TECHNIUM
Technium Vol. 14, pp.105-108 (2023)
ISSN: 2668-778X
www.techniumscience.com

Traditional House Built at ZEB standard in Rural Area of Romania

Emilia-Cerna Mladin
Department of Mechanical Engineering and Mechatronics
University POLITEHNICA of Bucharest
Bucharest, Romania
emilia.mladin@upb.ro

Madalina-Xenia Calbureanu-Popescu
Department of Applied Mechanics and Civil Engineering
University of Craiova
Craiova, Romania
madalina.calbureanu@gmail.com

Constantin Oprescu
Department of Medical Engineering
University POLITEHNICA of Bucharest
Bucharest, Romania
oprescu111@yahoo.com

Abstract*—*An energy analysis was performed on a house built in a Southern village of Romania. The house has a typical traditional architecture and size for a single-family dwelling and is made of concrete structural frame and adobe bricks, roofed with unheated attic. The zero-emission building (ZEB) performance could be achieved with proper thermal resistances for envelope elements, an air-to-water heat pump for underfloor heating and DHW and solar-panels mounted on the roof. The analysed house is the third of its kind built in the village neighbourhood in the last 10 years, proving its good living quality and cost affordability, as well as the local market demand. The extension of solutions to existing houses is proven feasible.

Keywords*—*ZEB, renewable energy, adobe house, rural development

I. Introduction

The last decades were marked by an increasing promotion of energy performant buildings, the last concept launched by the European Building Performance Directive proposal for recast in December 2021 [1] being the Zero Emission Building (ZEB), as an update for the Nearly Zero Energy Building (nZEB) defined by the same directive in 2010 [2]. A ZEB type of building requires low-to-zero emission and recyclable materials, diminished energy losses and use of renewable energy with the potential to cover all energy uses and maybe even with a surplus to deliver in the local grid as a prosumer. There is a low confidence that such a standard may be easily achieved at reasonable costs and for many buildings. Adobe material has relatively high thermal conductivity [3]. Even a poor insulating material can insulate effectively if it is large enough, which is the case of adobe construction [4,5]. Another advantage of adobe is its sound insulation [6]. Adobe is able to absorb heat during the day keeping the house cool and then release this stored heat at night, warming the interior of the house [7]. This behavior is due to the high specific heat capacity of adobe which is an important factor that allows this material to reduce the thermal gradient of earthen houses [3]. On the other hand, the ability of adobe to conduct heat is highly dependent on its moisture content, with a strong relationship between water content and heat conduction [8]. This paper shows that ZEB level is feasible for new houses with traditional rural materials like adobe but equipped with modern energy sources, as heat pumps and solar panels. The study-case is a single-family house built with adobe bricks on a concrete frame in a rural area of Romanian Southern plains. The energy analysis performed based on the building design and already existing construction revealed the credible potential for a ZEB case when under operation. The results increase trust that ZEB concept is viable, even in rural areas, where affordability for high investment costs is low but local sustainable materials are widely available.

II. Study-case description

The house is in the climate zone 2 of Romania, as shown in figure 1, defined by a statistical minimum temperature of -15ºC. This zone extends over large areas of the country, with many villages and potential for a local manufacture of adobe bricks. The house architecture is a simple, traditional one, with a living room and 3 bedrooms that sum 56 sqm out of a total of 84.

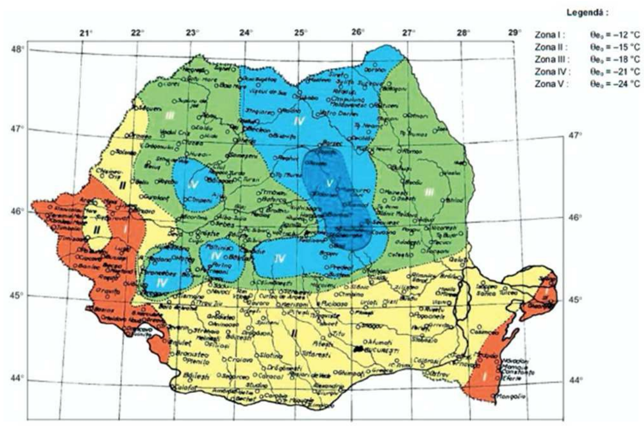

Fig. 1. Climatic zones of Romania

sqm ground floor, to accommodate a family with two children. The house is topped with an unheated attic and a roofing of bituminous shingles. The Southern façade drawing, showing the main entrance, is presented in figure 2. Details of envelope components are illustrated in the pictures of figures 3 and 4.

The adobe bricks are 45 cm thick and have an average thermal conductivity of about 0,35 W/mK. The concrete pillars are covered with adobe bricks 25 cm thick. The slab on ground is

TECHNIUM
Technium Vol. 14, pp.105-108 (2023)
ISSN: 2668-778X
www.techniumscience.com

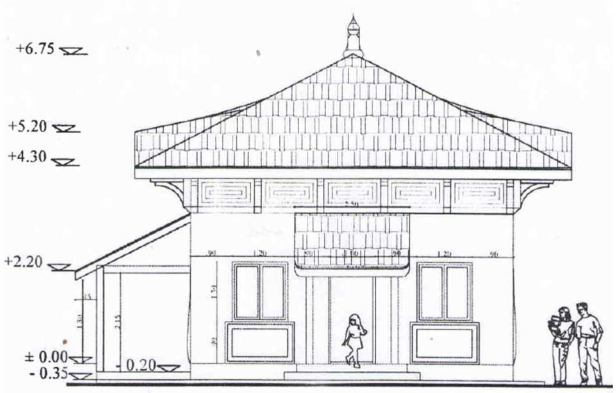

Fig. 2. Buiding Southern façade

made of 15 cm reinforced concrete thermally insulated underneath with 10 cm extruded polystyrene. The attic slab is insulated with 10 cm expanded polystyrene. Windows and external doors are triple glazed and with low-e coatings to preserve indoor heat. The internal and external finishings are made with plaster and washable paintings. The thermal resistances of the envelope elements, all corrected for thermal bridge effects, are presented in table 1:

TABLE I. THERMAL RESISTANCES OF ENVELOPE COMPONENTS

Envelope components	***Area***	***Thermal resistance***
	m^2	***m^2K/W***
Exterior walls	77,83	1,504
Windows	19,00	1,111
Upper slab toward attic	97,13	2,595
Slab on ground	97,13	4,420

A few details of the house while built are illustrated in figures 3 and 4.

Fig. 3. External and internal walls made of adobe

Fig. 4. The unheated attic walls filled with straws, previously treated for fire safety

The heating is provided by an air-to-water heat pump of 12 kW and SCOP = 4,7 through underfloor piping, as illustrated in figure 5. The pump provides also heat for the DHW (domestic hot water) in a storage tank, where solar thermal panels may also contribute by a separate piping circuit. During summer very hot days, when night natural ventilation is not sufficiently efficient for building cooling, the pump extracts indoor thermal energy while working in the reverse mode with SEER=4,1. The fresh air is provided through opened windows, as needed, especially that the rural environment is not polluted. LED technology is used to provide artificial lighting. The electricity is supplied from the community grid but may be supplemented by PV panels mounted on the house roof.

Fig. 5. Windows, doors and underfloor piping

III. BUILDING ENERGY ANALYSIS

A. *Numerical Simulation Methodology*

The energy analysis has been performed using the regulated national methodology for energy performance certification of buildings, known as Mc001-2007 [9]. This methodology has been derived from European standards and considers local statistical monthly climate data and normal indoor conditions when assessing heating or cooling needs for each yearly month "m", according to (1) and (2).

$$Q_{H,nd,m} = Q_{H,ht,m} - \eta^{win} \cdot Q_{g,m} + Q_h \text{ [W/mo]} \quad (1)$$

$$Q_{C,nd,m} = Q_{g,m} - \eta^{sum} \cdot Q_{C,ht,m} - Q_{nv} + Q_{deh} \text{ [W/mo]} \quad (2)$$

where

$Q_{H/C,nd,m}$ – heating/cooling needs

$Q_{H/C,ht,m}$ – heat transfer through the envelope by transmission and ventilation during heating/cooling

$\eta^{win/sum}$ – recovery factor of gains/losses during winter/summer

$Q_{g,m}$ – incidental heat gains, solar and internal

$Q_{h/deh}$ – heat associated with humidification or dehumidification of indoor air

Q_{nv} – heat removed by natural ventilation

The actual electricity consumption from the grid is derived by dividing the above terms by heat pump SCOP for heating/DHW and by SEER for cooling, and then subtracting potential energy production with locally mounted PV panels [10].

The electricity used for lighting depends on the lamp installed power and time of use. It is important to mention that the national regulation allows a building owner to act as a prosumer on the market, based on a compensation algorithm between its own equipment and the nearby grid [11]. The natural ventilation is not associated with energy use for itself but creates additional need for heating/cooling when replacing polluted indoor air with fresh (less polluted) outdoor air.[9]

B. *Numerical Simulation Results*

The numerical results are succinctly presented in table II below when no solar panels are installed, and all final energy use is of electrical type.

TABLE II. HOUSE ENERGY AND EMISSION INDICATORS FOR 2022

Utility	*Final energy*	*Non-renewable primary energy*	*Renewable primary energy*	*Emissions*
	kWh/yr	***kWh/yr***	***kWh/yr***	***kgCO₂/yr***
Heating	1278	3349	4718	382
DHW	990	2593	3652	296
Lighting	285	746	0	85
Cooling	146	382	0	44
TOTAL	**2698**	7070	8369	807
	kWh/m²yr	***kWh/ m²yr***	***kWh/ m²yr***	***kgCO₂/ m²yr***
TOTAL	**32,22**	**84,41**	**99,93**	**9,63**

The outdoor air renewable energy used by the heat pump in heating mode is 8369 kWh/yr or 99,93 kWh/m^{2}yr. Under these operational conditions, the house may be labelled as **nZEB**, according to the Romanian definition of this concept up to February 2023 [12, 13]: 30% of total primary energy to be locally available renewable, non-renewable primary energy below 111 kWh/m^{2}yr, and emissions below 30 kg/m^{2}yr.

In January 2023, a recast of the national methodology [14] modified the criteria for nZEB concept, and, for single-family houses in the 2nd climate zone, they are total primary energy at most 127,9 kWh/m^{2}yr and emissions below16,0 kg/ m^{2}yr. Moreover, the renewable energy from the national/local grid is also considered when checking the 30% contribution of renewable energy in the total primary energy. With the new methodology, the energy and emission indicators become those in table III.

TABLE III. HOUSE ENERGY AND EMISSION INDICATORS FOR 2023

Utility	*Final energy*	*Non-renewable primary energy*	*Renewable primary energy*	*Emissions*
	kWh/yr	***kWh/yr***	***kWh/yr***	***kgCO₂/yr***
Heating	1278	2557	5357	342
DHW	990	1979	4146	265
Lighting	285	569	285	76
Cooling	146	291	146	39
TOTAL	**2698**	**5397**	**9933**	**722**
	kWh/m²yr	***kWh/ m²yr***	***kWh/ m²yr***	***kgCO₂/ m²yr***
TOTAL	**32,22**	**64,44**	**118,61**	**8,62**

Under the new criteria, the house does **no longer comply with nZEB** requirement regarding the total primary energy which is (non-renewable and renewable) 183,05 kWh/m^{2}yr and the upper limit is 127,9 kWh/m^{2}yr.

Different scenarios may be now considered to improve the energy performance of this house. The easiest to be implemented are based on PV panels mounted on the Southern side of the roof. A panel type is chosen of size 2256 x 1133 x 35 mm (2.55 m^2) with 144 half cut monocristaline PV cells having the nominal electrical power of 540 W_{el} /panel and producing about 680 kWh/yr electrical energy under the local climatic conditions. Then two scenarios are analysed: 4 PV panels and 8 PV panels installed.

The energy simulation leads to the values and indicators presented for 2023 specifications and requirements [14] in figure 6 in kWh/yr and in table IV in kWh/m^{2}yr.

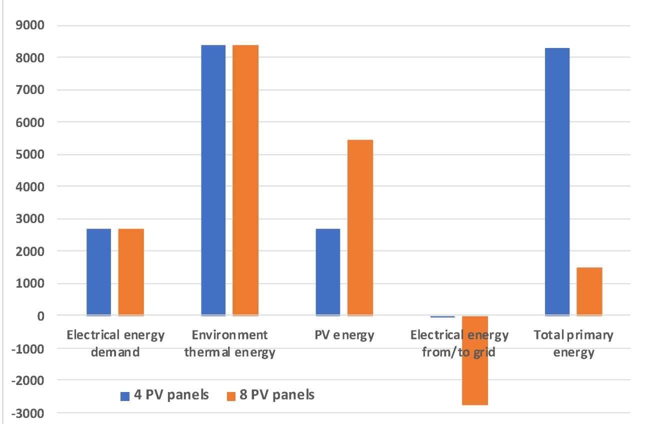

Fig. 6. Energy and Emission analysis for House with PV panels and 2023 Methodology

The compliance with the nZEB and ZEB requirements is clear from the values in Table IV.

TABLE IV. ENERGY AND EMISSION ANALYSIS FOR HOUSE WITH PV PANELS AND 2023 METHODOLOGY

	Electrical energy demand	*Renewable thermal energy*	*PV energy*	*Electrical energy from/to grid*	*Total primary energy*
	kWh/m²yr	***kWh/m²yr***	***kWh/m²yr***	***kWh/m²yr***	***kWh/m²yr***
4 PVs	32,22	99,93	32,48	-0,26	99,28
8 PVs	32,22	99,93	64,96	-32,74	18,09

In both scenarios, total primary energy is less than 127,9 kWh/m^{2}yr, renewable energy is well above 30% from the total primary energy and emissions associated with utility use of energy have zero values, since there is energy exported to the grid. The house may be then labelled as **nZEB and ZEB**. Moreover, it appears that extra electrical energy may be produced and used for other needs in the house or even supplied to neighbouring buildings, covering thus another recent concept, that of energy community.

Given the plane location of the house, solar thermal panels may also be installed on the roof with or without a combination with PV panels. It is proven now that achieving a ZEB level is not impossible, not event very expensive in the nowadays energy crisis.

IV. EXTENSION OF RES TECHNOLOGY TO EXISTING HOUSES

The solutions that ensured these high energy performances are available on the market and are more and more affordable as energy prices go up and RES technology becomes cheaper with increasing global competition. In Romania, there are about 3.810.737 single family houses in rural areas, which represents 69% of all buildings and are 2,8 times more than single family houses in urban areas [15]. According to the National Institute of Statistics [16], only single-family houses consumed 50% of the nationwide final energy in 2020, a bit more than in other years due to the pandemic when people stayed more home.

Long term renovation strategy [15] does commit to renovation of only 4% of the single-family houses in rural area, avoiding thus a fast and efficient road for emissions reduction and sustainable energy use exactly where the energy poverty is higher and use of wood for heating affects dramatically the national forests.

Renovation of houses in rural area may also include RES technology and become zero emission buildings (ZEB), triggering huge fossil resource savings. The energy savings when changing to RES technology is estimated from considering in the analysed house the traditional wood stoves with an average efficiency of 58%. The final energy would be 18339 kWh/yr (219 kWh/m^2yr) and primary energy would be 19806 kWh/yr (236 kWh/m^2yr), which means 2,8 more primary fossil energy than when heat pump is used. The equivalent CO_2 emissions from burning wood would be less than a half, but it is often forgotten that many polluting particles are emitted by woodfires [17]. The conclusion is that replacing wood stoves or boilers by heat pumps is beneficial for saving fossil resources and polluting less the environment. With increasing wood tariff and decreasing heat pump costs, the affordability becomes significant even in rural areas when it comes to decrease lifetime cost with energy in new as well as existing houses. It is incorrect to estimate a high percentage of ZEB in any country, focusing majorly on urban areas and forgetting villages just because the people density is higher in the former ones.

V. Conclusion

The long-standing tradition of earthen architecture around the world has demonstrated that it is possible to create magnificent, long-lasting buildings with one to many stories. The fact that the raw materials for adobe are readily available locally is one of its main benefits. In fact, it may be possible to create adobe from the soil removed from the construction site, which would cut down on energy-intensive processes like transportation. Adobe's low thermal conductivity helps keep indoor temperatures more stable and minimizes heat loss.

Energy analysis was performed to a one floor house with traditional architecture and adobe walls on concrete frame. Utilities are supplied with modern technology: air-to-water heat pump for heating, cooling, and DHW, as well as LED lighting, while fresh air is provided by natural ventilation. Results indicate that with adobe bricks of 45 cm thickness and thermal conductivity of 0,35 W/mK, this basic solution leads to energy performance of nZEB level, while additional PV panels of at least 2,2 kW led to zero emissions from the utility supplies, which is defined as ZEB level. More renewable energy used, the building becomes ”zero-plus”, using the extra energy produced nearby for own needs or it may be even used in neighbouring buildings. It is shown that the existing rural houses may as well benefit from new RES technology to boost the national transition to ZEB level in 2050.

Acknowledgment

The current study and paper were performed with the agreement of the house owners, E. and D. Malureanu, to whom the authors express many thanks.

References

[1] Proposal for a Directive of the European Parliament and of the Council on the Energy Performance of Buildings (recast) https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021PC0802&from=EN
[2] Directive 2010/31/EU of the European Parliament and of the Council, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0031&from=EN
[3] Parra-Saldivar, M.L. and W. Batty, 2006. Thermal behaviour of adobe constructions. Build. Environ., 41: 1892-1904.
[4] Baker, M.B., 1986. Using the earth to save energy: Four underground buildings. Tunnelling Underground Space Technol., 1: 59-65.
[5] Martin, S., F.R. Mazarron and I. Canas, 2010. Study of thermal environment inside rural houses of Napalos (Spain): The advantages of reuse buildings of high thermal inertia. Construct. Build. Mater., 24: 666-676
[6] Binici, H., O. Aksogan, D. Bakbak, H. Kaplan and B. Isik, 2009. Sound insulation of fibre reinforced mud brick walls. Construct. Build. Mater., 23: 1035-1041.
[7] J.D. Revuelta- Acosta, A. Garcia- Diaz, G.M. Soto- Zarazua and E. Rico- Garcia, 2010. Adobe as a Sustainable Material: A Thermal Performance. Journal of Applied Sciences, 10: 2211-2216.
[8] Rees, S.W., Z. Zhou and H.R. Thomas, 2001. The influence of soil moisture content variations on heat losses from earth-contact structures: An initial assessment. Build. Environ., 36: 157-165.
[9] Mc 001 – Ministry Order nr. 157/2007 regarding the Methodology for calculation of energy performance of buildings, Official Monitor nr. 126 bis, 21.02.2007.
[10] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.
[11] Government Ordinance 143/2021 that defines the prosumer and the quantitative compensation of energy produced locally, Official Monitor nr. 1259/31.12.2021.
[12] O. M. 386/2016 for updating the Norms C107 for calculation of thermo-technical properties of building construction elements, Official Monitor nr. 228, 28.03.2016.
[13] Legea 372/2005 updated in 2020, published in Official Monitor 868, 23 September 2020.
[14] Mc 001-2022 – Ministry Order nr. 16/2023 regarding the Methodology for calculation of energy performance of buildings, Official Monitor nr. 46 bis, 17.01.2023.
[15] Govern Decision 1034/27.11.2020 for Long Term National Strategy for Building Renovation, Official Monitor 1247, 17.12.2020.
[16] The World Bank under Agreement with the European Commission on Behalf of the European Union and Energy Balance of Romania, National Institute of Statistics, https://insse.ro/cms/en/content/energy-statistics, october 2022.
[17] American Lung Association, https://www.lung.org/clean-air/at-home/indoor-air-pollutants/residential-wood-burning.