Design and energy consumption assessment for a modular hospital in Romania

Ioan Silviu Doboşi [a], *Cristina* Marincu [b], *Silviana* Brata [c], *Stefan* Dună [d], *Nicoleta* Kaba [e], *Ioan* Bistran [f]

[a] Romanian Association for Building Services Engineers – Banat Branch, Timisoara, Romania and S.C. DOSETIMPEX S.R.L., Timisoara, Romania, ioansilviu@dosetimpex.ro.

[b] Department of Civil Engineering and Building Services, Politehnica University Timisoara, Timisoara, Romania, cristina.marincu@upt.ro.

[c] Department of Civil Engineering and Building Services, Politehnica University Timisoara, Timisoara, Romania, silviana.brata@upt.ro.

[d] Romanian Association for Building Services Engineers – Banat Branch, Timisoara, Romania and S.C. DOSETIMPEX S.R.L., Timisoara, Romania, stefan@dosetimpex.ro.

[e] Department of Civil Engineering and Building Services, Politehnica University Timisoara, Timisoara, Romania.

[f] S.C. DOSETIMPEX S.R.L., Timisoara, Romania, ioan.bistran@gmail.com.

Abstract. The European Commission has set the goal of making Europe CO_2-neutral by 2050, which requires decarbonising the building sector. Clear steps in this direction were made with the 2010 Energy Performance of Buildings Directive (EPBD), when the concept of nearly zero-energy building (NZEB) was introduced. Currently, NZEB is a mandatory requirement for all new building in the European Union. In Romania, the authorities have established maximum values of total primary energy consumption for NZEB's, out of which at least 30% must be covered form renewable energy sources. Achieving these requirements can be a great challenge, especially in certain building categories such as hospitals. This paper presents a study regarding the NZEB design and the energy performance assessment of a hospital building in Romania. The building in discussion is an infectious diseases hospital, whose aim is supporting potential sanitary system crisis generated by situations such as COVID-19 pandemic. The energy conservation design aimed the minimization of energy need through high thermal insulation, energy efficient windows, ventilation with heat recovery and LED lighting. Also, a renewable energy system consisting in PV panels was proposed. The energy consumption and on-site energy production was assessed by means of monthly method. The aim is to verify if the proposed design solutions assure the achievement of the NZEB standard as it is defined in Romania.

Keywords. Healthcare building, energy assessment, nearly zero-energy building, renewable energy.
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1. Introduction

In the last decade, the European Union is strongly focusing on the nearly zero energy building target, as a response to the climate problems generated by the high energy consumption in the building sector. In accordance with the Energy Performance of Buildings Directive, as of 2021, all new buildings in the European Union must be nearly zero-energy buildings (NZEB) [1]. Moreover, Member States must establish strong measures in the building sector to support the transition to a climate-neutral society by 2050. Although the NZEB concept was introduced more than a decade ago, the design, execution and operation of these buildings are still under debate, particularly in case of certain categories of buildings that require special operation conditions, such as hospitals. Following the EPBD requirements, in Romania, 'NZEB' is defined as a building with a very high energy performance, where the energy consumption to provide energy performance is almost zero or very low and is covered at least 30 % with energy from renewable sources, including energy from renewable sources produced on site or nearby [2]. NZEB specific requirements are determined by building category and climate zone in terms of maximum values for specific primary energy consumption and for specific emissions of CO_2. However, at this moment, the document that establishes the values of primary energy and CO_2 emissions is still not in force, although values and limitations were proposed. The COVID-19 pandemic and associated global crisis has brought into deeper attention the hospital buildings and their fundamental importance in the society. Hospital buildings are unique in terms of energy use as they require energy continuously throughout the year, with energy demand varying greatly depending on the functionality of each area. Medical procedures, laundry rooms, kitchen equipment, sterilization room equipment, laboratory tests, air conditioning, ventilation, and heating are all sources of energy consumption and implicit greenhouse gas emissions in hospitals. The ones connected to air conditioning, ventilation, and heating have the most potential to be improved in terms of energy efficiency among these consumption categories. In the EU, hospital buildings represent 7% of the non-residential building stock and are responsible for 10% of the total energy use in the non-residential building sector [3]. In Romania, the energy consumption in the healthcare sector represents approximately 4% of the total final energy consumption in buildings, while hospitals occupy 1% of the total national building stock [4]. In a study by Merlevede [5] on the energy in the European healthcare the following conclusions on the total energy consumption are presented: 41% to 87.5 % from the total energy consumption is related to heating, 2% to 17% corresponds to cooling and 15% to 40% is occupied by electricity for lighting and equipment. The variation between the minimum and maximum percentages are attributable to the geographical and economic variables, as well as the building's age, composition, and type of systems. Meeting the energy performance requirements in hospitals is a higher challenge than in other categories of buildings. The design and construction of hospital buildings is a complex activity for all specialists involved, especially when energy performance is one of the objectives. The interest in increasing the energy efficiency of hospital buildings has gradually increased throughout time and in the last years and several studies and documents on this topic were developed by researchers or public organizations [6-17]. This paper discusses the energy design and energy performance assessment of a new hospital building for infectious diseases, in the context of mandatory NZEB requirements and sanitary crisis generated by the COVID-19 pandemic. The energy design of the building aims at achieving a low energy consumption and use of renewable energy, while assuring the functionality and indoor environment specific to an infectious disease hospital. The energy assessment aims at verifying if the design of the building leads to a reduced total primary energy consumption and at least 30% share of renewable energy.

2. Methodology

2.1 The case study building

The object of this study is an infectious diseases healthcare facility. More specifically, it consists in the design of a modular hospital to increase the management capacity of the COVID-19 health crisis. Since the sanitary crisis overlaps with the enter in force of the NZEB mandatory requirements for all new buildings, designing this building became a greater challenge for all the involved specialists. The proposed construction is made of two buildings (from a constructive and dimensional point of view), located at 4.00 m from each other and connected by a secondary building, as seen in the situation plan in Fig.1.

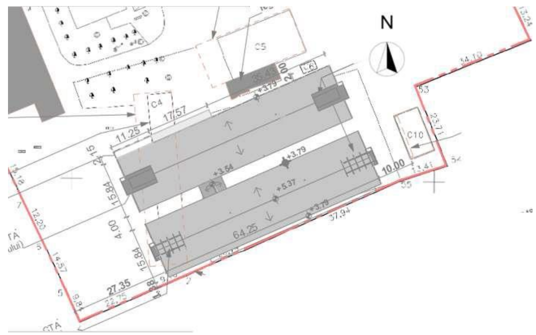

Fig. 1 – Situation plan

From a functional point of view, one part of the building will accommodate the reception area - hospitalizations with the area of investigations and adjacent sterilization and the intensive care unit for severely ill patients and the other part of the building will accommodate the infectious diseases ward for patients with mild or moderate forms, including spaces for medical staff. The whole building has a heated floor area of approximately 1950 m^2 and capacity of approximately 60 beds. Because the investor wants the hospital to be in use quickly, it was decided to have a modular construction system, with a fast execution that would allow the immediate operation of both sections of infectious diseases, in the context of the current pandemic. If necessary, the proposed superstructure can be dismantled and reassembled if the building is to be relocated in the future. Thus, the construction will be made on the structure of modular, repetitive steel frames, with exterior closures and interior partitions from sandwich panels, in compliance with the fire protection conditions of load-bearing and non-load-bearing elements, according to the regulations in force. The floor slab and foundation will be made of reinforced concrete. The enclosure of the modular hospital will remain on exposed sandwich panels. The roof is a smooth-sloping roof-type made of sandwich panels with mineral wool insulation. The design of the HVAC system was performed to comply with the admissible air purity limits required for the hospital spaces according to the Romanian norms, as well as for providing comfort conditions for accommodating patients and conducting hospital activities [17].

2.2 Energy design and assessment

The strategy of energy efficiency design in the case of the case study building consisted in minimization of energy requirements and the implementation of an alternative system for the energy supply from renewable sources. The energy consumption assessment of the building was performed using the software Doset-PEC, which is a calculation tool available on the Romanian market for the energy certification of buildings. The software performs monthly calculations and is based on the Romanian methodology for calculating the energy performance of buildings [20], [21]. Doset-PEC software tool calculates single-zone energy consumption for heating, cooling, mechanical ventilation, domestic hot water and lighting. When calculating the energy performance of the building, the following aspects were considered: the climatic zone and the orientation of the building, geometry and volume of the building, the composition of the construction elements of the building envelope, number of outdoor air exchanges (infiltration and mechanical ventilation), indoor climate conditions, characteristics of installation systems for heating, air conditioning, mechanical ventilation, and lighting.

To have as minimum as possible heating and cooling energy needs, the envelope elements of the building have low corrected U'-values, below the maximum corrected U-values for non-residential NZEB in Romania (Table 1). The values for U'_{max} are used just as reference values as this moment since the normative that proposes these values is still not in force. In terms of volumetry, the two constructions that compose the hospital have a rectangular shape, with vertical and horizontal geometrical regularity and has just a single level.

Tab. 1 – Thermal transfer resistances.

Envelope element	U' [m^2K/W]	U'_{max} [m^2K/W]	Area [m^2]
Exterior walls	0.20	0.34	1181.9
Windows	0.90	1.11	268.3
Roof	0.16	0.17	2080.2
Ground floor	0.19	0.20	2050

To reduce the losses through mechanical ventilation, the AHUs are equipped with heat recovery units with an efficiency of approximately 70%. Thus, the ventilation of the entire hospital is achieved with the help of 4 air handling units (AHU). The AHUs were dimensioned to ensure that the necessary number of air exchanges were achieved in the rooms connected to each AHU (Table 2).

Tab. 2 – Air handling units serving the whole building

Air handling unit	Served space	Supply/exhaust air flow [m^3/h]]
AHU1	Intensive care	7971/8483
AHU2	Patient's access	5184/5729
AHU3	Patient rooms	7265/8007
AHU4	Medical staff access	4315/4729

The number of air changes vary between 3 h^{-1} and 10 h^{-1}. The AHU's have the following characteristics: intermediate fluid heat recovery units, heating/cooling coils, inlet and outlet fans, filters upstream of the air handling unit and after the air intake fan, control for maintaining constant inlet air flow rates regardless of operating conditions, adjusting device to maintain levels of depression in rooms with a lower degree of asepsis than spaces with a higher degree of asepsis. The supply of thermal energy is made from an existing gas central heating.

Cooling is provided with a 250kW air-cooled chiller with built-in hydraulic module, axial fans with frequency converter and low-noise function at night. The transmission of heating and cooling in all rooms is proposed to be made up of the following systems: radiators 95 kW (panel type radiators in hygienic construction), fan coils for heating - 74 kW, AHU heating coils - 291 kW, cooling beams - 52 kW, fan coils for cooling - 52 kW, AHU cooling coils - 177 kW.

The interior air temperature was defined as an average for the whole building, considering the interior air temperature required in each type of space and the corresponding surface area. This simplification is necessary because the used calculation tool does not allow the definition of multiple thermal zones for the building simulation. The interior temperature differs depending on the room destination and were defined in accordance with the Romanian standards. Thus, the interior air temperatures for heating varies between 18°C and 24°C and the average value used in calculation is 21.2°C. The cooling temperature was set to 26°C.

The input data for domestic hot water calculations consisted in the number of use units (60 beds) and the daily specific needs per unit (56 l/unit/day). Lighting energy consumption was assessed considering an installed power of 7 W/m^2. The energy assessment was conducted using the standard weather for the location of the building.

As a renewable energy source, it is proposed to implement of an ON-GRID photovoltaic panel system on the roof of the building. The available surface on the roof allows the installation of 400 photovoltaic panels with 310 W power each. The system has 4 invertors of 25 kW each. The assessment of the PV energy production was performed using the freely available online platform [18]. This platform provides information about solar radiation and photovoltaic (PV) system performance for any location in Europe.

3. Results and discussion

3.1. Final energy consumption and on-site renewable energy production

Table 3 shows the final energy consumption broken down on energy type and category of consumption, The highest natural gas consumption is associated to heating while the highest electricity consumption is related to the mechanical ventilation system. The results were compared with other studies conducted at European level [20]. Similar values were obtained for heating and cooling, while significant differences were identified for lighting and ventilation energy consumption.

Tab. 3 – Final energy consumption

Category		Final energy [kWh/(m²year)]
Natural gas		
Space heating		51,12
Domestic hot water		38,36
	Total	89,48
Electricity		
Cooling		8,40
Mechanical ventilation		44,12
Lighting		15,75
	Total	68,27

Fig. 2 shows the monthly energy consumption against monthly electricity produced on-site from PV panels. It is noticeable that from April until August, the PV production is higher than the electrical energy consumption.

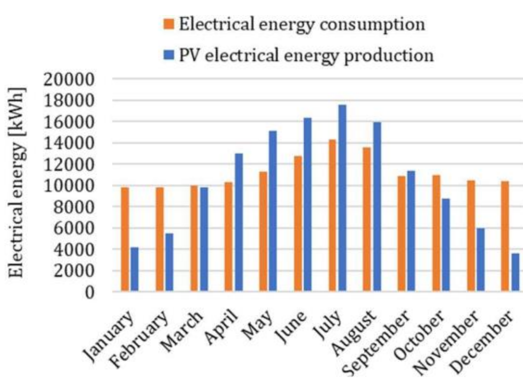

Fig. 2 – Total monthly electricity consumption and on-site PV production

The proposed photovoltaic system is connected to the national electricity grid, without any storage system. This means that in the absence of solar radiation (during the night) and during winter, when the PV production is lower, a major part of the needed energy will be imported from the national grid. Also, in the instances of time when the energy production is higher than what is consumed, the excess energy that is produced is exported to the grid. This means that only a part of the energy produced will be consumed directly on site. To assess the energy balance between imported and exported energy as accurately as possible, hourly energy simulations are the best solutions. However, since this design stage is just a preliminary one, the energy balance was performed considering that the monthly PV electricity production is primarily consumed directly on-site. From the total monthly PV energy production, the remaining difference after covering the building needs is delivered to the grid. The monthly electricity balance is presented in Fig. 3. In this hypothesis, we can see that from April until August, the electrical energy need of the building is covered entirely from PV production, while a lower remaining quantity of PV electricity is exported to the grid. From October until March, the PV panels cover only partially the electricity needs of the building, the rest being taken from the grid.

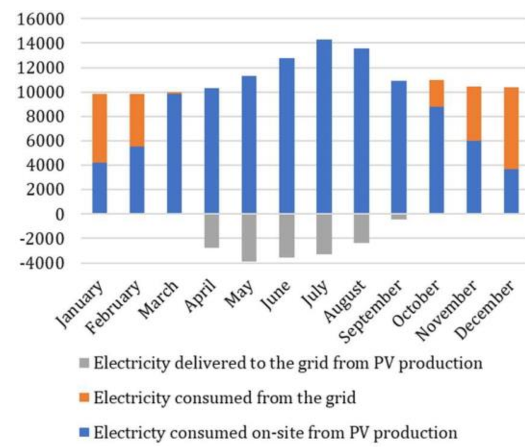

Fig. 3 – Monthly electrical energy balance

3.2 Total primary energy consumption and renewable energy share

The conversion to primary energy was made considering the Romanian conversion factors for each type of energy presented in Tab.3. The values of the primary energy for each energy source are obtained by multiplying the final energy with the corresponding conversion factor. The determination of equivalent CO_2 emissions is made based on primary energy consumption and the factors of conversion of primary energy into CO_2 emissions, depending on the type of energy source (Tab.3). The results of the conversion of final energy into primary energy as well as CO_2 emissions are presented in Table 4.

Tab. 3 – Primary energy conversion factors.

Energy source	Primary energy factor		CO_2 factor
	Non-renewable	Renewable	
Natural gas	1,17	0,00	0,205
Electricity from grid	2,00	0,50	0,299
PV electricity used on-site	0,00	1,00	0,00
PV electricity exported	2,00	0,50	0,00

When calculating the total primary energy, it is considered that the exported energy compensates the imported energy. Also, the on-site renewable energy production and use is weighted with renewable energy conversion factor 1 and non-renewable factor 0. The primary energy from non-renewable sources is calculated as the difference between the primary energy corresponding to the energy imported from the grid (natural gas and electricity) and the primary energy corresponding to the energy exported to the grid, both accounted with conversion factor 2.5. Thus, the energy exported to the grid is accounted in the energy performance of the building.

Tab. 4 – Primary energy values and CO_2 equivalent.

Category	Primary energy [kWh/(m^{2}year)]	
	Renewable	Non-renewable
Natural gas	-	104.69
Electricity consumed on-site from PV panels	57.03	-
Electrical energy consumed from the grid	5.63	22.50
PV electricity exported to the grid	4.20	16.79
Non-renewable primary energy [kWh/m^{2}year]	106.20	
Renewable primary energy [kWh/m^{2}year]	62.65	
Total primary energy (renewable and non-renewable) [kWh/m^{2}year]	168.84	
Renewable energy share from total primary energy	≈37%	
Total CO_2 equivalent	23.17 kg CO_2/(m^{2}year)	

4. Conclusions and future developments

The advantage of the presented solutions for this investment object, compared to other alternative systems, is that it fits very well with the concept of modular hospital, the photovoltaic panels can be easily relocated and reused when necessary. The total primary energy requirement of the analysed building is approximately 168.84 kWh/ m^2/year, out of which 37% represent renewable energy resulting from the proposed system of photovoltaic panels. The estimated annual CO_2 emissions are about 23.17 kg CO_2/(m^{2}year). This is in accordance with the legal provisions in force which stipulate that the total primary energy must be covered by at least 30% renewable energy for NZEB's in Romania. To be considered a NZEB hospital, the total primary energy consumption and CO_2 emissions should be below the values provided by the Romanian authorities for buildings in the healthcare sector. However, when this study was performed (February 2021), these values were not yet officially launched by the Romanian authorities. Nevertheless, to draw some conclusions, the temporarily available values, from documents that were in work at that moment, were used as reference. Thus, for NZEB building in the healthcare sector, located in Romania in climate zone I (where the investigated building is located), the proposed reference value for maximum total primary energy that was used for comparison is 179 kWh/m^2/year, while the reference value for CO_2 emissions was 37 kgCO_2/m^2 /year. Both values are higher than the ones obtained for the case study building. Thus, for the existing conditions when the study was performed, the proposed solutions for the case study building were enough to consider the case study building a NZEB hospital. However, throughout the year of 2021, the new Methodology for Calculating the Energy Performance of Buildings, referred to as MC001 is still work in progress, and some of the reviews might result in changes of the reference primary energy values and CO_2 emissions for building in the healthcare systems. Thus, in order to achieve the NZEB standard for the case study building, compared with the final reference values, supplementary energy conservation measures might be necessary. A primary measure could be reducing even more the heat losses through the building envelope by increasing thermal insulation. Moreover, the implementation of a heating system with renewable energy source such as ground-air heat pump might be a solution to be considered in order to limit the total primary energy consumption of the building.

Healthcare buildings are the most complex buildings in the non-residential sector, in terms of HVAC and operation conditions. Moreover, a variety and types of buildings exist within the healthcare category, starting with general hospitals, infectious diseases hospitals, clinics etc. Each type of healthcare building has specific operation requirements, which can result in very different energy needs from one type of healthcare building to another. Thus, for hospitals that require continuous functioning throughout the day, week and year, hospitals with intensive care units, emergency units, surgery room, the required energy will always be significantly higher than for a dental clinic for example. Therefore, when defining the NZEB limitations for buildings in the healthcare sector, different conditions should be provided depending on the category and type of healthcare buildings. This recommendation is in line with other existing studies [19], which recommend the increase of building types for which separate NZEB definitions are provided, as well as create a new subdivision in healthcare facilities.

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