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Study into the Energy Efficiency of Residential Buildings in Dobrogea

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***Abstract* – This paper deals with effect of friction dampers on seismic response of 2D steel frames in comparison with structures stiffened by large sections and centrally braced. For the present study three structures with six storeys are subjected to a time history analysis. To study the effect of dampers in structures in comparison with structures stiffened by large sections and centrally braced, are analysed the relative level displacements, maximum displacement on the top, variation of lateral acceleration at the last level and variation of the maximum seismic base shear force depending on the lateral rigidity. The results indicate that placement of friction dampers improve the response of structures in all analyzed terms.**

Keywords* – *carbon dioxide blueprint, energy efficiency, residential buildings

1. INTRODUCTION

A milestone on developing the sustainability concept was the argumentation, back in 1971, that natural resources stored in terrestrial deposits are irreversibly degraded when put to use in economic activity [1].

The last decades showed energy consumption and greenhouse gas emission as one of the major components of the sustainable development. As the residential and commercial buildings consume an increasing share of the total energy that is used by buildings, estimated at 40% [2], and in US the buildings and construction sector accounts for 36% of global final energy use and 39% of energy-related carbon dioxide (CO2) emissions [3] the interest in high energy performance buildings is a natural sequence. All over the world have been conducted studies on mitigating the energy consumption, increasing efficiency [4–6], assessing the economic indicators [5, 7, 8], forecasting energy consumption [2] and valuating green buildings [9]. The concept of green building, a building with less or no negative impact on both the environment and on its inhabitants, was introduced in 1993. It addresses a wide range of complementary issues, such as: mitigation of greenhouse gases emissions through fossil fuel lower consumption, reduction of scarce resources consumption (like water), recycling resources, reuse of materials wherever possible, use of renewable resources, and improvement of occupant comfort and wellbeing [9].

Thus, the earliest attempts to Net Zero Energy Building (NZEB) emerged in United States and Canada as a model for sustainable and energy neutral development in built environment [7]. The concept occurred in Europe as well, an early example being the Philips Experimental House Project in 1974 [7]. Further, the evolution of the concept in Germany led to establishment of the Passive House Institute (PHI) in the 1980's. Meanwhile, the British

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came up with the Zero Carbon concept. Valuable research has been conducted in Asia since 1985.

In Europe was adopted the Nearly Zero Energy Building (nZEB) concept, a more approachable model with clearly stated maximal source energy consumption and part of this consumption has to come from renewable sources. A more efficient model is that of Net Zero Energy Building (NZEB) which involves a total annual energy consumption that equals the amount of renewable energy locally created [10].

The nZEB definition introduced in European countries by the Directive 2010/31/EU was set within a vision of the 2020 Horizon. A new vision is established for the future years till 2050 by the Directive (UE) 2018/844 [12]. The present definition for nZEB, regarding individual residential houses due to 2021, stipulates a maximal consume of primary energy of 98 kWh/m^{2}a and 24 kWh/m^{2}a of Carbon dioxide emission, in Romania.

A major problem remains the existing buildings that do not meet the energy performance regarding the sustainable development. We intend to evolve to smart cities, but priorly we must have performant buildings to be equipped with smart technology for automation and energy control and such technology is expensive.

The renovation policies of the built environment must take into account a complex set of criteria, which in addition to the technical characteristics of the buildings should also refer to the set of economic, social and spatial conditions, according to [13]. EU target is to reduce energy consumption by 32.5% by 2030 and the Clean Energy for all Europeans package refers specially to existing buildings.

The rehabilitation of existing buildings and the improving of their energy efficiency are actions inserted in the large paradigm of circular economy, as circular economy is a detailed solution that will allow consumers to reduce harm to the environment [14].

After [15], circular economy refers to a "regenerative system in which resource input and waste, emission, and energy leakage are minimized". The guide for achieving the optimal performance levels [16] indicates, for the renovated residential individual category of buildings, the minimum primary energy consumption requirement of 152.11 kWh/(m^{2}a) for the first climate zone and 162.93kWh/(m^{2}a) for the second one.

The aim of the present study is to identify the best solutions from technical and economic viewpoint for improving the energy performance of an existing residential, individual house, in the specific context of Dobrogea, where local renewable sources of energy are favourable. Furthermore, the article presents some investigations on what would have been the energy consumption if the house were placed in a different climate zone in Dobrogea and had different cardinal orientation.

2. ASSESSMENT METHODOLOGY FOR THE ENERGY EFFICIENCY OF A HOUSE

2.1. The house description

Romanian Dobrogea is a region in the Eastern part of the country, between the Lower Danube and the Black Sea, with dry and sunny weather. Part of the region, close to the seashore, is included in the first climate class and the rest in the second one, according to the standard classification upon the temperatures in Romania, during the cold season.

The first climatic region is characterized by a yearly reduced temperature of 12.1℃ and the winter temperature for calculation is -12℃. The second one has yearly reduced temperature of 10.7℃ and the winter temperature for calculation is -15℃. The solar radiation has high intensity. Dobrogea is also the second area with wind potential that can be profitably used, especially the Black Sea Coast, and northern Dobrogea where the average annual wind speed is around 6 m/s. The lower wind turbulence in this region, comparative to other Romanian regions, is favourable to the energy exploitation of the wind potential.

The study regards the energy performance of a residential house, composed of ground floor and one storey as represented in Fig.1. It is medium sheltered from wind. The house is inhabited by 5 persons. The house is a one-family home, which features its main living areas distributed across a ground floor and first floor. The ground floor is reserved for daytime activities, mainly living room and dining area, oriented toward the inner garden, and the kitchen area positioned near the main entrance. The upper floor holds the master bedroom and guest rooms. Above the bedrooms, the staircase reaches the upper terrace, through an enclosed space that facilitates the transition between inside and outside.

The house's construction system is a simple reinforced concrete frame that holds masonry exterior walls. The original house was built in 1991, before the first Romanian regulation in accordance with the European one, C107-199, was issued.

Fig. 1 Facades of the building

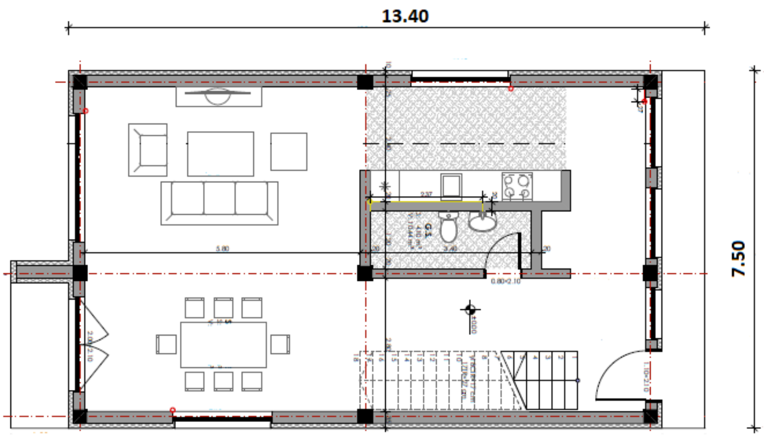

Fig. 2 Ground floor layout

The rectangular and trapezoidal type of building are considered to have the lowest life-cycle-cost, [17], so the rectangular shape of the house gives it potential in terms of life-cycle-cost. Moreover, the house is compact, according to [17]. A most refined compactness analysis is published by [18], based on footprint aspect ratio (r) and slenderness aspect ratio (k). The house has r=1.76 and k=0.89, which means a good compactness factor of γ=1.04.

The ratio of window to wall surface on two opposite external walls is the same, namely 35% for two opposite walls, and respectively 15% for the other two. So, the opposite external walls are similar with respect to the window area. The Southern wall of the existing house has a ratio of 35%. In a study on mid-latitude European cities, an optimal energy performance was noticed for detached houses within the range of 30–45% of window to wall ratio [6].

Table 1 The house geometry

Geometric features	**Value**
Heated area [m^2]	167.36
Area of the thermal envelope [m^2]	438.7
Windows area to wall area ratio [-]	24.5%
Heated volume [m^3]	622.76

The house has no mechanical ventilation or air conditioning, so the energy consumption refers to heating, illuminating and water heating. We considered by turn, that the house is placed in the first climate region and then in the second one. However, the energy consumption was analysed for different cardinal orientation of the building.

2.2. Brief description of the methodology

The Romanian methodology for the energy efficiency of a building assumes one dimensional steady heat transfer [12]. The methodology describes different methods to assess specific energy consumption for the entire building and its installations and to compare them to a reference house which has the same geometry, function, and location as the real one, but a thorough insulation so that its consumption is optimal. The energy performance of the reference house is calculated considering that the thermal resistance of the envelope components are the minimal admitted ones. This study focuses on the heating energy consumption, total primary energy, and carbon dioxide footprint for the real and the reference house placed in both climate regions specific for Dobrogea, so that one could notice the additional load due to the emplacement and orientation.

The major heat losses of a building, during the cold season, take place by conduction and convection, through the thermal envelope. The house's envelope is a rectangular one, with a slab-on ground floor and a flat walkable roof. The indoor air for residential buildings is considered constant, at 20℃. The house is heated by its own gas thermal central, which prepares the domestic hot water as well.

The thermal coupling between indoor air and outdoor air or ground, through each envelope component is characterised by the coupling coefficient, which depends on the thermal resistance and area of the construction element. The heat flux Q [W] that passes through a construction component, considering the stationary, one- dimensional heat transfer through an infinite, homogenous one-layer wall, depends on the coupling coefficient and the temperature difference between the two media the component connects. The thermal resistance is corrected, considering the thermal bridging.

Thus, the heat flux lost through the whole envelope is given by the relationship:

$$Q = H(\theta_i - \theta_e) \tag{1}$$

where:
θi, indoor temperature, [℃],
θe, outdoor average temperature during the cold season, [℃].
H- coefficient of total heat losses through the building's thermal envelope, [W/℃].

The coefficient of total heat losses through the envelope in relationship (2) has two components:

$$H=H_T+H_V \quad (2)$$

where:
H_T - coefficient of heat losses by conduction and convection, [W/℃],
H_V - coefficient of heat losses due to air permeability, [W/℃].

The heat flux lost through the whole envelope, Q, enters in an energy balance equation, along with the solar energy gain through the windows, Qs, and the internal energy gain from occupants and electric appliances, Qi. The difference represents the net heat needed by the building. The total energy needed for heating is the sum between the net heat and the energy losses at the distribution system and the radiators.

The energy gains influence the duration of the heating period, due to the value of equilibrium external temperature at which there are no heat exchanges between indoor and outdoor environment.

The calculation was performed monthly, along the entire heating period.

The assessment of the energy demanded by hot water preparation and lightning was done according to the same methodology. The same calculations were done for the reference house and then for each technical energy efficiency improvement solution. There were proposed four simple technical solutions (S) and three package solutions (P), as follows:

S1-External walls insulation; S2-Windows replacement with more energy efficient ones; S3-Ground floor insulation; S4-Upper floor insulation; P1-External walls insulation and windows replacement; P2-Ground and upper floor insulation; P3-Insulation of the entire envelope.

On both technical and economic grounds, one of these solutions was picked as the optimal strategy. For the optimal strategy, there were investigated the possibilities to cover with renewable energy part or all of the demanded energy.

3. RESULTS AND DISCUSSION

The energy demand of the original house and its correspondent reference house was assessed in accordance with their assigned location and cardinal orientation data. The building's geometry, geographical emplacement and climate are passive factors that influence the energy demand for heating, natural lighting, and natural ventilation. [6].

3.1. Strategies for enhancing the energy efficiency of the house

The double skin facades are considered as a very efficient technique that has the best carbon-saving potential [19]. Thus, we chose to cover the original house with a double-skin façade system comprising a rockwool insulation layer.

The results, regarding some indicators of the energy efficiency of the given house and the correspondent reference one, are collected in Table 2. We focus on heating specific energy and total specific energy consumption, where the latter includes not only heating, but also the energy consumed for hot water preparation and lightening. It is obvious the house's energy performance should be improved, as long as a big difference between the specific energy consumption of the given house, of 214.8 kWh/(m^2a), and its reference one's of only 128 kWh/(m^2a), may be noticed.

Table 2 Energy efficiency indicators for the original house, the reference one and the simple improvement solutions

Indicator	**Original house (OH)**	**Reference house (RH)**	**S1**	**S2**	**S3**	**S4**
Heat transmission coefficient [W/°C]	415.3	236.6	340.3	378.4	393.2	321.2
Heating period, [day]	231	196	221	231	228	217
Specific energy used for heating, [kWh/(m^2a),]	159.2	72.3	118.4	126.1	144.8	120.2
Total specific energy consumption, [kWh/(m^2a)],	214.8	128.0	160.5	168.2	186.9	162.3
Total specific primary energy, [kWh/(m^2a),]	254.9	144.9	195.1	203.5	224.1	197.1

The total specific energy consumption of the original building is in accordance with the average energy consumption for the houses built between 1990-1997, which ranks from 150 to 350 kWh/(m^2a) [16]. The average thermal resistance of the walls was between 0.65-1.17 m^2 ^{o}C/W at that time [16].

The total specific primary energy consumption of the reference house is about 144.9 kWh/(m^2a), much more than the requirements for a nZEB, which is only 98 kWh/(m^2a). As long as the weight in the total energy consumption of the house belongs to the heating energy, the thermal resistance of the envelope components should be increased above the minimal admitted ones.

The same indicators are given for the proposed simple technical solutions for energy efficiency improvement. A simple solution refers to the insulation of one single component of the thermal envelope. The insulation of the external walls, S1, the replacement of the old windows with new more performant one, S2, and the insulation of the upper floor, S4, are very much similar in terms of their energy indicator results: the heating specific energy is reduced from 159.2 kWh/(m^2a) to a value in the range 118.4-120.2 kWh/(m^2a). The insulation of the slab-on ground floor leads to lower heating energy saving, as the new value for the consumption is 144.8 kWh/(m^2a), an expected result, as the temperature difference between the media thermally coupled by the ground floor is smaller in comparison with the other thermal envelope components. The ground floor works between the indoor temperature and 10 ^{o}C, the temperature of the underground still water, as the water level influences the heat flux. From the technical viewpoint, the best solution is S1, the insulation of external walls.

The next stage consisted in coupling different simple solutions in order to get the so-called package solutions. The energy efficiency indicators are given in Table 3.

The package solutions P1, involving external walls insulation and windows replacement, and P2, referring to the insulation of both upper and ground floor, have very similar influence on the improvement of the energy efficiency: the specific heating energy decreases with at least 30%. The best technical solution is the total rehabilitation of the thermal envelope, P3, which leads to an important improvement. The heat transmission coefficient of the envelope decreases to a half of the initial one and the specific energy consumption for heating is only 60% of the given house's consumption. Conventional energy was considered. Despite these encouraging results, the total specific source energy is still higher than the value required from an nZEB, which means active measures regarding the lightening installations and hot water system should be taken in order to bring the house closer to an nZEB performance.

Table 3 The energy indicators for the package rehabilitation solutions

Indicator	P1	P2	P3
Heat transmission coefficient [W/°C]	313.6	321.2	225.87
Average outdoor temperature (cold season), [°C]	15.01	15.13	13.08
Equilibrium external temperature, [°C]	6.47	6.52	5.56
Heating period, [day]	216	217	194
Specific energy used for heating, [kWh/(m^2 a)]	112.3	105.5	63.9
Total specific energy consumption, [kWh/(m^2 a)]	154.5	147.6	106.1
Total specific source energy, [kWh/(m^2 a)]	188.4	180.9	124.5

Considering the recommended specific primary energy minimum consumption of 152.11 kWh/(m^{2}a) [16] for rehabilitated houses in the first climate zone, the last two package solutions fulfil this requirement and, furthermore, the package solution P3 offers a 30% decrease over the recommended value.

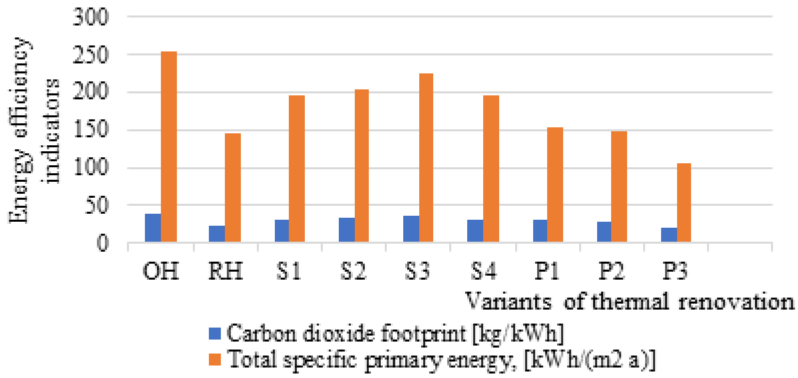

Fig. 3 Comparison of different variants of the house, in terms energy performance

Figure 3 shows a comparison among the analysed variants of the house. Regarding the impact on the environment, the package solution P3 allows the lowest values of either primary energy consumption, of 106 kWh/(m^2 a), or carbone dioxide, of 20 kg/kWh. In this case, the carbone dioxide footprint is lower than the nZEB's footprint, as stipulated for the current year.

These package solutions bring more important energy savings, but the additional investment is much higher. Further economic investigations were performed to decide which solution could be recommended from either technical or economic perspective.

3.2. Economic indicators

The investigations regarding the execution technology and costs, in the different rehabilitation scenarios, led us to retain only the technical solutions presented in Table 4.

Table 4 Energy performance and economic indicators

Indicators	**S1**	**S2**	**S4**	**P1**	**P3**
Saved energy [kWh/(m^2 a)]	54.3	53.3	52.6	67.3	108.8
Additional investment [EU]	5227	4282	5145	9510	14908
Payback time [year]	10	8	10	16	16

For these solutions there are given the savings regarding the total specific energy consumption and the economic indicators regarding the additional investment and the payback time. From the new perspective given by the values in Table 4, the most affordable solution is S2, the replacement of the windows, which implies a minimal investment and the shortest payback time at a very similar amount of saved energy in comparison with solutions S1 and S4. The package solutions P1 and P3 have the same payback time, but the saved energy is almost double in the case of P3, which is also the most expensive.

Affordable expenses may return valuable energy efficiency of old buildings. But none of the technical strategies presented above can turn the given house into an nZEB as long as no active measures are considered, and active measures involve high additional investment. So, the efficiency ensured by the total rehabilitation of the thermal envelope, P3, may be enhanced by the change of the type of lightening from mixed to LED and by a better management of the hot water preparation system.

3.3. Investigations regarding the use of renewable energy

The climate in Dobrogea is favourable to the use of solar and wind energy, which is an advantage to the locals. The photovoltaic panels (PV) may me mounted on the upper terrace of the house. The area may host a farm of 16 PV, South oriented and tiled at 45o to the horizontal plane.

Concerning the energy consumption of the rehabilitated house, the most efficient and affordable possibility refers to the use of 10 photovoltaic panels of 330Wp power and 1.68m2 and two wind vertical turbines of 1500W each. The small vertical wind turbines may be placed in the back yard of the house. This strategy would cover the whole energy demand. The additional investment will rise to 20 000 EU and the payback time would be of 10 years. Nevertheless, the additional investment supported by the house owner becomes affordable, of only 5000 EU, if the rehabilitation governmental programme is accessed [20].

This strategy is optimal, as it can turn the house into an NZEB on-grid one. The solar energy, collected during the day light, is complementary to the wind energy, mainly collected during the night, so the combination of these regenerable sources assures an almost continuous energy supply.

It is difficult and expensive to turn an existing house into a smart one, but the study brought a series of affordable strategies to improve the energy performance and to make it a neutral one.

3.4. The influence of emplacement and orientation of the house on the heating energy consumption

The influence of the climate zone on the heating energy consumption was assessed considering that the same house would be placed in the second zone. The heating energy is with 18% higher in the second climate zone, for the house with the same cardinal orientation. Regarding the influence of orientation on solar energy gains, there were compared the energy indicators for the house placed in the first climate zone, but for two different orientations: the Southern wall with 35% of total window area and the Southern wall with 15% of total window area. The exposure to wind is similar.

Table 5 The energy indicators for the reference houses located in the first climate zone, but with different orientation

Indicator	Southern wall with 35% of total window area	Southern wall with 15% of total window area
Energy gained from the sun, [kWh/a]	5410	5099
Energy used for heating, [kWh/a]	26725	27061

The results, given in Table 5, show the difference in solar energy gain and in the heating energy consumption between the two cases. The solar gains decrease with 5.75 % and the heating energy increases with 1.25% for the house with smaller window area to the South.

The possibilities to orient a new building are very wide, and this orientation influences not only the heat inputs, but also other aspects, such as lighting and possible overheating during the summer. These aspects should be referred to in future studies.

4. CONCLUSIONS

The study on energy consumption highlighted the specific climate of Dobrogea and its role as a passive context for the energy demand of a building. The gradual development of the study, from simple to more complex strategies, let us notice the influence of each component of the thermal envelope to the energy consumption for heating. A proper insulation and enhanced sealing capabilities have decreased the heat transmission coefficient of the thermal envelope by 46 %. The difference in the heating energy used by the same house but placed into two different climate zones in Dobrogea, is about 18%. The heating energy increases by 1.25% for the house with 15% of window/ wall area ratio oriented to the South, over the one with 35% oriented to the same cardinal point, for a house placed in the first climate zone.

The study showed that an existing house, which was not originally designed in accordance with the nZEB requirements, can be turned into an energy neutral one, by thorough measures to mitigate the energy demand and appropriate use of renewable energy locally produced.

The old buildings rehabilitation and improvement of energy efficiency methods have to prevail in the management of the local authorities.

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