BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi" din Iași
Volumul 68 (72), Numărul 3, 2022
Secţia
CONSTRUCŢII. ARHITECTURĂ
DOI: 10.2478/bipca-2022-0023

COMPARATIVE STUDY OF DIFFERENT SCENARIOS FOR ENSURING THE ENERGY PERFORMANCE OF AN EXISTING BUILDING

BY

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Received: March 3, 2023
Accepted for publication: April 4, 2024

Abstract. The recent legislative changes concerning the energy efficiency of buildings make it compulsory that high-performance solutions are considered for both buildings envelope and its technical system. While the new construction rate of the non-residential sector has been consistently high during the last decade, also rehabilitation works on existing buildings have been done, involving both expansions and energy efficiency works, as there are different sources of financing available to support the reduction the energy consumptions. When increasing energy efficiency of buildings both thermal rehabilitation works on the envelope and improvements on the efficiency of the technical system are needed. Thermal rehabilitation works will increase the thermal resistance of the enclosing elements, reduce heat losses, limit thermal bridges and air infiltrations. This paper presents a non-residential building, located in the IVth climate zone of Romania, for which a consistent expansion was needed in order to accommodate a larger number of occupants and, at the same time to comply with the current essential requirements. Thus, several scenarios were considered, which integrated renewable energy sources. The compliance with the

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performance indicators imposed by the new legislation in the field was analysed. The simulations were carried out in a dedicated software, and the results obtained were analyzed in terms of primary energy consumption and equivalent CO2 emissions.

Keywords: energy efficiency, buildings energy performance, envelope thermal performance, renewable energy, thermal performance.

1. General aspects

Reducing the conventional energy consumption by improving the energy efficiency of buildings and by increasing the share of energy from renewable sources are among the most important national and current concerns at the international and local level.

Romanian Norms regarding buildings energy efficiency have evolved over time, starting from 1973, but greater progress was achieved after 2010, with the implementation of European Directive 31. Another important milestone has been reached in 2016 with the amendments and additions to Law 372/2005, where the requirement for new buildings constructed after 2020 (2019 for public buildings) should reach the nearly zero energy buildings (NZEB) standards. Moreover, 2023 came with another important change - the publication of the new form of MC001 that drastically changed the energy efficiency standards. For example, the previous NZEB indicators were less difficult to be obtained than the new imposed ones.

Buildings are a central element of EU member states' energy efficiency policy, being responsible for approximately 40% of final energy consumption and 36% of greenhouse gas emissions, and approximately 75% of buildings are not energy efficient. Thus, energy efficiency is an essential component for the future measures and the building sector is one of the areas where efforts must be ramped up to achieve a European net 55% emission reduction target by 2030 (Attia *et al.*, 2022).

The concept of NZEB buildings determines an approach different from the traditional one, which we have already used. A building is considered an organism in continuous evolution, which over time must be maintained, rehabilitated and modernized in order to meet the demands set by users at a certain stage of its life. Improving building's energy efficiency relates to specific analyses and proposed interventions for reducing energy consumption, but without neglecting the appropriate comfort conditions. In Romania, according to Law no. 121/2014, the improvement of energy efficiency is established as a strategic objective of the national energy policy, due to the major contribution it has to achieve sustainable development, security of the energy supply and competitiveness, to save primary energy resources and to reduce greenhouse gas emissions.

The NZEB is defined according to the republished Law no. 372/2005 on the energy performance of buildings, as a building having a very high energy performance, whose energy consumption from conventional sources is almost equal to zero or is very low and is obtained, to the greatest extent, with energy from renewable sources, including energy from renewable sources produced on-site or nearby, and is covered as follows:

a) in proportion of minimum 30% with energy from renewable sources, including energy from renewable sources produced on site or nearby, within a radius of 30 km from the GPS coordinates of the building, starting from 2021;

b) minimum proportions of energy from renewable sources, including renewable energy produced on-site or nearby, within a radius of 30 km from the GPS coordinates of the building, for the periods 2031-2040, 2041-2050 and after 2051, are established by Government Decision.

In the same law is stated that all new buildings, for which the reception at the end of the construction works is carried out starting from 31st of December 2020, need to be NZEB. In the new published methodology for determining the energy performance of buildings, MC001-2022, are given the minimum conditions in terms of total primary energy (kWh/m^{2}year) and equivalent CO2 emissions (kg CO_2 /m^{2}year).

In addition to the efforts of constructing new energy efficient buildings, improving the energy efficiency of the existing building stock is essential. This is not only to meet the national medium-term energy efficiency targets, but also to meet the medium and long-term objectives of climate change strategies and the transition to a competitive low carbon economy by 2050.

The analysed building is placed in the IVth climate zone of Romania and it is a non-residential building. The maximum values for the performance indicators are given in Tab. 1.

Currently, the new methodology MC001-2022 imposes that, for the deep renovated buildings, the minimum requirements are:

- maximum allowed limit values for the total primary energy consumption (from renewable and non-renewable sources);
- maximum allowed limit values for the equivalent CO_2 emissions;
- minimum 10% from the total primary energy consumed by the renovated building is provided from renewable sources.

Table 1

Maximum values for non-residential buildings

Maximum values	Total primary energy (kWh/m^{2}year)	Equivalent CO_2 emissions (kg CO_2/m^{2}year)
NZEB buildings – Horizon 2020	170	49
NZEB buildings - 2022	107.4	13.9
Deep renovation - 2022	124.3	20.6

Deep renovated buildings are defined as those buildings that, after renovation, improve their energy performance with more than 60%.

Thus, implementing the NZEB performance criteria to an existing building is not an easy task, taking into account that the indicators are much stricter and that some elements cannot be changed (e.g. orientation towards the cardinal points, materials etc.).

2. General presentation of objectives

The proposed construction has height regime Ground Floor + 1 Floor (G+1 Fl) and it is placed in Suceava County. The existing building, that has the destination of a cafeteria, has a built-up area of 407 m2 and a gross area of 814 m2. Besides improving the thermal efficiency of the building, it has been aimed to increase the capacity for serving meals, as well as to ensure the spaces necessary for food storage, the construction of the spaces and flows necessary for the kitchen to function according to current regulations. Thus, a consistent extension of the building was proposed (Fig. 1). Within this objective, an area with separate external access will be created for cooking classes, intended for young people, for life skills development activities – cooking together. The layout of the buildings was designed so that separate accesses for children can be ensured to the dining areas on the ground and first floor, as well as distinct accesses for supplies and staff.

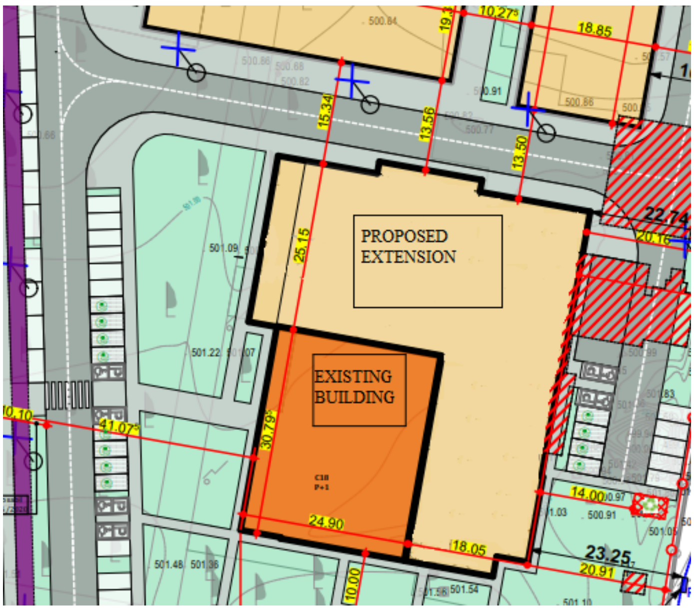

Fig. 1 – Layout of the analyzed building.

In the proposed architectural solution, the height regime is of G+1 Fl (Fig. 2), the built area of 2,535 m^2, the built-up area of 4,161 m^2 and the usable area is 3,291.47 m^2.

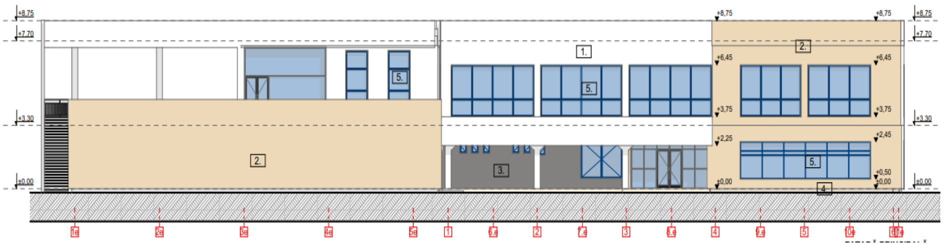

Fig. 2 – Main façade of the proposed building.

The existing building has continuous concrete foundations, while the superstructure is made of columns, beams and prefabricated reinforced concrete floors.

The proposed extension will be made in a reinforced concrete frame system. The outer walls will be made of brick masonry walls together with a building thermal insulation system designed in a mixed system: ventilated wall composed of 20 cm mineral wool, ventilated air layer and elements of facade cladding with wood-imitation composite panels and classic facade system, thin decorative plaster mounted on fiberglass mesh.

For the socket area, the thermal insulation will be made of extruded polystyrene, 15 cm thick and will also continue below the level of the sidewalk with 30-40 cm. The outer carpentry will be made of aluminum, with three heat-insulating glasses with argon between the glass sheets. At the level of the slab on the ground, a thermal insulation layer of extruded polystyrene of 15 cm was provided.

3. Thermal efficiency of the elements of the envelope

In order to fulfil the minimum energy performance requirements specific to energy performance of buildings, it is recommended that each element of the envelope meets the requirement:

$$R'_m \geq R'_{min}\ [m^2K/W] \tag{1}$$

where:
R'_m – average corrected thermal resistance;
R'_{min} – minimum corrected thermal resistance.

The elements of the envelope and their geometric and thermal characteristics are summarized in Table 2. For the analysed building, the average corrected thermal resistance on the whole envelope of the building is 3.742 [m^2K/W].

Table. 2
Characteristics of the building's envelope

Envelope element	Area (m^2)	R (m^2K/W)	R' (m^2K/W)	R'_{min} (m^2K/W)		
				MC001-2016	MC001-2022 (deep renovation)	MC001-2022 (NZEB)
Outer walls NW	230.85	6.06	3.436	1.80	3.00	3.00
Outer walls SE	232.62	6.06	3.163	1.80	3.00	3.00
Outer walls NE	168.9	6.06	3.036	1.80	3.00	3.00
Outer walls SW	189.47	6.06	3.297	1.80	3.00	3.00
Outer carpentry NW	118.11	0.87	0.87	0.77	0.83	0.83
Outer carpentry SE	116.34	0.87	0.87	0.77	0.83	0.83
Outer carpentry NE	127.8	0.87	0.87	0.77	0.83	0.83
Outer carpentry SW	133.03	0.87	0.87	0.77	0.83	0.83
Joint wall	176.33	0.86	0.766	1.1	1.1	1.50
Upper slab (pedestrian terase)	1122.16	11.64	6.914	5.00	5.00	6.00
Upper slab (non-pedestrian terase)	1121.3	11.58	8.096	5.00	5.00	6.00
Slab on ground	2239.71	5.29	9.221	4.50	4.50	5.00

4. Proposed scenarios

In order to carry out a relevant analysis, three scenarios were analysed in order to identify the proper solution. In all of them, the use of renewable energy sources so that the 30% minimum contribution can be achieved.

Numerical simulations, having as input the proposed layout of the building, were generated using a specialized calculation software (AllEnergy v. 9.0) to make an authentic analysis regarding the energy consumption for the five categories of consumers: heating, hot water, lighting, ventilation and conditioning. As can be seen and in Fig.3 the largest share of energy consumption is due to the building's heating system and the use of the spaces at a proper indoor temperature (68%), and the second one is the consumption due to the buildings lighting.

Therefore, considering the characteristics of the building and the performance indicators specific to NZEB buildings, different scenarios for the technical system were taken into account, as follows:

- Scenario 1: Heating – natural gas, Hot Water – 50 % from natural gas + 50% from solar panels (SP), Lighting – 50% from photovoltaic panels (PV), Ventilation + Conditioning – electric energy from national energy system (NES);
- Scenario 2: Heating – heat pumps (VRV/VRF), Hot Water – from natural gas + 50% from SP, Lighting - 50% from PV, Ventilation + Conditioning – electric energy from NES;
- Scenario 3: Heating – biomass, Hot Water –biomass + 50% from SP, Lighting – 50% from PV, Ventilation + Conditioning – electric energy from NES.

The computations carried out for the proposed scenarios have been used to compare the values of the performance indicators of an NZEB building.

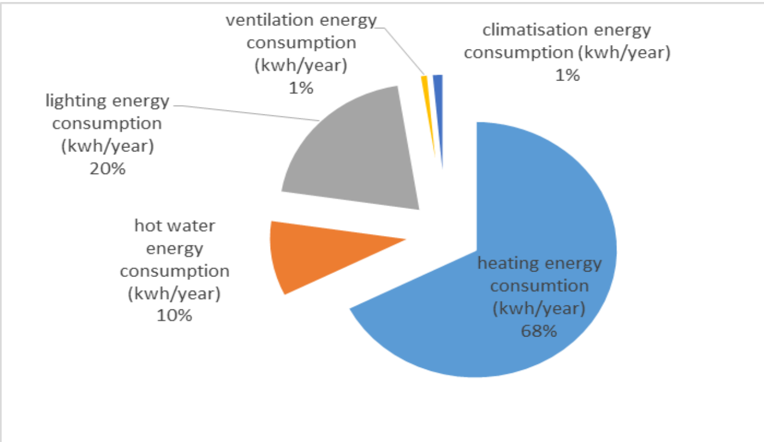

Fig. 3 – Building energy consumption (in percent).

5. Results

In order to determine the amount of primary energy consumed for the analysed building, the conversion factors of final energy into primary energy were used, corresponding to each type of fuel or energy source (Table 3) using the values from MC001-2022.

According to the same methodology, the computational formula for determining the primary energy is:

$$E_p = Q_{f,h,i} \cdot f_{h,i} + Q_{f,v,i} \cdot f_{v,i} + Q_{f,c,i} \cdot f_{c,i} + Q_{f,w,i} \cdot f_{w,i} + Q_{f,l,i} \cdot f_{l,i} \quad (2)$$

where:
E_p – the primary energy consumption using i type source of energy (kWh/year);
$Q_{f,h,i}$, $Q_{f,v,i}$, $Q_{f,c,i}$, $Q_{f,w,i}$, $Q_{f,l,i}$ – the final energy consumption for each type of consumer (heating, ventilation, conditioning, hot water, lighting);
$f_{h,i}$, $f_{v,i}$, $f_{c,i}$, $f_{w,i}$, $f_{l,i}$ – the conversion factors into primary energy, in accordance to Table 3.

Table. 3
Conversion factors from final energy into primary energy

Energy source	Primary energy conversion factor (f_{Ptot})
Natural gas	1.17
Biomass (wood pellets)	1.08
Thermal energy produced with solar panels	1
Thermal energy of the environment (air, soil, etc.) for heating and cooling	1
Electric energy consumed from NES (for lighting, heat pumps, chillers, etc.)	2.5
Electric energy produced with PV panels and consumed directly by the building	1
Electric energy produced with PV panels and exported in the NES	2.5

To determine the equivalent amount of CO_2 emissions associated with the use of the building, CO_2 emission factors have been used, corresponding to each type of fuel or energy source presented in Table 4 (MC001-2022).

The equivalent CO_2 emissions are determined according to the same methodology using the following relation:

$$E_{CO_2} = \sum_i (E_{p,i} \times f_{CO_2}) + \sum_j (CR_j \times RP_j \times f_{ref,CO_2,j}) - \sum_i (E_{ex,i} \times f_{CO_2,ex,i}) \quad (3)$$

where:
E_{CO2} – the equivalent amount of CO_2 emissions associated with the use of the building, using each source of energy (kg CO_2/year);
f_{CO2} – the conversion factor into equivalent CO2 emissions, in accordance to Table 4;
CR_j – refrigerant charging capacity of the cooling equipment, in kg;
RP – annual refrigerant loss rate, in %;
$f_{ref,CO_2,j}$ – the conversion factor equivalent CO_2 emissions, in kg CO_2/kg of lost refrigerant;
$E_{ex,i}$ – primary energy associated to the final energy produced by the building and exported, (kWh/year);

$f_{CO_2,ex,i}$ – the conversion factor of the exported primary energy into equivalent CO_2 emissions, (kg CO_2/kg).

Table. 4

Conversion factors from primary energy into equivalent CO_2 emissions

Energy source	Conversion factor (f_{CO_2}) (kg CO_2/kWh)
Natural gas	0.202
Biomass (wood pellets)	0.039
Electric energy consumed from NES	0.107
Solar energy	0.000
Energy from the environment (air, soil, etc.)	0.000

Taking into account the fact that no energy is exported in the system, for the three scenarios presented in the previous section, using the final energy consumptions, the corresponding values for primary energy and equivalent CO_2 emissions were determined (Table 5 - 7).

Table. 5

Energy performance indicators in the 1st scenario

Energy consumption breakdown	Primary energy (kWh/year)	Specific primary energy (kWh/m2year)	CO_2 equivalent emissions (kg CO_2/year)	CO_2 equivalent emissions (kg CO_2/m^{2}year)
Heating	219014.506	66.540	44240.930	13.441
Hot water	19163.742	5.822	3871.076	1.176
Lighting	125513.685	38.133	6736.994	2.047
Ventilation	7541.1	2.291	806.898	0.245
Conditioning	10606.238	3.222	1134.867	0.345
TOTAL	381839.270	116.009	56790.765	17.254

Table. 6

Energy performance indicators in the 2nd scenario

Energy consumption breakdown	Primary energy (kWh/year)	Specific primary energy (kWh/m2year)	CO_2 equivalent emissions (kg CO_2/year)	CO_2 equivalent emissions (kg CO_2/m^{2}year)
Heating	234994.228	71.395	11338.655	3.445
Hot water	31208.048	9.481	3871.076	1.176
Lighting	125513.685	38.133	6736.994	2.047
Ventilation	7541.1	2.291	806.898	0.245
Conditioning	8467.958	2.573	596.691	0.181
TOTAL	407725.019	123.873	23350.314	7.094

Table. 7
Energy performance indicators in the 3rd scenario

Energy consumption breakdown	Primary energy (kWh/year)	Specific primary energy (kWh/m2year)	CO_2 equivalent emissions (kg CO_2/year)	CO_2 equivalent emissions (kg CO_2/m^2year)
Heating	211398.660	64.226	8579.278	2.606
Hot water	31549.459	9.585	1332.429	0.405
Lighting	125513.685	38.133	6736.994	2.0469
Ventilation	7541.1	2.291	806.898	0.245
Conditioning	10606.238	3.222	1134.867	0.345
TOTAL	386609.142	117.458	18590.466	5.648

6. Conclusions

The proposed scenarios showed different results for the analyzed indicators. In terms of specific primary energy, the 1st scenario (using natural gas for heating) is the most advantageous one, but in the same time is the most disadvantageous in terms of equivalent CO_2 emissions. The most balanced values are obtained for the 3rd senario (using biomass for heating), as can be seen in Fig. 4 - 5.

By comparing the obtained values for the analysed scenarios it can be stated that while the analysed building has fullfilled the previous NZEB – Horizon 2020 indicators, according to the new regulations from 2023 only deep renovation criteria can be achieved.

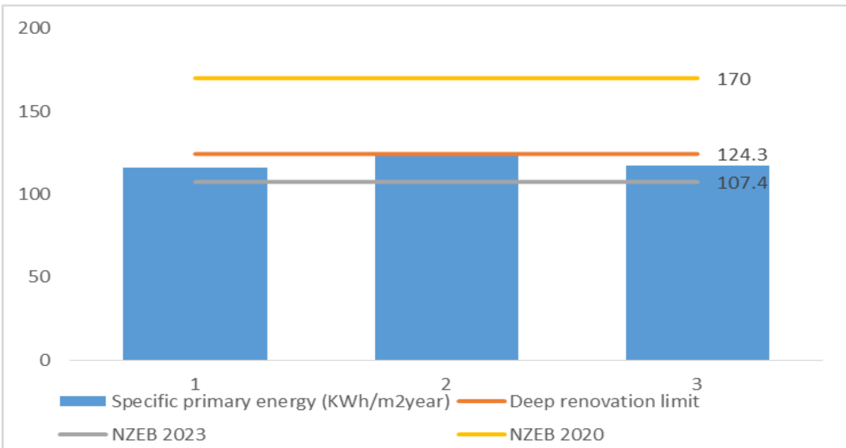

Fig. 4 – Specific primary energy for the analysed scenarios (kWh/m^{2}year).

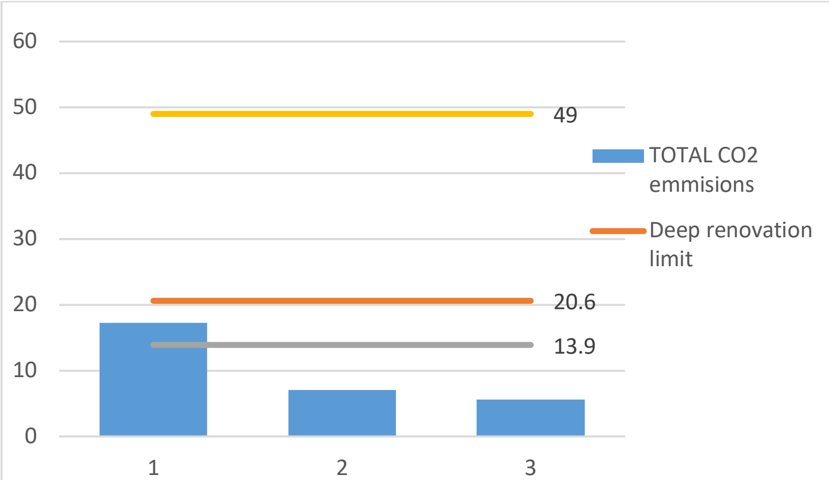

Fig. 5 – Equivalent CO_2 emissions for the analysed scenarios (kg CO_2/m^2 year).

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STUDIU COMPARATIV ÎN VEDEREA ASIGURĂRII PERFORMANȚEI ENERGETICE A UNEI CLĂDIRI EXISTENTE

Noile modificări legislative în domeniul eficientizării energetice a clădirilor fac necesară adoptarea unor soluții performante în ceea ce privește atât anvelopa clădirii cât și sistemul tehnic al acesteia. În timp ce rata de construire în sectorul nerezidenţial a fost relativ ridicată în decursul ultimului deceniu, au fost realizate totodată şi lucrări de reabilitare ale clădirilor existente, ce au presupus atât extinderi şi măsuri de eficientizare

energetică a acestora, existând disponibile diferite surse de finanțare ce sprijină realizarea lucrărilor ce generează economii de energie. Pentru creșterea eficienței energetice a clădirilor sunt necesare atât lucrări de reabilitare termică a anvelopei, cât și îmbunătățirea eficienței sistemului tehnic. Lucrările de reabilitare termică vor duce la creșterea rezistenței termice a elementelor de închidere, vor reduce pierderile de căldură, vor limita punțile termice și infiltrațiile de aer. În prezenta lucrarea se prezintă analiza propunerii de reabilitare termo-energetică pentru o clădire nerezidențială, situată în zona climatică IV a României, la care s-a optat pentru o extindere consistentă pentru a putea acomoda un număr mai mare de ocupanți și pentru a respecta toate cerințele esențiale de calitate. Astfel, s-au avut în vedere mai multe scenarii, ce au integrat utilizarea surselor regenerabile de energie, pentru care a fost analizată respectarea indicatorilor de performanță impuși de noua legislație în domeniu. Simulările numerice s-au realizat utilizând un soft de calcul specializat, iar rezultatele obținute au urmărit limitarea consumului de energie primară și a emisiilor echivalente de CO_2.