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NEARLY ZERO ENERGY BUILDINGS (NZEБ) – A SUSTAINABLE FUTURE FOR THE BUILT ENVIRONMENT AND BULGARIAN EXPERIENCE

Krasimir G. GEORGIEV

Institute of Mechanics- Bulgarian academy of sciences

Acad. G. Bontchev St., bl. 4, 1113 Sofia, Bulgaria

e-mail: krasimir.georgiev@imbm.bas.bg

Abstract

The concept of Nearly Zero-Energy Buildings (NZEБs) represents a transformative shift in the design, construction, and operation of buildings, aiming to significantly reduce energy consumption and environmental impact. The revised Energy Performance of Buildings Directive (EU/2024/1275) [1] requires all new buildings to meet higher levels of performance than before, by exploring more the alternative energy supply systems available locally on a cost-efficiency basis and without prejudicing the occupants' comfort.

As global concerns about climate change, energy security, and resource depletion intensify, the building sector, which accounts for approximately 30–40% of global energy consumption and associated greenhouse gas (GHG) emissions, has come under increasing scrutiny. NZEБs are designed to minimize energy demand through high-efficiency systems and passive design strategies while meeting the remaining energy needs through renewable energy sources produced on-site or nearby.

In this context we are going to share the Bulgarian experience and show several examples of such buildings from Bulgaria.

Keywords: *Nearly Zero-Energy Buildings, NZEБ, energy efficiency, sustainable architecture, renewable energy, building design, passive house, smart buildings, net-zero, green construction.*

Introduction

Climate change and all its consequences are priority issues, especially in the last few decades. Buildings (commercial, residential) are major contributors to energy consumption. Energy consumption in buildings is increasing significantly annually due to the increasing population, the need for more living space, and the needs and services for human comfort. Many factors influence the energy consumption used for heating and cooling buildings, such as the structure of the wall, the window/wall ratio, the orientation of the building, and the weather conditions. However, the current scenario of building construction and the way it is operated and maintained have a significant impact on the total energy and water use of the world's resources. Reducing energy use in buildings and homes will significantly reduce energy consumption and consequently greenhouse gas emissions.

The European Unions' ambition for improvements in the construction sector is to be carbon neutral by 2030 for all new buildings, both office and residential. All of the new buildings in the EU

should have been constructed as nearly zero-energy buildings (nZEB) since 2021 [2] However, some Eastern European countries with very old and not efficient building stock that consists mainly from buildings from old concrete panels and not insulated buildings struggle to implement the 2018 Energy Performance of Building Directive recast requirements [3]. Next to the economic challenges, equally essential factors hinder renovating the existing residential building stock and adding newly constructed high-performance buildings sourced primarily from renewable energy sources.

Decarbonization of buildings and the construction sector is very critical to achieve the commitment of the Paris Agreement and to reach the United Nations Sustainable Development Goals. Last researches show that 40% of the total energy consumption and 36% of the CO₂ emissions in Europe comes from buildings. Therefore, the EU has decided to take drastic measures in particular in the construction sector, as they are central to the EU's energy efficiency policy. This has led the European Commission to create Directives on Energy Efficiency which oblige the improvement of the energy efficiency of buildings, thus, introducing the concept of NZEB or Near Zero Energy Building. This desire is reflected in The European Commission's long-term strategy for 2050, which acknowledges the necessity of an almost complete decarbonization of the building sector to achieve its climate objectives. In this article, we explain what exactly an NZEB building is and its importance in sustainable development.

Before providing a more formal definition of what Near Zero Energy Buildings, more commonly known as NZEBs, it is important to clarify the confusion that these buildings do consume energy, but it also produces and stores energy. As for the nearly-zero energy buildings, the very small amount of energy still required for zero-emission buildings is covered by energy from on-site and nearby renewable energy sources, including from renewable energy communities and efficient district heating and cooling (in accordance with Article 26(1) of the 2023 Energy Efficiency Directive) [4].

1. EU regulations

In response to the hardships and global energy market disruption caused by Russia's invasion of Ukraine, the latest European Commission document RePower [5] provides a wide range of alternative renewable energy sources that are now available and should be an integral part of all new buildings, such as photovoltaic systems for electricity (generated on-site via PV or hybrid PV thermal on the roof or nearby) powering electric heat pumps, capturing both ambient and solar heat pumps, as well as solar thermal heat. Solar energy can provide a significant part of a building's electricity and heat demand, either through solar thermal collectors, solar PV (with heat pumps) or a combination of both, including hybrid PV-thermal technologies. Through supporting policies and regulations that ensure a level playing field for all solar technologies and do not favor one over the other, national and local authorities can promote the most efficient solution for each situation.

In all EU directives, it is committed that developing a sustainable, competitive, secure and decarbonized energy system. [6] establish ambitious Union commitments to further reduce greenhouse gas (GHG) emissions by at least 55% by 2030 compared to 1990, to increase the share of renewable energy used, to save energy in line with Union-level ambitions and to improve Europe's energy security, competitiveness and sustainability. To achieve these goals, the 2016 review of EU energy legislation combines a reassessment of the EU's 2030 energy efficiency target, a review of Directive 2012/27/EU of the European Parliament and of the Council and Directive 2010/31/EU [7].

2. Bulgarians Definition and Scope of NZEB

According to The National Nearly Zero-Energy Building Plan 2015–2020 (NPSBNPE) that was developed on the basis of Article 9(1) of Directive 2010/31/EU on the energy performance of buildings the legal Bulgarian definition of nZEB is:

'A nearly zero-energy building' is a building that cumulatively satisfies the following conditions:
a) the building's energy consumption, expressed as primary energy, corresponds to energy performance Class A for that type of building;
b) at least 55% of the energy used (supplied) for heating, cooling, ventilation, domestic hot water and lighting is energy from renewable sources produced in the building or in its close surroundings.

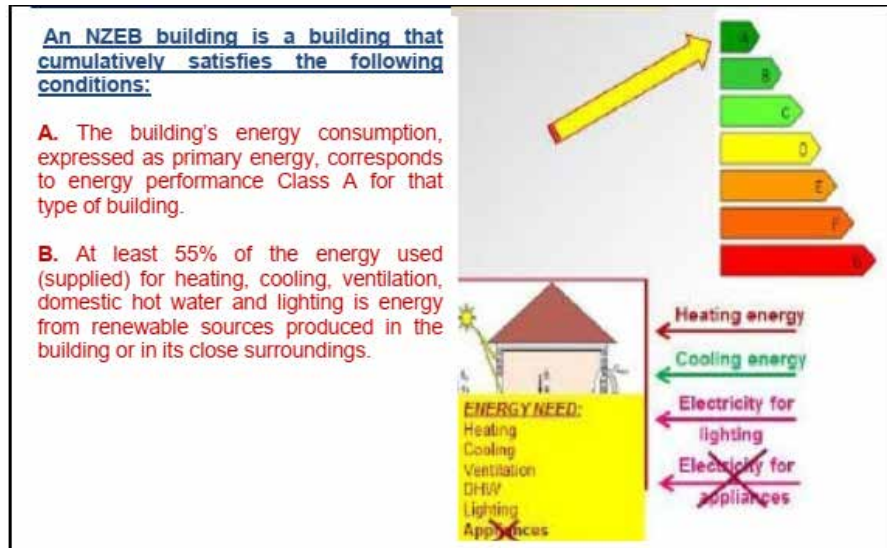


Fig.1. nZEB definition for Bulgaria

Key characteristics of NZEBs include:

- Very low energy demand for space heating, cooling, ventilation, hot water, and lighting.
- High-efficiency systems including HVAC, lighting, and appliances.
- On-site or nearby renewable energy generation, typically from solar PV, solar thermal, wind, biomass, or geothermal sources.
- Smart building technologies for real-time monitoring and control of energy use.
- Lifecycle assessment considerations, including embodied energy in construction materials.

3. nZEB examples from Bulgaria

3.1. Demonstrational pavilion with the innovative design built in the Scientific Campus II of the Bulgarian Academy of Science



Fig. 2. InDeWaG Demonstration Pavilion, Sofia, Bulgaria

This InDeWaG Demonstrational Pavilion, is located on II campus of the Bulgarian Academy of Sciences in Sofia. It is a pioneering project demonstrating innovative Water Flow Glazing (WFG) technology. This demonstrator is part of the EU-funded InDeWaG (Industrial Development of Water Flow Glazing Systems) project, aiming to advance nearly Zero Energy Building (nZEB) standards through cutting-edge façade and interior systems (fig. 2). The building is oriented in clear geographic directions east-west, north-south. The pavilion is a glass-encased structure measuring 7.0 by 7.0 meters, with WFG

modules installed on the east, west, and south façades. The north façade, along with the roof and floor are well-insulated to minimize energy losses. Each WFG unit contains a circulating mixture of distilled water and glycol, which absorbs solar radiation and transports the generated heat through a pipe system. This system allows the façade to function as a heating and cooling unit, depending on the temperature of the circulating fluid. Inside, the pavilion has interior partition walls made of similar glazing elements, providing radiant heating or cooling to maintain comfortable indoor conditions [8]. The building is equipped with a monitoring system that tracks energy gains and demands, validating the performance of the WFG technology in real-time. The WFG technology significantly reduces the need for conventional HVAC systems by utilizing the thermal properties of water to regulate indoor temperatures. This approach not only enhances energy efficiency but also contributes to the building's compliance with nZEB standards as defined by Bulgarian legislation. The pavilion also incorporates rooftop photovoltaic panels and a heat pump, further supporting its sustainable energy goals. The InDeWaG project is a collaborative effort involving multiple European partners. The project's objective is to develop cost-effective, industrial-scale FFG elements that can be integrated into various building types across different climate zones. The pavilion serves as a prototype for these technologies, providing valuable data to inform future applications.

One major objective of the pavilion is to show the integration of the WFG technology into heating, ventilation and air conditioning (HVAC) systems in winter and summer modes. The second objective of the project is to prove that this building meets the requirements for nZEB in Bulgaria.

3.2. Family house located in Bistrice, Bulgaria with investor Lubomir Stoyanov

This family house located in the village of Bistrice is laid out on a single storey with a total heated



Fig.3. nZEB Family house - Bistrice, Bulgaria

area of 212 m². Following the recommendations of the REECL team, Mr Stoyanov decided to build a nearly zero-energy building nZEB home by upgrading the building services to underfloor heating provided by highly efficient heat pump and architecturally improving the details of the building envelope. [9] This led to improving the designed energy performance rating of the building from 177 kWh/m² to 83 kWh/m² making the house meet the EU nZEB standards for Bulgaria.

Mr. Stoyanov was motivated to build a nZEB house because of the wide range of benefits it offered such as: low impact from future energy price increases; better internal comfort due to more uniform interior temperatures; reduced costs of ownership due to improved energy efficiency and the materials used for building the house; reduced monthly cost of living; improved reliability – modern heat pump technologies that can last over 20 years. The extra cost of energy efficient building services is minimized for new construction compared to an afterthought retrofit and the property will have a higher resale value as potential owners will Details:

- Investments: Air to water heat pumps; underfloor heating and cooling; warm/cold air fan convectors; wireless control system; thermal insulation; doors and windows.
- Investment Size: €42,396
- Financial results: Payback of 14 years
- Energy savings: 7,250 kWh per year
- CO₂ savings: 4,952 kg per year

- Impact: Reduced energy bills; improved living comfort; better internal air quality; improved sound insulation.

3.3. The fist mobile “Zero Energy Caravan” in Bulgaria



Fig.4. Mobile "Zero Energy Caravan"

The Zero Energy Caravan [10] is designed to be completely self-sufficient and not require external power sources to function. This means that the caravan uses only renewable energy sources such as solar panels, wind turbines or hydro sources to generate power for lighting, heating and cooling.

Zero-energy caravans reduce dependence on fossil fuels and carbon emissions, which is essential for protecting the environment. They can also be used in remote locations where mains electricity is not available, such as campsites, caravan parks or even as homes to live in.

The aim of the initiative is to raise public, media and professional interest in the benefits and advantages of energy efficiency. Through projects such as the Zero Energy Caravan, we strive and create the most understandable and intuitive tools possible through which people can see, touch and feel the benefits of zero energy buildings.

Conclusions

NZEBs mark a crucial evolution in building design and urban planning. By minimizing energy demand and maximizing renewable supply, they address climate, economic, and social challenges simultaneously. Although barriers remain, the trajectory of NZEBs is clear and increasingly attainable. With supportive policies, technological innovation, and market transformation, NZEBs will become the norm in both new construction and renovation across the globe.

Nearly Zero-Energy Buildings represent a vital strategy for mitigating climate change, improving energy security, and creating healthier indoor environments. Their success lies in the convergence of passive design, cutting-edge technologies, supportive policy, and behavioural change. As market maturity grows and costs continue to decline, NZEBs are poised to transition from niche innovation to standard practice.

However, to unlock the full potential of NZEBs, a coordinated effort across sectors is essential—combining public policy, private sector investment, professional education, and community engagement. The path forward requires not only technological innovation but also a rethinking of how buildings are conceived, valued, and integrated into the broader energy ecosystem.

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**БУДІВЛІ З МАЙЖЕ НУЛЬОВИМ СПОЖИВАННЯМ ЕНЕРГІЇ (NZEB) – СТАЛИЙ
ШЛЯХ У МАЙБУТНЄ ЗАБУДОВИ ТА БОЛГАРСЬКИЙ ДОСВІД**

Красімір ГЕОРГІЄВ

Інститут механіки Болгарської академії наук

ул. акад. Г. Бончев, 4, 1113 Софія, Болгарія

<https://orcid.org/0009-0002-3675-9863>

Анотація

Концепція будівель із майже нульовим споживанням енергії (NZEB) є трансформаційним підходом до проєктування, зведення та експлуатації будівель, що має на меті суттєве скорочення енергоспоживання та впливу на довкілля. Оновлена Директива про енергетичну ефективність будівель (ЄС/2024/1275) вимагає, щоб усі нові будівлі відповідали вищим стандартам ефективності, ніж раніше, з урахуванням можливостей використання місцевих альтернативних джерел енергії на основі оцінки економічної доцільності та без шкоди для комфорту мешканців.

У контексті загострення глобальних проблем зміни клімату, енергетичної безпеки та виснаження ресурсів, будівельний сектор — який становить приблизно 30–40% світового енергоспоживання та пов'язаних з ним викидів парникових газів — перебуває під дедалі пильнішою увагою. NZEB-проєкти передбачають мінімізацію потреби в енергії за допомогою вискоелективних систем та пасивних архітектурних рішень, а решта потреб покривається за рахунок відновлюваних джерел енергії, виробленої на місці або поблизу. У статті представлено болгарський досвід на прикладі кілткох таких будівель побудованих за вказаною концепцією.

Ключові слова: будівлі з майже нульовим споживанням енергії (NZEB), енергоефективність, стала архітектура, відновлювана енергія, проєктування будівель, пасивний дім, розумні будівлі, нульовий енергетичний баланс, зелене будівництво.