ENERGY EFFICIENCY MONITORING OF AN EARTH-SHELTERED HOUSE AFTER 4 YEARS OF USE

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Abstract. The paper presents the results of monitoring the behavior of a house protected from the ground in terms of energy efficiency after four years of use. The building was built between 2012-2015, being made of ceramic blocks walls confined with reinforced concrete elements, and as a top closing building envelope component, a green roof system is implemented. It is situated near Iasi, in the North East of Romania. Starting with the summer of 2015 the house was inhabited by a family having four members. Wood was used as fuel for heating during the cold season. Thus, the average amount of four seasons consumption is compared with the one of a traditional/conventional house.

Keywords: earth-sheltered house, energy efficiency, living comfort

1. Introduction

An earth-shelter building is a structure (usually a house) with earth (soil) in direct contact with the walls, on the roof, or that is entirely buried underground. Earth acts as thermal mass, making it easier to maintain a steady indoor air temperature and therefore reduces energy costs for heating or cooling. Earth sheltering became relatively popular after the mid 1970’s, especially among environmentalists. However, the practice has been around for nearly as long as humans have been constructing their own shelters. [1], [2], [3], [4].

The hovel is a type of semi-buried house, known in Romania as “bordei” and in neighboring countries under the name borrowed from Romanians. It is the oldest known permanent dwelling in Romania, identified in archaeological sites from prehistory to the present day. It coexisted from antiquity until after the First World War with the surface house, dominating the Danube plain. [5]

According to standard STAS 6054/85, in Romania the frost depth is between 0.70 m and 1.10 m below ground level. Because below the freezing depth of the soil, the earth's
temperature is relatively constant, around 8-12° C, substantial savings are made in the energy demand for heating this type of house in winter, or cooling during summer.

In 2012, the author, as the beneficiary of a new home, decided to build a modern hovel in Romania, near the city of Iasi, thus being among the first constructions of this type in the area. The town of Iasi is situated in the III-rd climatic zone which is defined by an exterior temperature of -18°C as defined by the Romanian climatic map [5] After three years the construction was ready to be inhabited by a family of 4 members.

2. Building layout, used construction materials, heating and air ventilation systems

The house has a footprint on the ground around 222 square meters, as shown in figure 1, and a height regime of two floors. The basement, as presented in figure 2, has the function of a garage having one exterior wall on the North side with a large door with 3,00 mx 2,20 m. The building envelope is described by the green roof, the walls in contact with the ground, the walls in contact with the exterior, and the slab on the ground. At the basement the walls in contact with the ground and the floors are made of reinforced concrete.

A thermal insulation of 10 cm thickness is placed on the exterior side of the walls and under the bottom floor. Additionally, a waterproofing system is also mounted on the exterior side. The ground level has two lateral facades in contact with exterior. The longitudinal façade with windows and doors is oriented on South-West. The other lateral is in contact with the exterior on 30% on the North direction. [6]
The rest of the facades and the roof are covered with soil in variable thickness. The walls of the ground floor in contact with the exterior are made of ceramic hollow blocks confined with reinforced concrete elements. The structural walls are presented in figure 3. The roof floor is made of ceramic hollow blocks and reinforced concrete. The thickness of the walls and floor is 25 cm. A thermal insulation layer of 10 cm thickness of polystyrene is placed on the exterior walls in contact with the ground. The exposed facades on the West side have a thermal insulation of 15 cm. On top of the terrace roof there is a thermal insulation layer with variable thickness from 30 cm on the West side to 10 cm on the East side. The building materials used are presented in table 1 [7].

| Building element                                      | Materials                          | Thickness (cm) | Thermal conductivity (\(\lambda\) W/mK) |
|------------------------------------------------------|------------------------------------|----------------|-----------------------------------------|
| Basement wall                                        | Reinforced concrete                | 25             | 2.5                                     |
| Ground level wall                                    | Ceramic hollow blocks              | 25             | 0.234                                   |
| Roof floor ceramic and reinforced concrete            | Ceramic hollow blocks and concrete | 25             | 0.51                                    |
| Windows joinery                                      | Glass (3 layers)                   | 1.2            | 0.9                                     |
| Thermal insulation roof                              | Polystyrene                        | 30 ... 10      | 0.035                                   |
| Thermal insulation walls and floors in contact with ground | Polystyrene                       | 10             | 0.035                                   |
| Thermal insulation for walls in contact with exterior | Polystyrene                        | 15             | 0.035                                   |
For the fresh air demand a piping system was mounted, as presented in figure 4. There are 3 pipes with 110 mm diameter with the length between 30 m to 50 m. The pipe system has a 3 meters’ level difference between the ends.

The heating system was based on a wood stove of a 24 kW nominal power. For increased autonomy and less time in the wood supply for the stove, it was mounted a 1000 l tank puffer. During the winter season from October close to May, the hot water was provided by the heating boiler which has one coil and one electric resistance of 3 kW. The heating system is presented in figure 5.
Table 2
List of radiators

| Room          | Dimensions (h x l mm) | Power (w) | Surface (m²) |
|---------------|-----------------------|-----------|--------------|
| Basement Office | 600 x 600             | 840       | 10.33        |
| Upper Office  | 900 x 900             | 1260      | 10.53        |
| Kitchen       | 600 x 600             | 840       | 14.31        |
| Living        | 800 x 800 + 600 x 800 | 2520*     | 38.20        |
| Bedroom 1     | 600 x 900             | 1260      | 12.30        |
| Bedroom 2     | 600 x 900             | 1260      | 12.35        |
| Bedroom 3     | 800 x 1200            | 2700      | 21.46        |
| Bathroom 1    | 300 x 500             | 300       | 3.16         |
| Bathroom 2    | 300 x 500             | 300       | 3.16         |
| Bathroom 3    | 300 x 500             | 300       | 3.16         |
| Bathroom 4    | 600 x 900             | 600       | 6.38         |
| Hall 1        | 600 x 200             | 300       | 7.85         |
| Hall 2        | 600 x 900             | 1260      | 24.23        |
| TOTAL         | 12480                 | 167.62    |              |

*used only when the outside temperature under - 15°C

The radiators are made of aluminum as it can be seen in figure 6, having the characteristics mentioned in table 1. The chimney for smoke evacuation of the stove was mounted in a combined system of two stainless steel pipes with 200 mm diameters.
The exterior of the house is presented in figure 7. The vegetation is completely indigenous and natural. There is no irrigation system. On the facade exposed to the sun (South-West) there are trees that are offering shading in the evening for the facades directly exposed to solar radiation.

2. Measurement recordings during operation

Starting from the first year of operation, i.e. the summer of 2015, it was observed that the initial humidity value was around 70%...80% caused by the building materials, like mortar and finishing materials moisture. For monitoring purposes, were mounted five sensors for the interior and exterior temperature and humidity measurements. These were monitored for four years from summer of 2015 to winter of 2019, during 4 winters.
and 4 summers. Some examples of recordings are presented in fig. 8 indicating at the same moment an increased exterior temperature on the exposed façade of 52.8°C and a temperature of 27.3°C on the interior living room. The black thermometer shows similar reading during winter time. These temperatures were measured in the exterior environment and the living room in 2016, during summer and winter.

Fig. 8 - Thermometer sensors

Fig. 9 Temperature history in July and January 2015 – 2019 [8]
3. Results and Discussion

Every year during summertime, quantities varying from 14 m$^3$ to 18 m$^3$ of wood were bought. The total amount and the monthly wood consumption on each season are presented in figure 10. For the interior temperature values of 22 up to 23°C, the wood consumption depended on the outdoor weather which has been presented in figure 9 which represent the outside temperature variation in July an January/February from 2015 to 2019.

![Monthly wood consumption](image1)

Fig. 10- Monthly wood consumption data

For an average of 14.5 m$^3$ amount of wood in 4 years, the total heating energy was 30450 kW/year. Considering the heating system efficiency at 80% the annual heating consumption for 267 m$^2$ of usable area is presented in figure 11 [9].

![Annual heating energy consumption](image2)

Fig. 11 - Annual heating energy consumption
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A conventional house of a neighbor with 80 m² usable area, based on the owner's statement, consumed in the 2017 – 2018 season around 10 m3 having the annual heating energy consumption of 210 kWh/m²/year. At EU level, the average annual specific consumption per m² for all types of buildings was around 180 kWh/m² in 2013. It differs among countries: from 55 kWh/m² in Malta and 70 kWh/m² for Portugal or Cyprus, to 300 kWh/m² in Romania (or 285 kWh/m² in Latvia and Estonia) which is significantly higher than the EU average. However, even for countries with a similar climate, significant discrepancies exist (e.g. 200 kWh/m² in Sweden, 18% lower than Finland). Such differences are partly explained by climatic conditions, type of buildings and statistical definitions. [10]

The average price for 16 cubic meters of wood (e.g. beech, oak, hornbeam) was around 1500 €. So the medium annual cost for 267 m² was around 5,62 €/m²/season (year) for heating.

In terms of cooling the living area the effort is zero. The maximum temperature at a humidity value of 65% on the hottest day was 27 °C in Living room, with a high level of indoor comfort. In the rest of time the temperature is around 23°C up to 24°C in during summer. At the basement level the temperature is almost constant during summer and winter, varying from 18°C … 20°C.

For the domestic hot water consumption during summer, the electric boiler is set to work with a timer on hourly intervals around 4 hours / day (1 hour in the morning, 1 hour at noon and two hours in the evening) which means 25% of total amount of electric energy in a month.

The main aspect which can substantially change the comfort is humidity, if this is greater than 70%. In order to maintain the humidity level under 70%, it was very important to monitor this value and to assure the air circulation through the natural ventilation pipe system.

The system of house semi-buried and the roof covered with 15 cm of soil showed to be efficient having a big thermal mass. From September until December the heat stored in the surrounding massive earth reduced the heat losses of the house which translated in 30% less wood used for heating. During January and February of almost every year the exterior temperature was below -10°C. To have an average indoor temperature of 22 °C, the amount of wood consumed was double. The annual average per square meter in terms of heating energy consumption is 90 kW/m²/year placing the building in energy efficiency class B.

4. Conclusions

In this paper are presented some observations and data recorded during a period of 4 years of building usage of an earth sheltered house built near Iasi, in North-East of Romania.
The system has been proven to be affordable to heat almost 267 m² of usable area resulting an average of 90 kW/m²/year, a B class of heating energy efficiency. The advantages of thermal inertia are obvious for all types of weather. During summers, the interior comfort is natural within the optimal limits without any additional effort to cool the air or dehumidify it.

Some of the main disadvantages observed can be mentioned: the additional effort regarding a proper waterproofing of the buried surfaces, and the addition of all the layers of the green roof system. Regarding the use of wood as a fuel for heating, although the system is automated and the energy consumption is very low, there are some inconveniences such as the supply of wood, the processing, the storage but also the removal of ash. One of the alternatives which can be implemented is a combination of heat pumps, natural gas and solar energy which is considered to be implemented in the following years.

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