NZEB design principles for affordable single-family housing accounting for regional climatic conditions

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Abstract. The architecture should be specific to a certain place and a certain culture, not only from the standpoint of formal integration in the existing building stock, but also from the perspective of adapting to the regional climatic conditions. Thus, the importance of a “regional” applied concept in the global context regarding NZEB (Nearly Zero Energy Building) design must be emphasized. This paper presents a methodology for evaluation of a NZEB single-family house, taking into account specific climatic characteristics and use of passive design principles for cost optimization. Based on detailed climate data, the most efficient passive measures for the studied region were analyzed. The single-family housing project was evaluated through a BIM (Building Information Modeling) methodology and the result was optimized and compared with National and European standards for NZEB.

1. Introduction

Since the beginning of the 21st century, research in the fields of construction and architecture has focused mainly on energy efficiency and NZEB ( Nearly Zero Energy Building) design. The definition of a Nearly Zero Energy Building, according to EU standards, suggests a building with a very high energy performance, where the energy requirement from conventional sources is very low or almost equal to zero and is mostly covered by energy from renewable sources, including energy that could be produced on-site or nearby the building site.

On this matter, the Romanian Methodology states that in order to ensure the total energy consumption of a Nearly Zero Energy Building, renewable energy sources (non-fossils) should cover at least 30% of the total calculated primary energy of the building. Both in the case of new and existing buildings it is intended that architectural and technical solutions should meet the minimum requirements in terms of costs. Also, energy and environmental parameters must be defined in relation to climatic and technological zonal restrictions [1].

This paper analyzes in terms of NZEB principles a single-family house, a version of a previous design within the Modellus research project (supported by UEFISCDI, Model for a sustainable single-family dwelling integrating architectural concepts and high energy performance systems with minimal environmental impact, PN–III–P2–2.1–BG–2016–0074, Contract 61 BG din 01/10/2016) and subsequently upgraded with renewable energy systems and adapted to climatic conditions for Galați County, Romania.
2. Regional climatic conditions in the context of NZEB design

Energy efficiency in buildings is primarily dependent upon regional climatic conditions and landscape features, a basic knowledge that still needs revaluation, with regard to the following main issues:

- uniformity of Romanian building stock developed in the modernist period that still affects the realm of constructions [2];
- need for optimized, highly efficient but also affordable housing projects in accordance with NZEB principles.

For the latter, simply relying on vernacular understanding of climate and use of local materials and techniques is not enough. In-depth knowledge and climate data driven decisions can bridge the gap from average to high performance energy efficiency design by selecting and optimising the best construction solutions for a specific region. Although there is a large spectrum of both passive and active sustainable design measures that can be implemented, not all have a significant impact on the overall building performance. Therefore, all technical solutions need to be filtered and adapted to micro-climatic and landscape conditions in order to maximise efficiency and avoid affecting the indoor climate comfort, resulting in decreased energy performance over time [3].

2.1. Regional design

“Regionalism is more than a stylistic category. It is an attitude towards design that endeavours to bring about positive change through the introduction of appropriate technologies” [4]. Design strategies that account for regional specificity in terms of climate data and landscape build upon and refine embedded cultural and technological concepts.

Studying and responding to regional conditions by developing and enhancing built forms as part of environmental systems is a strategy for better responding to all sustainable criteria: environmental, social and economic [4].

2.2. Integration of NZEB principles in house design

According to scientific research in the field of NZEB, passive design, along with energy efficient systems and renewable energy systems are the main contributors to an integrated successful NZEB approach, as shown in figure 1 [5].

![Figure 1. NZEB design – PA (Passive approach), EES (Energy efficient systems), RES (Renewable energy systems) [5].](image)
Thus, passive design aims at reducing the total energy demand through efficient envelope configuration. The main objectives are increase of solar heating and heat loss prevention. The energy efficient systems and the renewable energy systems are both used to supplement the passive design strategies in order to minimize the energy consumption.

2.2.1. Orientation accounting for regional climatic conditions. Passive solar design represents a combination of methods for organizing the spaces of a building, for an optimized exploitation of solar radiation input.

When it is possible to choose the construction site, the favorable South orientation (Northern hemisphere) must be fully exploited (9:00 AM – 15:00 PM, 10:00 AM – 14:00 PM, the time interval depending on the region). In cold climates, the seasons when the house needs to be heated (optimal intake of solar radiation) are late autumn, winter and early spring, while in warmer climates, the heating season can last only a month. Also, orientation of a house’s East-West axis with more than 10 degrees from the South direction can lead to excessive heating during summer (especially in hot climates). Therefore, for an increased solar intake, the solar maps for each region must always be consulted.

2.2.2. Envelope configuration accounting for regional climatic conditions. The building envelope is decisive for the final energy balance.

When discussing the building geometry data, the compactness index (ratio between the external surface and the indoor volume) and the glazing ratio are usually good indicators for estimating energy efficiency and indoor comfort levels. The envelope configuration should also take into account the regional climate data. For example, the traditional houses in Moldavia use a classical proportion with a ratio between height and length of 2/3, 3/4 and sometimes 1/1, depending on altitude.

Regional climatic conditions may also influence: shape and slope of the roof, design of intermediary spaces (for the traditional Romanian house, an intermediary space provides shading during summer and sheltering from winds during winter), glazing shape and ratio, use of local materials.

2.2.3. Renewable energy systems integration. Integration of renewable energy systems in building architecture (located either on the building or near the building) should be carefully considered in the context of NZEB design, both from the economic efficiency standpoint and environmental impact.

3. Case study. Methodology for evaluating a NZEB single-family house

This paper evaluates a compact single-family house, previously designed within the Modellus research project, further upgraded with renewable energy systems and also adapted to climatic conditions for Galați County, Romania.

The main objective of this research was improving the overall model’s energy performance accounting for data and strategies provided by Climate Consultant 6.0 Software. The house model was designed and simulated according to specific site conditions, Galati County, characterized by higher temperatures during summer and stronger winds than the previously analyzed site. Galați is situated in the climatic zone II.

3.1. Functional and spatial configuration

The project of the single-family house analyzed in this paper is a contemporary reinterpretation of the Romanian traditional household, with a built area of 74.50 m² and a total area of 156.21 m². The house model takes the form of the traditional barn, whose flared walls at the top, in an inverted growth, are meant to ensure the façade’s protection from bad weather. To the north, the floor is amplified to create and protect an intermediate area that ensures greater thermal efficiency.

The house’s shape, with part of the attic in console allows shading of the South-facing glazed surfaces during summer, without preventing the solar gains in the winter (figure 2).
The association of architectural elements such as greenhouse – fireplace – staircase plays both an aesthetic role and can improve the overall energy efficiency, if the staircase and hearth components are made of high density materials, thus ensuring thermal inertia. The house’s shape can be inscribed in a parallelepiped, with the base of 10 × 10 meters and a height of 7.5 meters, achieving, thus, the ratio specific to vernacular houses.

3.2. Climate Consultant 6.0 data output for Galați, Romania
The Climate Consultant 6.0 Software, developed by UCLA Energy Design Tools Group, was used for obtaining a data set that establishes a direct connection between outdoor conditions and indoor

![Figure 2. Axonometric views of the single-family house model.](image)

![Figure 3. Sun shading chart for Galati, Romania – hourly average temperatures below, within or above the comfort zone.](image)
comfort, thus enabling a more accurate thermo-energetic configuration for the house model. Climate Consultant software translates climate data into charts that can be interpreted by construction specialists for an accurate regional environmental model (figure 3, figure 4).

The graphs summarize the specific climatic characteristics for Galați; it is observed that the main parameters to be considered are: share of hours with low temperatures, high minimums and maximums, important seasonal variations, irregular winds with increased intensity from the north.

**Figure 4.** Wind wheel for Galati, Romania.

**Figure 5.** Psychrometric chart for Galați, Romania – passive design strategies for maximizing annually indoor comfort.
In figure 5 are synthesized the temperature and humidity characteristics for each hour in a year and is emphasized the comfort zone as well as means of expanding it through passive measures. Also, the psychrometric chart provides a hierarchical classification of these strategies.

3.3. Integration of climate data set in house design

Based on data provided by the Climate Consultant 6.0 software and study of specialized literature, a series of passive systems and strategies have been implemented in the single-family house design, as shown in Table 1. The measures indicated by the software have been analyzed in economic terms, in direct proportion to their indicated ratios. Thus, some of these measures, with low impact and high costs of implementation have been discarded, in order to address the economic factor.

Table 1. Design strategies, share of comfort hours increased by implementation of passive design measures.

| Design strategies                        | Share [%] | Means of implementation                                                                 |
|------------------------------------------|-----------|-----------------------------------------------------------------------------------------|
| Sun shading for windows                  | 12.1%     | All windows have been fitted on the exterior with solar blinds.                          |
| High thermal mass                        | 5.1%      | For sustainable reasons, the house has a light wooden structure. To compensate for this aspect and ensure thermal mass, dark slates have been used for pavement and the greenhouse space has been associated with an adjacent stone fireplace with a capacity to store heat during daytime and release it during night. |
| Direct evaporation cooling               | 3.3%      | No Considering the low impact, with the exception of plant evaporation, this strategy has not been implemented. |
| Natural ventilation cooling              | 9.4%      | Fresh air intake is supported by the openings on the Northern facade, while the polluted air is removed at the upper level through the West-facing windows. The open floor plan and the double-height living room provide conditions for a better air flow. |
| Passive solar direct gain high mass      | 17%       | - The Southern facade has a much greater ratio of windows than the Northern facade.       |
|                                          |           | - High performance (Low-E) glass panels have been implemented on Eastern, Western and Northern facades and clear glass panels on the Southern facade for maximum solar gain. |
|                                          |           | - Floor plans have been organized in such manner that winter sun penetrates throughout the whole day. |
| Outdoor spaces wind protection           | 3.5%      | Deciduous trees have been planted extensively on Northern and Eastern side, to protect from wind, but not on the Southern side, in order to avoid shading the passive solar windows. |
| Dehumidification                        | 4.5%      | No Considering the low impact, this strategy has not been implemented.                 |

Compilation of multi-annual climate data from previous years is essential for design optimization, but these results need to be adapted to future climate change conditions. As such, according to Intergovernmental Panel on Climate Change, a linear temperature increase of 0.2 degrees Celsius per
decade has been reported, a tendency that continues and will be accelerated. Mid-term and long-term flexible and dynamic design measures need to account for future climate change, aspect resulting in the necessity to decrease heating demand and increase cooling demand, as well as revaluation of PV systems efficiency [6].

3.4. Single-family house energy evaluation and optimization
An energy evaluation for the proposed single-family house design was simulated using ARCHICAD EcoDesigner Software [7], as shown in figure 6, figure 7 and figure 8. Energy demand values were extracted on the basis of an accurate 3D house model; the values for thermal resistance for each element (wall, roof, slab, etc.) being calculated according to Romanian methodology and standards.

The location coordinates have been set for the town of Galați.

![ARCHICAD EcoDesigner - Energy balance.](image-url)
In the previous house model version, designed within the Modellus research project, the registered values for heating and cooling were: 21.19 kWh/m²/a (heating) and 19.43 kWh/m²/a (cooling). The climate coordinates were set for Iași County, Romania. The energy evaluation was also done using ARCHICAD EcoDesigner Software.

Compared to the previous version, a series of changes were made for the single-family house model, based on NZEB principles, specific climate data for Galați and recommendations from Climate Consultant 6.0: implementation of high performance glazing (Low-E) on Northern, Western and Eastern facades, clear glass panels on the Southern facade for maximum passive solar gain, dark slate for floors, stone fireplace to increase the thermal mass, protection measures against wind through landscaping, renewable energy systems.

Thus, the new simulation values for net heating energy and net cooling energy are 25.95 kWh/m²/a and 10.53 kWh/m²/a (total net energy is 36.48 kWh/m²/a). The cooling demand is lower in this case scenario thanks to implementation of additional passive measures, as previously presented in table 1. The calculated primary energy value is 107.89 kWh/m²/a (value under 111 kWh/m²/a, as imposed by the Romanian methodology) and the CO₂ emissions are 2.59 kg/m²/a (low environmental impact).

The low value for electric energy consumption for lighting and appliances (1302 kWh/a) has been achieved by using strategies specific for smart houses (use of operational schedules, LED lights and high performance appliances) leading also to cost reduction over the lifetime of the building.

3.5. NZEB design principles for an affordable single-family house

Table 2 summarizes the NZEB design principles applied for the analyzed house model and presents a comparison of values obtained following the ARCHICAD EcoDesigner energy evaluation with the Romanian standards.
Table 2. NZEB design principles - comparison between simulation results and national requirements.

|                  | Romanian methodology | Single-family house model |
|------------------|-----------------------|---------------------------|
| Energy demand    | The buildings energy demand should be clearly defined and thresholds for maximum allowable energy, compiling heating, cooling and electricity demand, should be set [8]. | Maximum specific primary energy demand for climatic zone II: 111 kWh/m²a [1] | 107.89 kWh/m²a |
| Renewable share  | A threshold for minimum renewable energy from active systems should be established, on an increasing percentage slope from 2021 to 2050, leading towards 100% [8]. | Minimum 30% [9] | 58.6% |
| CO₂ emissions    | For meeting the EU long-term sustainable targets, the buildings CO₂ emissions related to the energy demand is recommended to be below 3 kg CO₂/m²a [8]. | 24 kg CO₂/m²a [1] | 2.59 kg CO₂/m²a |

The low CO₂ emissions and the overall favorable primary energy consumption has been achieved by employing renewable sources for heating and hot water preparation (wood pellet heater and 18 m² solar thermal collectors) as well as correctly attributing the input for energy source factors in accordance to Romanian energy share (that includes 2% solar, 10% wind and 28% hydro). The settings in ARCHICAD EcoDesigner Software do not permit assessments that include PV systems.

Table 2 also indicates some differences between Romanian legislation and EU directives, most evident in CO₂ emissions demand. The research’s objective has been to achieve a performance within EU recommendations, through the previously mentioned strategies.

4. Conclusions

The NZEB concept imposes a series of restrictions and enforces the need for an integrated approach to architectural design that takes into account regional and landscape specificity. To this extent, Climate Consultant 6.0 software represents a useful tool for an accurate approach to thermo-energetic envelope configuration, establishing a direct connection between outdoor conditions and indoor comfort.

For the analysed single-family house, the specific design measures provided by Climate Consultant 6.0 led to a significant reduction in overall energy consumption.

The house model meets the requirements imposed by NZEB as follows: the primary energy value is 107.89 kWh/m²a (value under 111 kWh/m²a, as set by Romanian methodology), the renewables share is 58.6% (whereas Romanian methodology states that renewable energy sources should cover at least 30% of the total calculated primary energy of the building) and the CO₂ emissions are 2.59 kg/m²a (EU regulations stipulate that a building’s CO₂ emissions should be below 3 kg CO₂/m²a).

To conclude, the single-family house has a low environmental impact and can be also affordable over time by implementation of energy efficient systems (smart house systems for LED lighting, use of operational schedules and high performance appliances).

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**Acknowledgments**
This research was undertaken as part of a research project supported by UEFISCDI, Model for a sustainable single-family dwelling integrating architectural concepts and high energy performance systems with minimal environmental impact, PN–III–P2–2.1–BG–2016–0074, Contract 61 BG din 01/10/2016.

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