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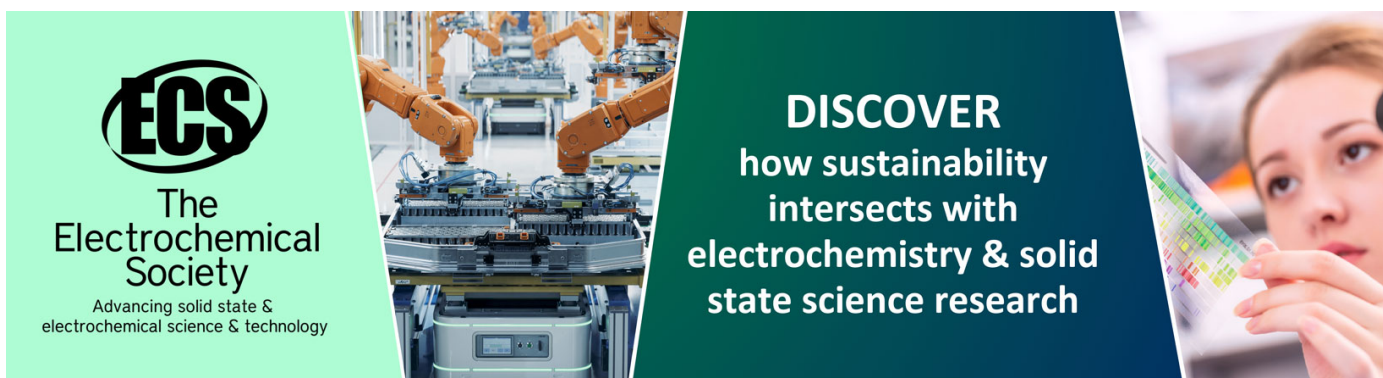
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Certification of “Nearly Zero-Energy Buildings” as a Part of Sustainability

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Abstract. This article draws attention to the need of certifying Nearly Zero-Energy Buildings (NZEB). It concerns buildings with a very low energy demand that will have to meet certain standards after 2021. Certification process should include on-site tests confirming quality of buildings and comfort of their use. This research presents methods of building certification that are popular around the world. The authors’ contribution to science lies in the presentation of a building certification method developed in Poland. It is the first certificate of energy-efficient buildings (MCBE Certificate) in Poland, developed together by the scientists at the Cracow University of Technology, experts from the National Energy Conservation Agency and experts of the Polish Academy of Sciences. The assumption of the certificate was derived from the case study based on the methodology for calculating energy performance of buildings. The requirements of the MCBE Certificate were determined based on energy analyses carried out for various types of buildings. The certificate is based on a multi-criteria approach to the assessment of energy-efficient buildings.

1. Introduction

The concept of sustainability can be traced back to the 1970s in Europe when it was first noticed that the earth's natural resources are being depleted. Scientists developed the "Limits to Growth" report in 1972 [1]. This report marked the beginning of efforts to protect the environment. Sustainable development is also subject to many analyses and studies by representatives from many scientific fields [2–5]. This strategy combines efforts of politicians, local governments, industry and science as well.

Sustainable development is an idea summarized in the WCED (the World Commission on Environment and Development) report of 1987 - "Our Common Future" (Brundtland Commission Report, Our Common Future, Oxford University Press, Oxford 1987) [6]: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” This idea has found legitimacy in Poland since 1997 according to the article 5 of the Constitution of the Republic of Poland which reads as follows "The Republic of Poland safeguards the independence and inviolability of its territory, ensures freedom and human and



civil rights and citizens' safety, protects national heritage and ensures environmental protection, guided by the principle of sustainable development."

The Polish definition of sustainable development appeared as late as in 2001 in the Environmental Protection Law Act of 27 April 2001 where in article 3 point 50, it is specified what sustainable development is " socio-economic development, in which the process of integrating political, economic and social activities takes place, preserving the natural balance and sustainability of basic natural processes to guarantee the ability to satisfy the basic needs of individual communities or citizens of both contemporary and future generations." Additionally, in the Spatial Planning and Development Act of 27 March 2003 in article 1 point 50 it is stated that sustainable development is based on "principles of shaping spatial policy by local government units and government administration bodies, as well as the scope and methods of proceeding in matters of allocating land for specific purposes and establishing rules for their development."

The largest energy consumers are construction and transport sectors. Construction sector is responsible for around 40% of global energy consumption. An inseparable element of such a large consumption of an exhaustible fuel source, such as fossil fuels (coal, oil, gas), is pollution of the environment. One important element of sustainable development is therefore the reduction of energy consumption in construction. The policy of European Union member states aims at minimizing energy consumption in construction in a very concrete way. Directive 2010/31/EU, adopted by member states in 2010, introduced the concept of the NZEB. NZEBs should become a standard in all EU countries after 2021, and for buildings owned by local government after 2019. All member states will have to introduce the NZE building standard in a few months. NZEBs are characterized by very low energy consumption resulting from, among other things, the use of modern technologies and renewable energy sources [7].

One very important element of achieving low energy consumption in buildings is to ensure very high quality workmanship. The quality of workmanship can be determined by means of on-site testing. In addition, by analyzing a building during occupancy, it is possible to assess the comfort of use of the premises, which should be treated as a multi-faceted issue [8].

As the technical regulations establishing the standard of NZEBs do not regulate issues related to on-site testing, building certification is a very important element.

Certification of a building's energy efficiency is a very important instrument which enables that the quality of buildings, their influence on the environment and on their users to be evaluated. Membership of the European Union has obliged Poland to implement building standards aimed at reducing energy consumption. Like in other EU countries, there is a demand for designing nearly-zero energy buildings.

The need for evaluation and guarantees that the buildings that are being built have adequate quality has forced the Malopolska Centre of Energy-efficient Buildings (MCBE) to develop energy efficiency (MCBE) certificate. It is the very first energy efficiency certificate in Poland to take into account local climate conditions, energy distribution and architectural regulations.

The MCBE certificate includes four important areas: energy efficiency, comfort of use, the carbon footprint (environmental impact) and on-site measurements characterizing actual energy consumption. The first building to have passed the certification procedure was the Malopolska Laboratory of Energy-efficient Buildings (MLBE) at the Cracow University of Technology.

The first part of the paper presents the methodology of certification. The on-site testing required for issuing a MCBE certificate is discussed in the second part. Specific attention is paid to testing the airtightness of a building's envelope, highlighting that this is a necessary step in a building's certification process. The purpose of the article is to demonstrate the need for certification of energy-efficient buildings. The certification process must include on-site tests verifying the quality and comfort of use of buildings. The authors present their own, original process of building certification (MCBE certificate). It is the first certificate developed for Polish climatic conditions.

The building sector in Poland has been undergoing significant transformations to fulfil Poland's obligations as a member state of the EU through the implementation of Directive 2002/91/EC and its

more detailed version, 2010/31/UE [9] concerning the energy performance of buildings. The Directive enforces the design of buildings with low energy consumption – “nearly zero-energy buildings” (NZEBs). The process of NZEB design affects the selection of materials and insulation systems in particular. The resulting buildings should optimally use the renewable energy, for example, by using airtight envelopes and orienting the structure to utilize solar energy. Designing energy-efficient buildings is a challenge for architects, especially in the area of providing protection from overheating and ensuring the comfort of the occupants [10–12]. As shown in Figure 1, comfort is closely related to energy optimization [13–17].

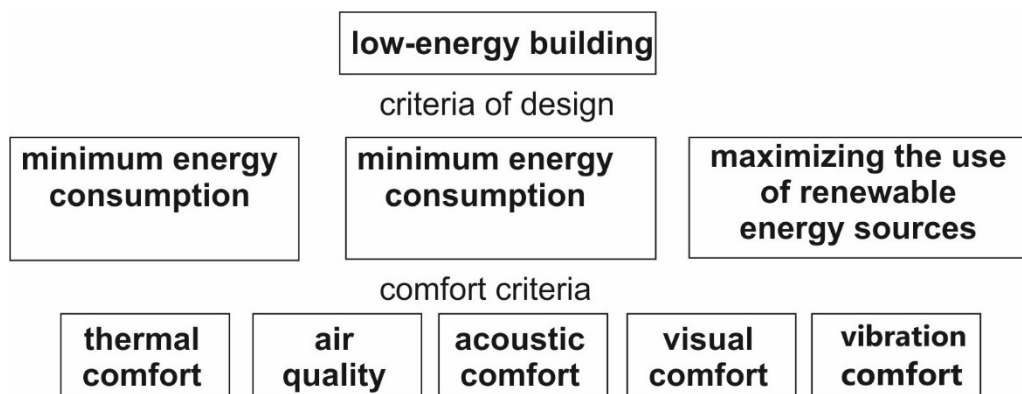


Figure 1. Criteria considered in designing NZEB [8].

Certification is a way of ensuring that the design and construction of a structure meets high standards in design, construction and occupancy. This can be reached using different methods. One of the most popular ones is the LCA method (life-cycle assessment). The assessment includes processes that start with the selection of raw materials, production of building materials and usage of the buildings to the extent of how they affect natural resources and whether they emit harmful substances even by their demolition at the end of a building's service life. Although it is not possible to eliminate the impact of buildings on the environment, tools such as LCA minimize their negative impact. This analysis takes into account important environmental indicators such as the greenhouse effect, soil and water acidification, photochemical ozone synthesis ability and fresh water consumption.

Other certification methods are generally less comprehensive than the LCA [18]. Examples of evaluation systems are listed in Table 1. Table 2 shows factors taken into consideration in various certification systems.

Table 1. Assessments developed in various countries [19].

System	Environment	Social aspects	Economic aspects	Status
EU Flower	yes	no	no	under development
BREEAM	yes	partly	no	for environmental assessment
LEED	yes	partly	no	the USA, not adapted to EU conditions
DGNB	yes	yes	partly	Germany only

SBTool	yes	yes	yes	research
CASBEE	yes	yes	yes	Japan only

Table 2 lists the most popular assessment systems. For each assessment system, the areas in which the building is assessed are presented (factors considered).

Table 2. Factors considered in various assessment systems.

System	Country/organization	Considered Factors
BREEAM	UK	management comfort energy transport water consumption materials land use ecology waste
LEED	USA	sustainability water management energy use atmospheric pollution materials and resources indoor environmental quality innovation and design process
SBTool	International Initiative for a Sustainable Built Environment (iiSBE)	consumption of resources environmental burden indoor environmental quality quality of service economy management transport and communication
CASBEE	Japan	quality of the building internal environment quality of service external environment environmental burden energy use raw materials and consumables external environment

All of the environmental assessment systems listed are time-consuming because they cover all phases of construction. Each of them has been developed for specific climatic conditions, the available construction materials and local code requirements.

2. Methods

Similarly, the scope of the Malopolska Energy-efficient Building Certificate (MCBE) contains efficient energy use, minimal influence on the environment, health and the comfort of the occupants.

The certification process starts during the design stage, in which the MCBE team helps to determine the design parameters for the project. During the construction phase, experts check whether the building is being built in accordance with the construction details that have been prepared. Indoor environmental quality is checked when the building enters the occupancy stage. Additionally, the carbon footprint of the building is determined to show its impact on the environment.

A building that meets the MCBE certificate criteria shown in Figure 2 brings only positives for the user starting from health, through better living comfort, protection of the environment, up to not-insignificant savings for the owner. Such a building requires considerably less energy for heating and ventilation in comparison to traditional technology, and uses heat from a variety of renewable energy sources, while also using natural light.

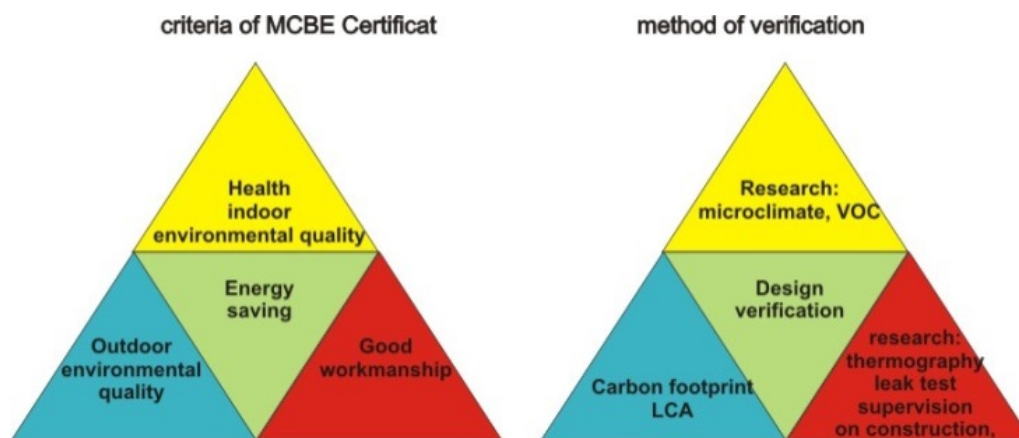


Figure 2. MCBE Certificate criteria.

Building simulations are performed to verify the design of energy conservation features. The simulations include calculation of heating energy demand, domestic hot water requirements, cooling (if there is a cooling installation in the building) and lighting (in the case of public buildings) for different building types.

As a basis for performing the calculations during building's certification in the Malopolska Voivodship, the authors adopted the method from the Ordinance of the Minister of Infrastructure and Development of June 3rd 2014 on calculating the energy performance of a building or dwelling. Calculations for primary and final energy are carried out in accordance with the methods published in the corresponding literature [20–33].

Weather data

The Małopolska Voivodship has three different climate zones that meet the requirements of the PN-80/B-02403 standard [34]. MCBE experts require that the MCBE certificate takes into account all three climatic conditions. The figure below shows the breakdown of the climate zones shown in Figure 3.

Calculations were performed for the following types of buildings:

- Single-family residential
- Three single-family residential buildings with different A/V* coefficients,
- Multi-family residential – four multi-family residential buildings with different A/V* coefficients,
- Residential building with commercial premises



Figure 3. Climate zones in the Malopolska Region.

- Public buildings – two office buildings with different A/V^* coefficients, two school buildings with different A/V^* coefficients and one high-rise building

- Commercial – two commercial buildings with different A/V^* coefficients

* A/V coefficient is a coefficient of the shape of the building. $A [m^2]$ is the surface envelope of the building, $V [m^3]$ is the volume of a building.

Table 3. Geometric parameters for the analyzed buildings.

Model of the building	Usable area	The cubic capacity with controlled temperature	A/V [1/m](shape coefficient)	The degree of glazing in exterior walls
	$[m^2]$	$[m^3]$	$[1/m]$	$[-]$
Single-family 1	150.0	367.5	0.66	0.09
Single-family 1 with garage	178.9	448.6	0.63	0.07
Single-family 2	122.1	310.9	0.73	0.09
Single-family 3	149.2	356.3	0.80	0.08
Multi-family 1	5286.7	13713.7	0.32	0.23
Multi-family 2	2627.3	6581.7	0.35	0.20
Multi-family 3	1956.1	4996.9	0.44	0.18
Multi-family 4	966.5	2404.8	0.47	0.16
services part	1956.1	5175.9		
Living part	1480.3	3749.2	0.44	0.18
Services part	475.8	1426.7		
Office 1	4952.8	17209.2	0.10	0.60
Office 2	11031.4	38873.4	0.12	0.59
Sports hall 1	633.4	2620.4	0.41	0.06
Commercial1	10062.1	83313.9	0.16	0.00
Commercial 2	2261.2	13197.4	0.26	0.06
School 1	2 651.0	10668.7	0.18	0.07
School 2	2663.7	11156.4	0.31	0.07

In the analysis of all the buildings, the following heat transfer coefficients used for the various regions have been listed in Table 4.

Table 4. Overall Heat Transfer Coefficients (U [W/m^2K]).

Type of Partition	U [W/m^2K]
External wall	0.15
Ground floor	0.20
Ceiling above unheated space	0.15
Roof above unheated space	0.25
Windows	0.9
External walls	1.3

Heating system

The calculations of energy demands were carried out in two ways. The first was for central heating provided by gas, while the other was for energy supplied by a local heat distribution network.

The analysis includes natural and mechanical intake-exhaust ventilation with heat recovery efficiencies up to 80%. The tightness of the building in the case of natural ventilation is $n_{50} = 3.00$ [h^{-1}] while in the case of mechanical ventilation $n_{50} = 1.5$ [h^{-1}].

Hot Water System

Calculation of the final and primary energy demand was carried out for two commonly used installations. The first one used gas to heat water, while the second relied on the local heat distribution network. The tables show the efficiencies used in the calculations.

Non-renewable primary energy coefficients EP [kWh/m^2 annual]

Non-renewable primary energy coefficients are in accordance with the regulation referring to energy performance of buildings and data provided on the websites of the suppliers.

- Network gas = 1.1;
- Electric energy $w = 3.0$;
- MPEC (network heat)-Krakow 2013w = 0.62;
- MPEC (network heat)-Nowy Sacz = 1.3;
- Heat from geothermal sources - Podhale Region $w = 0.39$

3. Results

In the undertaken analyses, the following values that meet the requirements of the Małopolska Energy-Efficient Building Certificate resulted. The results of the analyses have been presented in Tables 5, 6, 7.

Table 5. Values of the U parameter for the Malopolska Energy-Efficient Building Certificate and its method of verification.

Parameters			Coefficient U [W/m ² K]		Method of verification
External			walls:		architectural and building documentation
a)	8°C	$t_i \geq$	16°C	0.15	
b)		$\leq$	$t_i <$	16°C	0.45
c)		$t_i < 8^\circ\text{C}$			0.90
External			Roofs		architectural and building documentation
a)	t_i	$\geq$	16°C	0.15	
b)	8°C	$\leq$	$t_i < 16^\circ\text{C}$	0.30	
c)	$t_i < 8^\circ\text{C}$			0.70	
Ground			floors		architectural and building documentation
a)	t_i	$\geq$	16°C	0.20	
b)	8°C	$\leq$	$t_i < 16^\circ\text{C}$	1.20	
c)	$t_i < 8^\circ\text{C}$			1.50	
External			windows		architectural and building documentation
a)	t_i	$\geq$	16°C	0.9	
b)	$t_i < 16^\circ\text{C}$			1.4	
External doors				1.3	architectural and building documentation
Energy consumption [kWh/m ² a] (location: Krakow, Poland)					
EP coefficient(Primary Energy)				70	energy performance
EU coefficient (Energy Use) single-family building				60	energy performance
EU coefficient (Energy Use) multi-family building				40	energy performance
On-site tests					
Leak test				yes	Blower Door
Air quality				yes	VOC equipment
Thermo-vision				optional	Thermal camera
Thermal comfort				optional	Thermal equipment comfort

Table 6. Reference indicator of energy demand for heating and cooling EU'_{ref} taking account of the correction value factor related to the location of the building ΔE .

Type of building	Reference indicator of primary energy demand $EU'_{ref} = EU_{ref} \Delta E$ [kWh/(m ² annual)]			
	Kraków	Nowy Sącz	Tarnów	Zakopane
Single-family building	60.0	58.8	56.4	74.3
Multi-family buildings	40.0	39.2	37.6	49.5
single-family houses with a system of cooling	62.5	61.3	58.8	77.4
multi-family buildings with the installation of cooling	42.5	41.7	40.0	52.6
public buildings	60.0	58.8	56.4	74.3
public buildings with cooling installation	65.0	63.7	61.1	80.5

Table 7. Reference indicator of energy demand for heating and cooling EU'_{ref} taking account of the correction value factor related to the location of the building ΔE .

Type of building	Reference indicator of primary energy demand $EP'_{ref}=EP_{ref}\Delta E$ [kWh/(m ² annual)]			
	Kraków	Nowy Sącz	Tarnów	Zakopane
Single-family	70.0	68.6	65.8	86.6
Multi family	70.0	68.6	65.8	86.6
single-family houses with a system of cooling	75.0	73.5	70.5	92.8
multi-family buildings with the installation of cooling	75.0	73.5	70.5	92.8
public buildings	120.0	117.6	112.8	148.5
public buildings with cooling installation	145.0	142.1	136.3	179.5

The certificate was developed for newly-designed buildings [35] as well as already existing ones [36]. Buildings equipped with renewable energy sources have an EP indicator at a low level [37]. For such buildings it will be easier to obtain the MCBE certificate than buildings powered by non-renewable energy sources. The first new building granted the MCBE Certificate has been the super innovative Malopolska Laboratory of Energy-Efficient Buildings (MLBE) (Figure 4).

MLBE building is erected in the centre of Krakow and is adapted to its surroundings. The MLBE building is equipped with renewable energy sources: photovoltaics, solar panels and ground heat exchangers.

Geometric parameters of the MLBE building:

- Usable area of the building: 1,039.39 m²
- Volume of the building: 5,050.41m³
- Number of floors in the building: 5
- Building height: 19.24 m
- Roof geometry - flat roof



Figure 4. The experimental Malopolska Laboratory of Energy-efficient Buildings (MLBE).

The MLBE building is a fully automated laboratory for on-site testing of energy efficiency technologies.

In the MLBE building, scientists conduct experiments to confirm the energy efficiency of currently used technologies [35].

The MLBE possesses the following features:

- 6 independent heating sources
- 14 independent climate zones
- 3 thermal wells (125 m)
- 2 ground heat exchangers
- 3000 sensors

Table 8 presents the thermal parameters of the MLBE.

Table 8. Thermal parameters of the MLBE.

Type of partition	U heat transfer coefficient[W/m ² K]
External wall	0.12
Ground floor	0.10
Roof	0.13
Windows	0.70
External door	0.80
Energy consumption coefficient	[kWh/m²a]
EP	119.6
EU _{H+W}	13.6

4. Conclusion

One of the elements of the strategy of sustainable development is the reduction of energy consumption in the construction sector. Member states are introducing building standards with almost zero energy demand. It is necessary to verify the actual energy efficiency of buildings. Certification is such an element. The building certification process is a very important element, which ensures a high level of energy efficiency in buildings. The MCBE certificate is the first certificate based on Polish climate conditions, developed by scientists from the Cracow University of Technology in cooperation with experts from the National Energy Conservation Agency and experts from the Polish Academy of Sciences. The method selected for analysis (case study) based on [23] allowed the certification level of the Małopolska Energy Saving Certificate to be determined. Calculations based on the analyses allowed the optimal levels for individual assessment criteria for NZEB buildings to be determined. On-site tests are the most important tasks of the Małopolska Certificate of Energy-efficient Buildings. On-site testing, which is a part of the certification process, ensures a high level of energy efficiency in buildings and a high level of comfort of use. The certificate was developed for newly designed buildings as well as already existing ones. An important aspect in the assessment of certified buildings is a multi-criteria approach, taking into account the criteria of energy efficiency, quality of workmanship, comfort of use and impact on the external environment. NZEB should largely be supplied with renewable energy sources, which is also the assumption of the Certificate prepared by scientists and experts. The MCBE certificate is an important contribution of science to the strategy of sustainable development in Poland.

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