fittings also reduce the load bearing capacity of the reinforced concrete core of the wall.

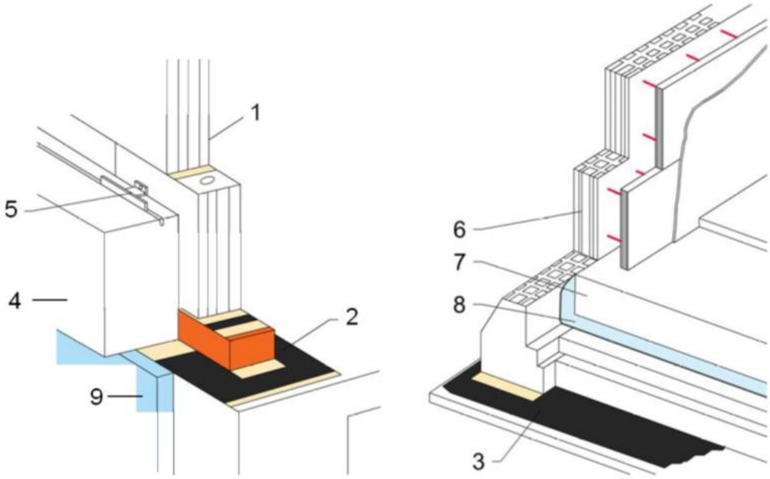
1.4 table – External walls suitable for nearly zero energy buildings

Type of wall	Schematic example	Example of a wall
Masonry walls to full thickness		
Load-bearing wall with contact thermal insulation		
Walls with „lost“ thermal insulation formwork		
Lightweight walls		

High thermal resistances can be achieved with various types of light external walls. These walls are produced by dry construction processes with high productivity of work on the construction site.

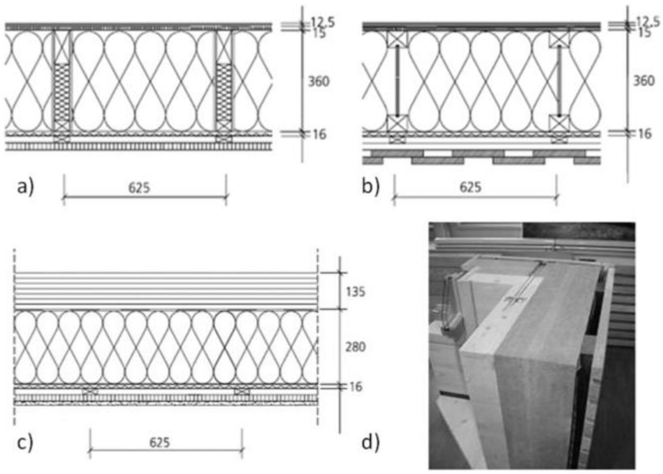
Examples of masonry walls suitable for nZEB are shown in Figure 1.16. For these walls, detail is problematic at the base, where it is necessary to remove the thermal bridge. The thermal bridge can be removed by inserting a sufficiently load bearing material into the foot of the load bearing part of the wall (e.g. foam glass or a special product). The solution of laying a house on a reinforced concrete slab placed on a layer of thermal insulation, which is connected to the thermal insulation of the external wall, is often common (Figure 1.16 on the right).

In the standard of passive houses the wooden buildings are built quite often. In the case of the use of effective thermal insulation, the required high thermal resistances of the external walls with a wooden load bearing structure are achieved at relatively small thicknesses, Figure 1.17. On the other hand, the wooden supporting structure creates various thermal bridges in the wall, which must be carefully eliminated. It is also necessary to ensure high airtightness of wood-based external walls. Particular attention must be paid to details such as electrical sockets and switches, various wall penetrations, wall contacts with windows or doors and the like in terms of airtightness.



1.16. figure - Examples of external walls suitable for nearly zero energy buildings

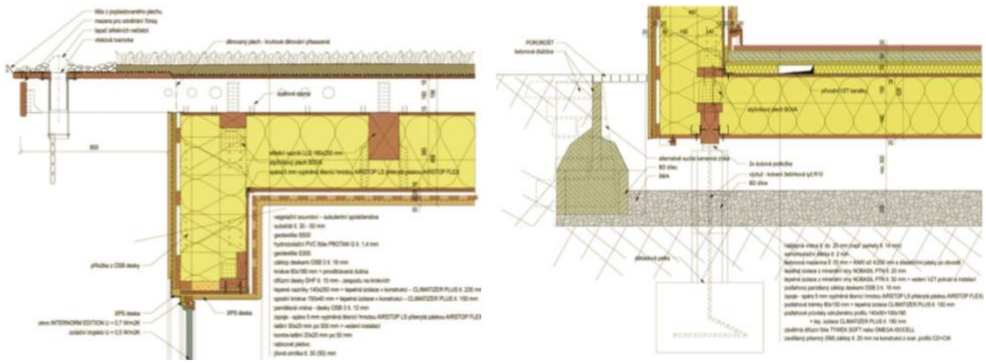
1 - wall made of cement sand bricks, 2 - foam glass, 3 - waterproofing, 4 - thermal insulation (e.g. expanded polystyrene), 5 - thermal insulation clip, 6 - formwork fittings made of expanded polystyrene, 7 - floor support layer, 8 - separation layer, 9 - thermal insulation (e.g. made of extruded polystyrene)



1.17. figure – External walls of wooden houses suitable for nZEB
(Bebej and Sedlák, 2011*)*

a) wall post construction, b) wall post with the use of I-shaped posts, c) wall with a load bearing layer of glued laminated wood, d) example of a wall with a load bearing layer of glued laminated wood

Figure 1.18 shows examples of carefully designed details in the envelope of wooden construction. The individual components of the buildings are very good designed as well as the buildings as a whole. In the process of designing passive buildings, certification schemes and design procedures have been created that can be directly applied to the construction of nZEB.



1.18. figure – Examples of carefully designed details in envelope of wooden constructions

Virtually all systems using renewable energy sources can be easily integrated into buildings constructed according to the principles of passive buildings.

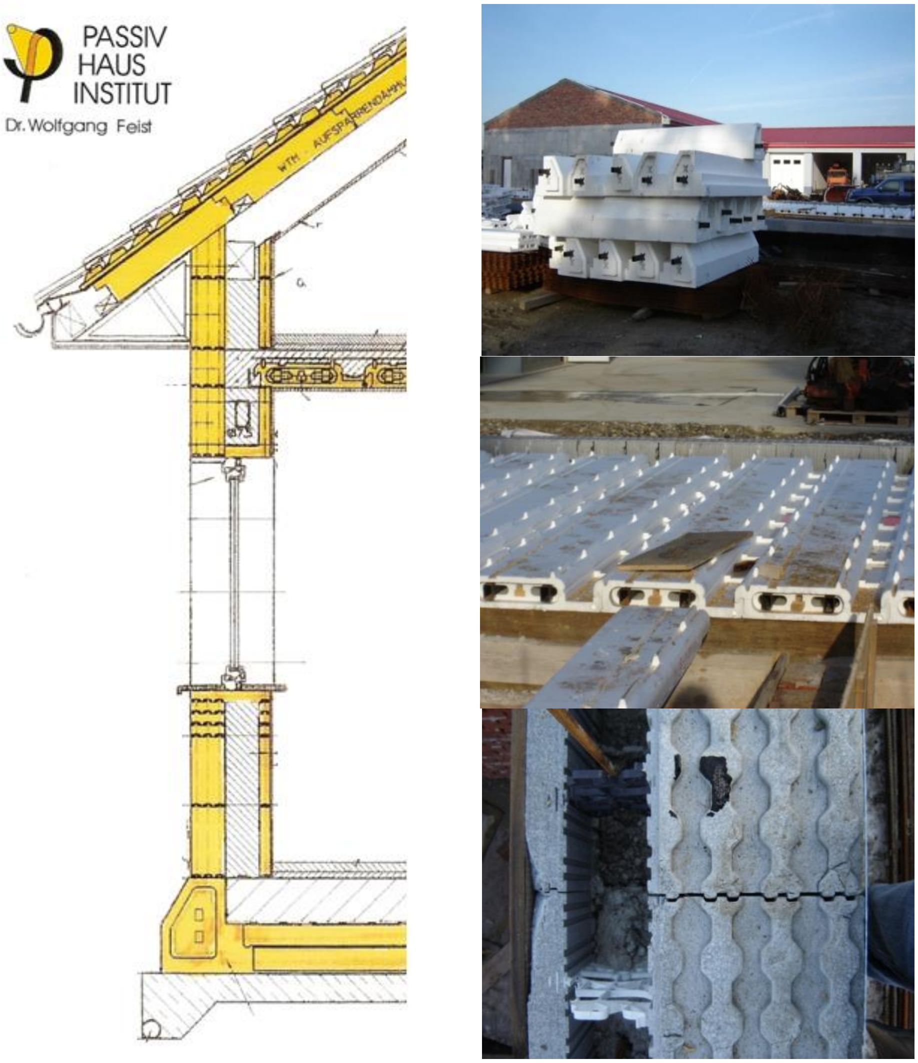
Already in the early stage of design of passive buildings, systems have been developed that meet the required standards developed at the Passivhaus Institut (web1). One such system was the Innovativbau Thermomodul building system, which was certified by the Passivhaus Institute, Figure 1.19. The Thermomodul system is characterized by consistent thermal insulation of envelope of a passive building with consistent removal of thermal bridges and high airtightness of a building envelope.

The thermal resistance requirements of both flat and pitched roofs are traditionally higher than the thermal resistance of vertical walls. The reason is the increased heat loss due to the stratification of air temperatures in the room (the upper part of the room has a higher temperature than the part near the floor). In winter, heat losses increase due to the increased difference between indoor and outdoor environments. Another reason is the increased heat loss from the surface of the roof structure caused by heat radiation towards the cold sky (especially during cloudless nights). To some extent, the increased thermal resistances of roof structures can be justified by the increased wind speeds during flow around.

In the case of nZEB, it is recommended to design roof thermal resistances up to 10 m^2.K/W. Even in the case of very effective thermal insulation, their thickness is at least 400 mm to achieve mentioned thermal resistance. Examples of structural solutions of pitched roofs suitable for nZEB are shown in Figure 1.20.Floors on terrain in heated zones of nZEB should have an effective thermal insulation of at least 150 mm thick.

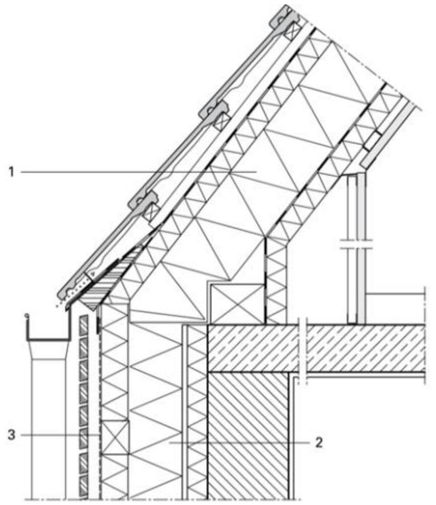
1.5.2 Transparent parts of the envelope of nearly zero energy buildings in the climatic conditions of Central Europe

Even in the case of the design of windows and other transparent parts of nZEB envelopes, it is appropriate to proceed from the standards that have become established in this area when designing passive buildings.



1.19. figure – **The construction system of the passive house Thermomodul realized on the building in Bratislava – Petržalka (Photo: Jozef Hraška)**

The thermal transmittance through the whole window should be $U_w < 0.75$ W/(m^2.K). In nZEB design cases, it is desirable to design windows with an even lower thermal transmittance. Although windows with such features are available, they are expensive and need to be considered comprehensively in specific cases. There are several certification schemes to evaluate the energy efficiency of windows. Some require that both frames and window glazing in passive houses have a thermal transmittance of less than 0.75 W/(m^2.K). Others allow higher thermal transmittance through the frames (e.g. $U_f < 0.95$ W/(m^2.K)), while this value must be compensated by the increased thermal insulation of the glazing so that the resulting value $U_w = 0.80$ W/(m^2.K).



1.20. figure – Pitched roofs suitable for nZEB
a) detail of the pitched roof at the gutter, b) axonometric example of the pitched roof
1 - thermal insulation between rafters, 2 - thermal insulation of the wall between lathes, 3 – vapor permeable foil

Today, glazings with U_g values of ≈ 0.5 W/(m^2.K) are already on the market, so such a procedure is possible. When choosing glazing, it is not possible to look only at its thermal insulation properties. Light transmittance is also important (generally higher than 60%, in the case of residential buildings light transmittance values of at least 70% are recommended) and solar factor (total solar energy transmittance), which should be at least 50% in residential buildings (*g*-value of 0.5). Some certification schemes also state limits of deterioration of the thermal insulation properties of windows due to the installation of windows in the building envelope.

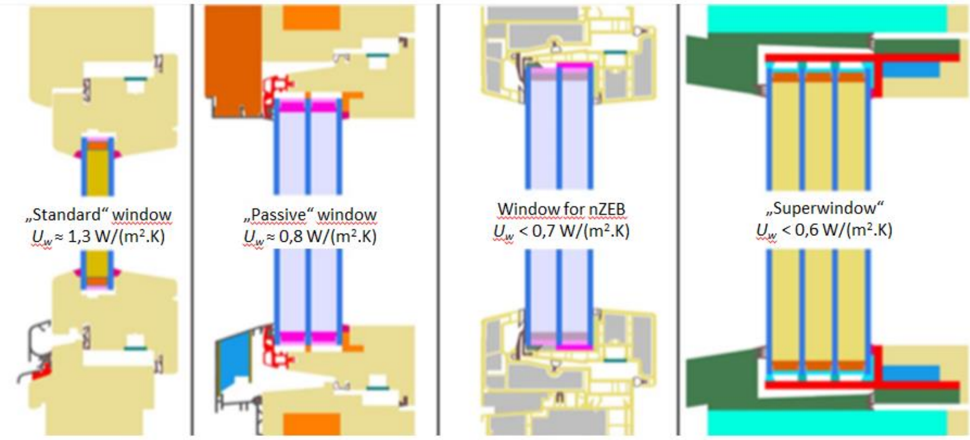
Reducing the *U*-values of glazing has its pitfalls. Low values increase the risk of overheating of buildings and in air conditioned buildings also the consumption of energy for cooling. In the case of office buildings with large glazing and significant indoor heat gains, the choice of windows with U_w < 0.60 W/(m^2.K) (recommended by several authors for nZEB) can be counterproductive. An increase in cooling costs can exceed the heat savings for heating. Glazing with high thermal resistance usually transmits less daylight, which also translates into increased costs for artificial lighting. Shading by glazing with low *g*-values is not recommended in the climatic conditions of Central Europe, especially in the case of residential buildings. Window shading should be provided with a mobile shading technique.

The very high thermal resistances of the glazing increase the risk of condensation of water vapor on the outer surface of the glazing, and in extreme cases icing may form here. In (Gläser and Szyszka, 2011) it is stated that the risk of condensation on the outer surface of the glazing can be effectively reduced by the low emissivity of the outer surface of the glazing. In order to reduce the frequency of icing to a minimum, the emissivity of the outer surface of the glazing should be reduced below 0.1. However, such emissivity values are difficult to achieve in practice so that they can withstand weather conditions and surface maintenance for a long time. This problem increases with smaller window inclinations, with roof sloping windows it is greater than with vertical windows, if the glazing is in an almost horizontal position, the problem will be exacerbated.

Heat losses caused by glazing are greatest in the spacer frame of the glass panes. They are a frequent cause of condensation of water vapor on the inner surface of the glazing. Conversely, with respect to the condensation of water vapor on the outer surface, the point of contact of the glass sheets is with the least risk of condensation. Research and innovation of windows suitable for nZEB is currently focused on spacer profiles for glazing and frame structures with high thermal resistance.

The following parameters must be considered when selecting glazing for nZEB:

- Glazing heat transfer coefficient (thermal transmittance) U_g (W/(m^2.K)),
- Solar factor, *g*-value (-),
- Visible light transmission, τ_v (-)
- Internal surface temperature of the glazing (°C),
- Risks of condensation on the inner and outer surface of the glazing,
- Color rendering index, *Ra* (-),
- Total glazing thickness (mm),
- Glazing weight (kg/m^2).

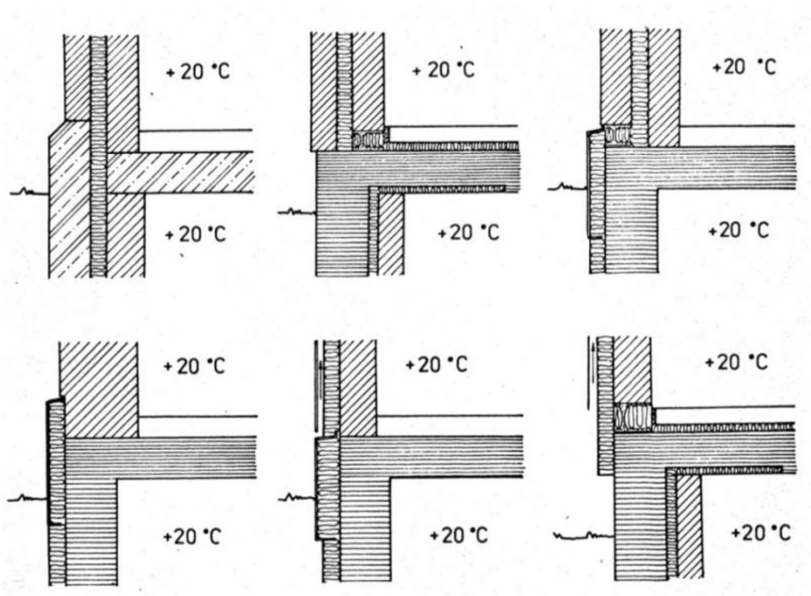


1.21. figure – Examples of windows that meet the standards of passive buildings and nZEB (Goldstein et al., 2016)

The internal surface temperature of the glazing of a passive building shall not be lower by more than 4.2 K from the average indoor air temperature. This measure reduces the fall of cold air from the glazing to the user's feet, which negatively affects the thermal comfort (also known as ankle draft). In passive houses this problem is considerable due to the larger area, especially of the southern windows, and also because there are usually no radiators under the windows in passive houses. "Superwindows" (i.e. high performance windows, Figure 1.21) are suitable for buildings in very cold locations.

1.5.3 Thermal bridges

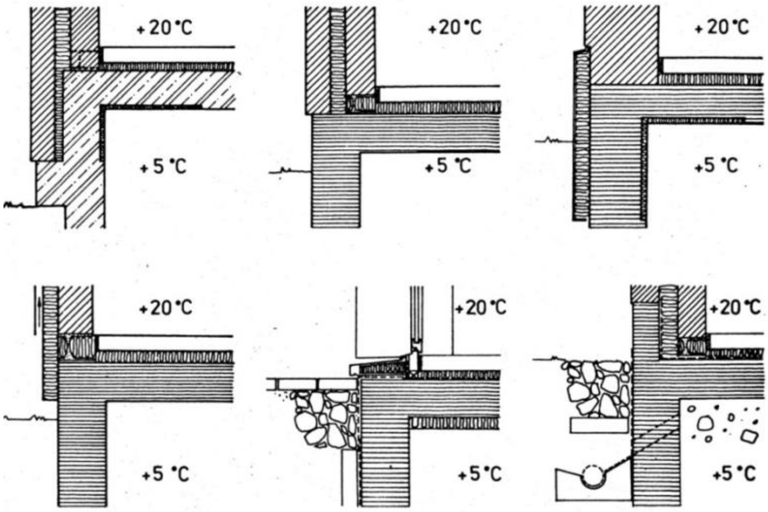
Thermal bridges need to be eliminated with particular care in the case of nZEB envelope. In the case of highly thermally insulated envelopes of nZEB buildings, insufficiently designed thermal bridges can increase heat losses by up to 30%.



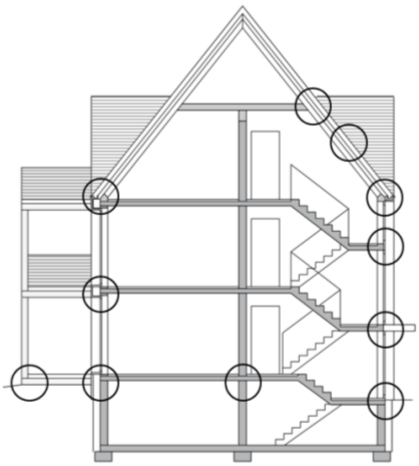
1.22. figure – Examples of elimination of thermal bridges at massive external walls in the contact with a heated underground floor (Hraška, 1992)

Of course, the problem of thermal bridges has different weights for different types of materials and constructions. Figures 1.22 and 1.23 indicate several possibilities of elimination of thermal bridges in the case of masonry external walls in contacts with basements and foundations. In the case of external walls made of conductive material (reinforced concrete, solid fired bricks, sand lime bricks, etc.), special attention must be paid to the detail at the place of foundation.

In various building systems this problem is solved by inserting a special element in the foot of the external wall. In the case of non-system solutions, it is important that the inserted materials have sufficient thermal insulation properties, sufficient load bearing capacity and are not absorptive.



1.23. figure – **Examples of elimination of thermal bridges at massive external walls in the contact with unheated underground floor or in contact with the subsoil (Hraška, 1992)**

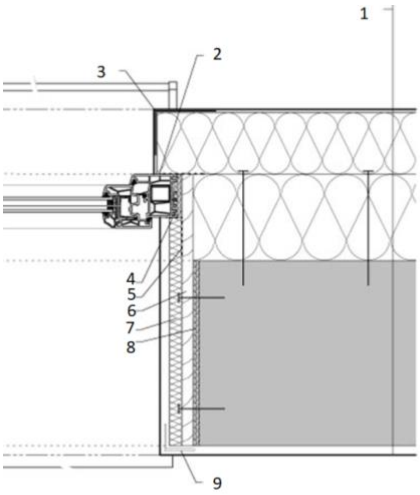


1.24. figure – **Typical places of thermal bridges in buildings**

1.25. figure – **Example of elimination of thermal bridges in window linings**

1.26. figure – **Windows installed in the plane of thermal insulation of the wall**

One such material is foam glass, which is relatively expensive. Foundation of nZEB is recommended on thermally insulated reinforced concrete slabs.In general, there are a large number of thermal bridges in building envelopes, through which heat spreads in two or three directions (2D or 3D thermal bridges). Figure 1.24 indicates some typical places of occurrence of thermal bridges in the envelope of a building. Figure 1.25 shows one way of reducing heat losses through window linings by covering window frames with thermal insulation. A more



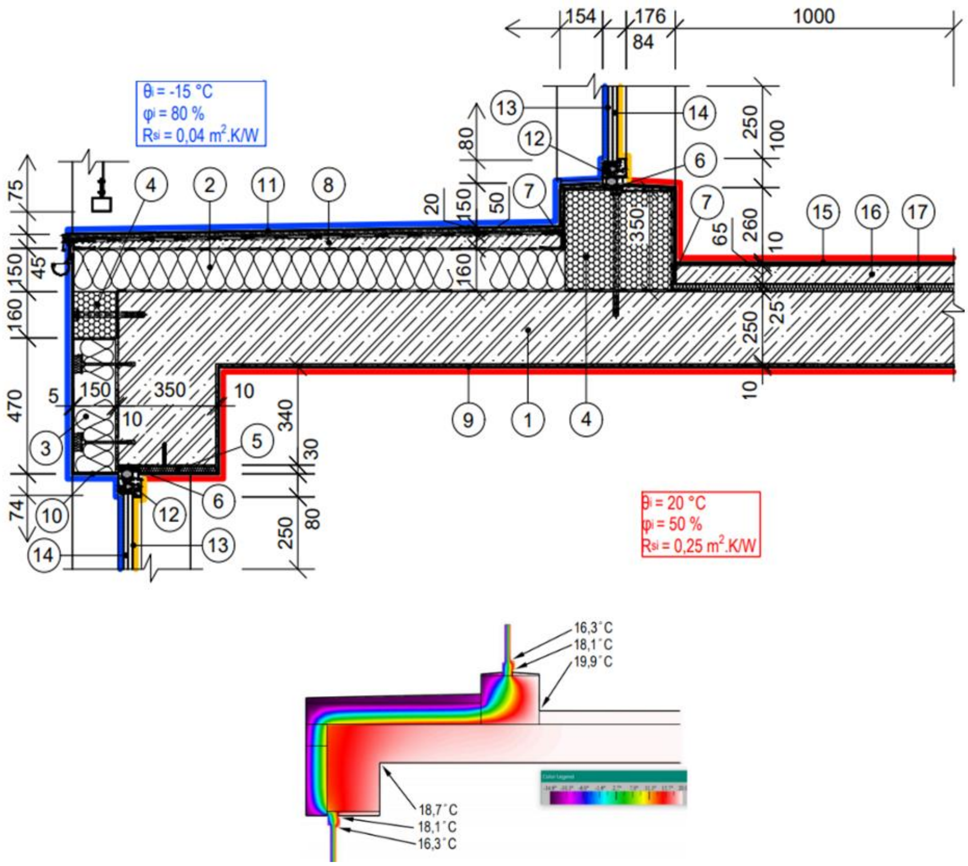
1.27. figure – Detail of the window installation in the nZEB lining
1 - thermally insulated wall, 2 - outer vapor permeable foil, 3 - corner strip, 4 - polyurethane foam, 5 - inner vapor barrier foil, 6 - OSB board, 7 - thermal insulation, 8 - polyurethane foam, 9 - corner profile

effective reduction of heat losses through the window lining is achieved when the window is installed in the plane of the thermal insulation of the wall, Figure 1.26. Such design is recommended for nZEB, where windows with high thermal insulation parameters are used and where additional heat loss by thermal bridges is very undesirable. This method of window mounting is more expensive because it is necessary to install the supporting elements carrying the window. The difference in costs between the solutions according to Figure 1.25 and Figure 1.26 do not cover the energy savings for heating, which are achieved by the solution according to Figure 1.25 at current energy prices for heat.

However, in the broader context of designing nZEB and considering a long term time horizon, we can reach different conclusions from financial analyzes. In Figure 1.27 is an example of a window instalation that can be recommended for nZEB. The level of quality of elimination of thermal bridges is commonly assessed by analysis of two dimensional temperature fields, Figure 1.28 and Figure 1.29.

1.6 TRANSFORMATION OF EXISTING BUILDINGS INTO NEARLY ZERO ENERGY BUILDINGS

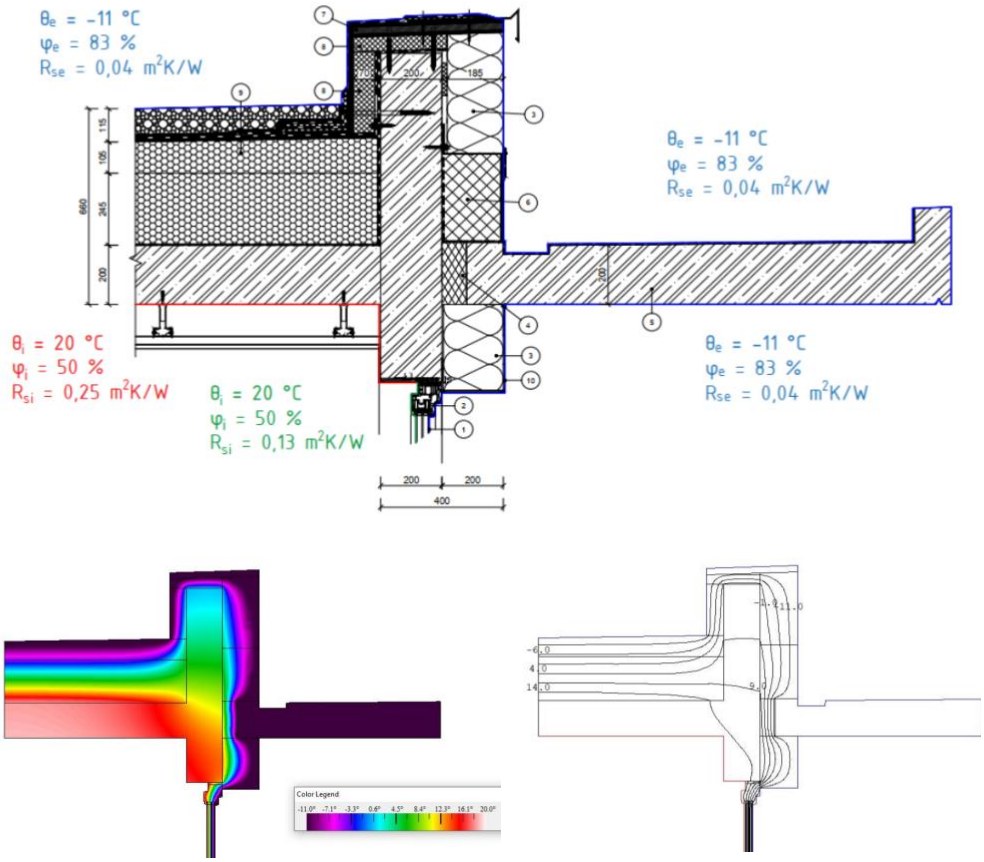
A large part of the existing building stock in the countries of the European Union is decades old and with high energy consumption. Old buildings make up three quarters of the total building stock in the EU. According to the European Commission's very ambitious plan (Simon, 2017), these buildings should be transformed to a standard of nearly zero energy buildings by 2050. The motivation of this plan is mainly the sustainability of the development of civilization and the reduction of the global warming of the planet. Decarbonisation is also a goal in this plan. Measurable indicators of progress in this area and their evaluation in 2030 and 2040 are required.
Specific objectives and measures in this area are to be set by individual EU Member States. In Central European countries, the process of building insulation has been going on for a long time in order to reduce their energy requirements to a cost optimal level. It is known that thermal insulation and sealing, especially of office buildings, increases the need for energy to cool them.



1.28. figure – Temperature field in the place of the balcony of a residential building

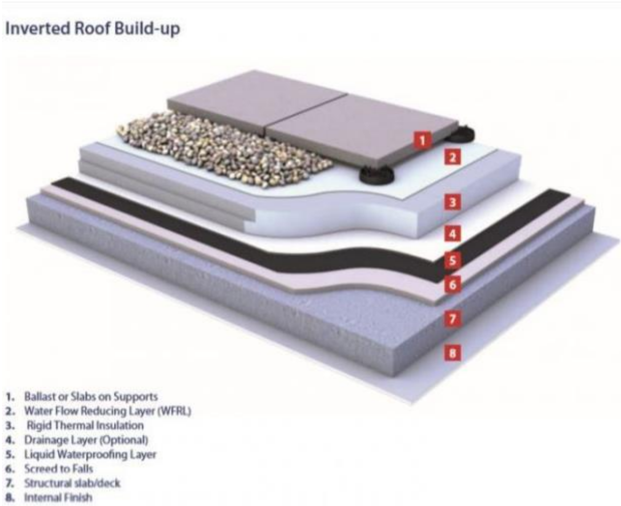
The use of renewable energy sources is not always economically advantageous. We present this information to indicate, at least in part, that the transformation of existing buildings into nearly zero energy buildings requires a comprehensive and individual approach that differs from common design practice. Integrated building design is required, with an emphasis on a balanced multidisciplinary approach in which the environmental aspects and the lifecycle of buildings are given increased weight.

A key step in the transformation of existing buildings to the nZEB standard is the substantial improvement of the thermal insulation of the envelope of existing buildings. From this point of view, the most problematic is the insulation of the floors of heated spaces, which are in direct contact with the terrain (subsoil). Although the losses of subfloor heat are relatively small in terms of the total heat loss of the building, they represent a serious problem in the nZEB standard. Increased attention must also be paid to the partitions between heated and unheated spaces. In the past, very low thermal resistances were required for these walls, resp. in the past, thermal engineering requirements for such partitions have not even been set.



1.29. figure – Temperature field at the end of the roof and external wall of a residential building

The method of additional thermal insulation of roofs depends on their type and technical condition. If the waterproofing of the flat roof is in good condition, it is possible to use the so-called inverted roofs (Figure 1.30.). This involves laying a non-hygroscopic thermal insulation on the waterproofing layer and loading it with gravel. A technique is also used in which already unsatisfactory waterproofing is punctured in many places in order to substantially reduce its vapor diffusion resistance and a new thermal insulation and a waterproofing layer with a lower diffusion resistance factor is added.



1.30. figure – Inverted roof details (source: www.lrwa.org.uk)

The modernization of existing buildings will create new spaces by creating a pitched roof with an attic, while a pitched roof can meet demanding energy efficiency requirements. The thermal resistance of pitched roofs of existing buildings is usually increased by thermal insulation from the interior side. One of the several important requirements is compliance with fire safety.

Although several techniques have been developed in the past for thermal insulation of buildings, the insulation of existing windows and doors in the external walls cannot be used in the nZEB standard. In recent decades, the thermal properties of windows and doors have improved significantly. These properties in terms of thermal resistance and airtightness are incomparable to traditional windows, which are located in older existing buildings. Replacing old windows with new ones is easy in most cases, but it is expensive. In many cases, monument protection requirements in some countries do not even allow windows to be replaced. At present, the risk of overheating of buildings is increasing in connection with lifestyle, extreme thermal insulation and global warming. When replacing the windows, the installation of effective sun protection must not be forgotten. In specific cases, additional windows or glazed thermal buffer spaces may be added as part of the thermal insulation and sun protection.

Each building is unique and its transformation into nZEB needs to be carefully and professionally prepared in terms of design. Given the huge size of the EU's older building stock, the task of decarbonising and transforming it into the nZEB standard by 2050 is extremely challenging.

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