# Energy consumption and thermal comfort in a passive house built in Romania

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ABSTRACT: This paper mainly presents the measured energy consumption and the variation of the comfort parameters of a passive house built in the city of Timisoara, Romania. Energy efficiency of the house and the thermal comfort offered to the occupants is directly connected with the proper design of the building envelope and the good functioning of the heat pump and of all the other equipment. In order to determine the real energy consumption of the building and to keep under observation the climatic comfort parameters and the good functioning of the equipment, the house is under continuous monitoring for over a year now. Thus, the residential building has a complex monitoring system composed of a series of sensors and electric data recorders which measure various parameters and the electrical energy consumption of the house. The monitoring system was installed in the idea of validating that the design of the house in terms of envelope and equipment is close to the passive house standard through both energy consumption and comfort offered to the occupants, regardless of the weather conditions. Currently, we have the monitoring data after more than one year of monitoring. So, the paper focuses on presenting the precedents regarding the annual energy consumption of the house after one year of monitoring, problems encountered with monitoring and data processing and also information about thermal comfort in the house.

## 1 INTRODUCTION

### 1.1 *General overview on energy efficiency and thermal comfort*

It is well known that the construction sector is responsible for a high percentage of energy consumption and consequently has a great implication in the depletion of global resources and environmental pollution (Ding 2007). Throughout the entire life-cycle of a building, approximately 80% of the total energy consumption occurs in the usage phase of the building. Therefore, a way of reducing the environmental impacts of a building is improving the energy performance of the building (Kashreen 2009). The European Union published the Energy Performance of Buildings Directive EPBD as a legislation regarding the energy performance of the buildings for the European member states and aims to promote improvements in the energy efficiency of a building. Measures such as increasing the thickness of thermal insulation, use of elements having low heat transfer coefficients for the envelope and usage of renewable or non-conventional resources are the main factors taken into account by architects, engineers, authorities and the society as a whole.

Throughout Europe there are many different concepts of energy efficient buildings that are generally known as buildings with a lower energy demand than common buildings. One of these concepts is the passive house concept. In order to achieve the passive house standard, a house must have an annual heating/cooling requirement for at most 15kWh/m$^2$/year and a total energy footprint of less than 120kWh/m$^2$/year (Feist 2007).

A passive house combines high-level comfort with low energy consumption. Passive components like insulation, advantageous orientation, heat recovery, air tight envelope are the key elements. Thanks to the high level of thermal insulation, heat recovery system and solar gains, a passive house doesn't need to be heated actively to a large extent. The low amount of additional heat which needs to be supplied is frequently realized with heat pumps (Ochs 2011).

Careful implementation of details and good planning are crucial in obtaining a building with very low energy for heating. A proper design and execution can lead to a high energy efficient building which consistently provides pleasant indoor and surface temperatures. The passive house concept can be adapted to any climate zone; the general approach is the same. Depending on the climatic conditions, the quality and type of components, materials and equipment may vary.

The research into passive houses proves good thermal climate during the winter season due to the additional insulation and air tightness of the building envelope. In Thullner's thesis two different opinions are presented regarding thermal comfort in a passive house in summer season. One of the statements sustains that in summer times the risk of higher indoor air temperatures appears compared to a traditional house. Due to the well-insulated and airtight envelope it is difficult to reduce these excessive temperatures. The second opinion sustains that it is possible to ensure comfortable indoor climate during summer without active cooling by ventilating at night when the outdoor temperature is lower and avoiding penetration of warm air at daytime. Thus, the low indoor temperature is maintained due to the well-insulated and air tighten envelope. The main idea is that high quality indoor thermal comfort can be achieved also during summer if the incoming warm air or overheating due to sun-faced gazed areas are avoided (Thullner 2011).

In Romania, passive houses are a relatively new concept. Currently there are five passive houses built in the whole country. This article refers to a passive house located in the city of Timisoara, west side of Romania. From climatic perspective, Romania is situated in an area with a temperate climate with four seasons. The differences between the temperatures in the hot season and the temperatures in the cold season are very high. Therefore, particular attention should be paid to both heating during winter and cooling in summer time. The purpose is to avoid temperature drop in the elements of the envelope during cold season and also to prevent overheating in the hot season.

By monitoring the passive house from Timisoara, the energy consumption is measured and temperatures are kept under observation. After a relevant period of monitoring some conclusions can be drawn regarding energy efficiency of the building and the thermal comfort offered to the occupants.

### 1.2 *Characteristics of the passive house built in the city of Timisoara, Romania*

The monitored passive house built in Romania is part of a duplex and has a usable area of approximately 144 $m^2$. The house was designed and built so that the construction costs are minimized (Stoian et. al. 2012). Common materials were used, such as reinforced concrete, bricks, wood and polystyrene. The house has a regular shape and a compact volume so it was easy to achieve an air tight envelope and minimize thermal bridges. Opaque elements of the envelope were insulated with expanded polystyrene plates. So, for the walls a polystyrene layer of 300 mm thickness was used. The roofing system is a non-traffic terrace, with a slope of 2%.

Due to the very high level of thermal insulation, the heating demand of the house is low and the heat supply is realized with an air-water heat pump. The domestic hot water production will be assisted by solar energy through a solar panel. The presented house uses a ventilation system with heat recovery. Therefore, most of the heat is contained inside the house, preheating the intake air for the ventilation system through underground heat exchangers.

In Figure 1 are presented the layers of the roof for the passive house and in Figure 2 is presented the stratification for the foundation and ground floor of the house. As we can notice, these envelope elements are very well-insulated aiming to achieve the passive standard.

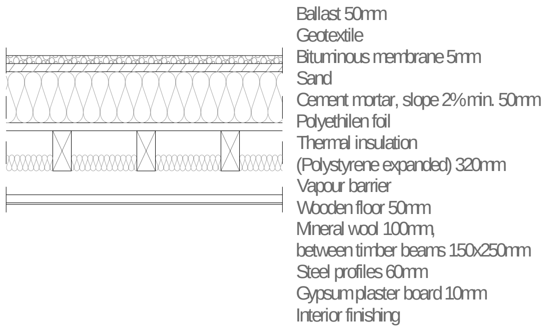


Figure 1. Layers used for the roof terrace.

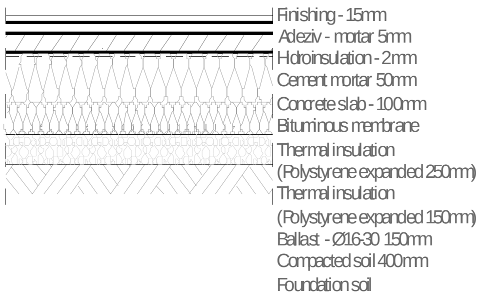


Figure 2. Layers used for the ground floor.

In the design phase of the building the energy demand was assessed using the Passive House Planning Package PHPP in order to see if the residential building is a passive house in the concept stage (Feist et. al. 2007). Evaluating the theoretical energy performance of the building by using the PHPP tool allowed the designer to test different design solutions against a set of criteria. Thus, was obtained a value of 15 kWh /$m^2$year for heating and cooling. The results are promising and indicate that the house is properly designed and can achieve the passive house standard.

## 2 MONITORING THE PASSIVE HOUSE

### 2.1 *Implementation of the monitoring system and measured energy consumption*

Implementing the monitoring system in the passive house built in Timisoara, represents a practical way of verifying if the design adopted for the studied house leads to the desired and expected results of energy efficiency. The system registers and collects data which is uploaded to a web server where diagrams available for online visualization are created.

The components of the monitoring system result from the need to make data available online and the physical measurements that had to be taken. Therefore the system contains a central unit and a number of ambient/energy flow meters. The monitoring system records data from 41 sensors, with the measuring pace set to 1 minute (Sabau et. al. 2013).

After more than one year of monitoring there is sufficient recorded data in order to assess the annual energy consumption of the building and thus evaluate its energy performance. The energy consumption of the building is monitored through 4 electric data recorders (Table 1). It is expected that the higher energy consumption to be registered for heating, ventilation and hot water. The energy consumption for household appliances can have large variations which generally depend on the behavior and lifestyle of the occupants and number of household appliances.

Table 1.Electrical energy consumption sensors.

| Recorder ID | Electrical energy consumption | Unit |
|---|---|---|
| EL1 | House hold | W |
| EL2 | Lighting | W |
| EL3 | Heating, ventilation, hot water | W |
| EL4 | Exterior | W |

In Figure 3 is presented the monthly electrical energy consumption of the building divided by categories of consumers. As we can see, for the winter months is recorded a much higher energy consumption than for the rest of the year. The consumption is much higher due to the heating demand of the house in the months with low temperatures. We can see that during the year the energy consumption for heating, cooling and ventilation vary greatly compared to the other consumptions.

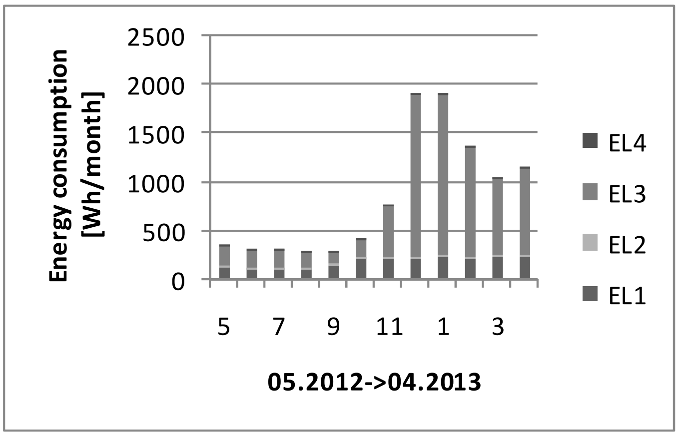


Figure 3. Monthly electric energy consumption.

The total specific energy consumption of the building obtained through monitoring is 45.8 $kWh/m^2$year and the specific energy consumption for heating, cooling and ventilation is 19.85 $kWh/m^2$year, which is more than calculated with PHPP. From the heating and cooling energy consumption perspective, the discussed house does not subscribe the passive house standard but the difference is slightly small.

## 2.2 *Analysis of the thermal comfort parameters*

An essential criterion of thermal comfort is the temperature difference between the surface temperature of the envelope element and the temperature inside the room (C107/2005). Some studies present recommended guideline values for thermal comfort and hygienic climate in a residential building. The recommended operative temperature for winter times varies between 20° C and 24° C and for the summer the guideline values are contained between 23° C and 26° C (Thullner 2010). Normally, in case of a passive house, the well-insulated envelope ensures that in the winter months the heat stays in the house, meaning: evenly warm surfaces in the room, uniform and constant indoor climate and no fluctuations in temperature.

In Figure 4 and Figure 5 we can observe how the interior temperatures vary in the cold season and in the hot season.

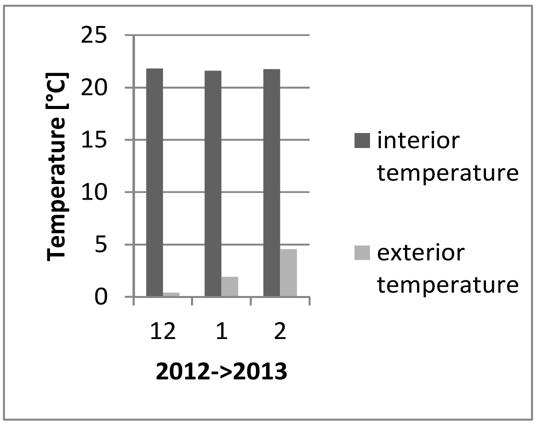


Figure 4. Temperatures in winter months

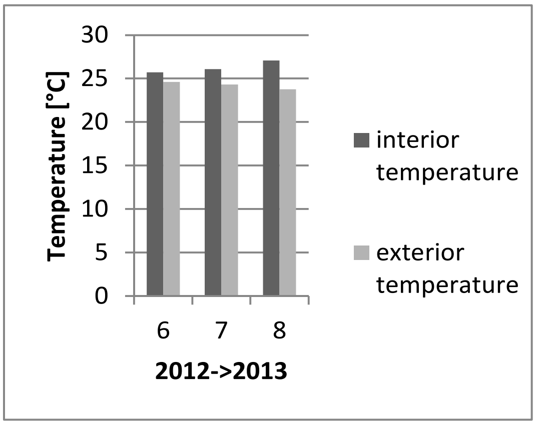


Figure 5. Temperatures in summer months.

From the charts represented in Figure 4 we can observe that in winter conditions the temperature inside the house is kept at adequate values for thermal comfort. On the other hand, for the summer season we can notice in Figure 5 that the registered temperatures are slightly higher than recommended. After processing the data recorded by the temperature sensors mounted across the wall we managed to obtain the variation of the temperature from exterior to interior. The results for the winter and summer months are presented in Figure 6 and Figure 7.

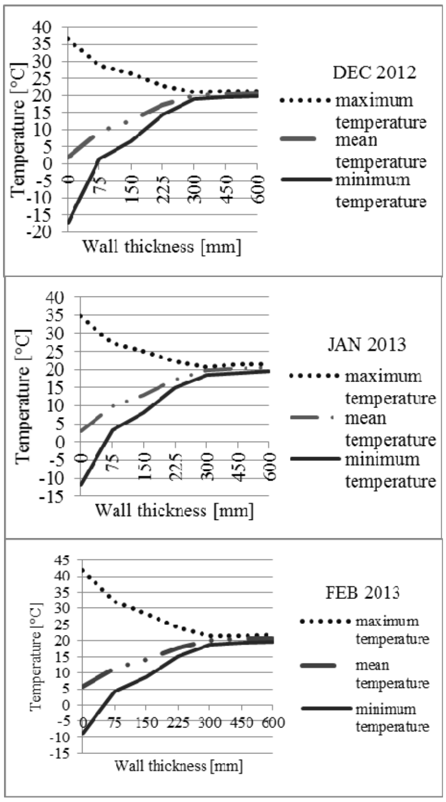


Figure 6. Wall temperatures in winter months.

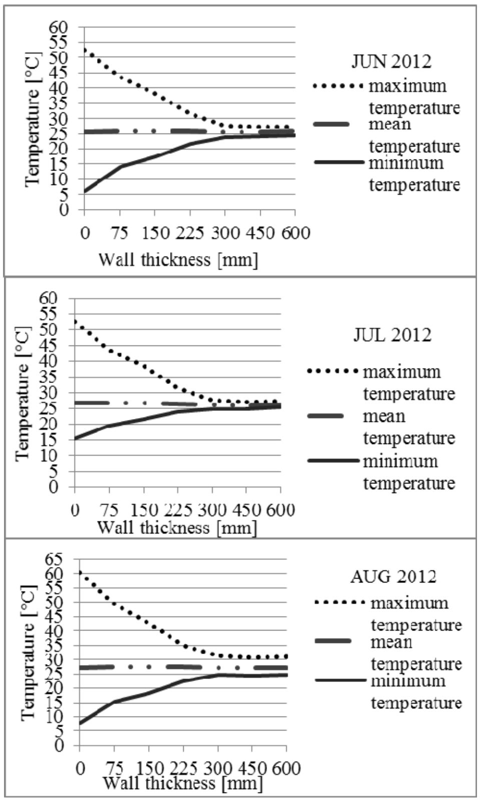


Figure 7. Wall temperatures in summer months.

By analyzing the graphics for the winter months (Fig. 6) we can see that despite the big difference between the temperatures at the exterior surface of the wall, the temperatures within the wall, starting from the interface between the polystyrene plate and masonry, strive to remain constant. Comparing these temperatures with the interior air temperatures (Fig. 6) we can state that the difference is very small, for about 1 or 2 Celsius degrees. In summer season (Fig. 7) we can notice a slight overheating of the envelope element where the temperatures at the inner surface of the wall tend to values between 25 and 30 Celsius degrees.

Figure 8 shows how the interior air temperature varies with the exterior temperature during the monitoring year.

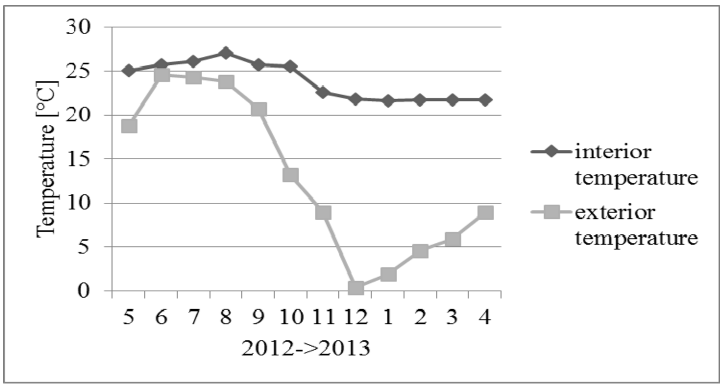


Figure 8. Interior and exterior temperature variation during the monitoring year.

As we can see in the chart in Figure 8, the interior air temperature, in both warm and cold months, has values which largely comply with the recommended guideline values for thermal comfort and hygienic indoor climate, independent of the exterior temperature. This fact proves effective thermal insulation and also effective building solution chosen for the envelope element.

## 3 CONCLUSIONS

The research presented in this paper suggests the growing attention and consideration for the need of building energy efficient houses, being passive houses or nearly zero-energy buildings. Although the passive house concept is not widespread in Romania, such a house can easily be built using techniques and materials which are common in the construction industry of the country.

Implementing a monitoring system in a low-energy house is essential for validating its energy performance and moreover it can lead to further improvement in energy efficiency. Monitoring of the passive house built in the city of Timisoara, Romania, led to a series of relevant conclusions that might be helpful for further development of such type of houses and improvement of the used techniques, planning and detail.

The energy consumption results obtained after one year of monitoring are approximately equal to the estimated consumption in the design phase. As presented earlier in this paper, the registered energy consumption for heating/cooling is 19 kWh /$m^2$year, value which is slightly higher than the estimated value of 15 kWh /$m^2$year. On the other hand, the total registered energy consumption is 45.8 kWh /$m^2$year. This value is far below the value of 66 kWh /$m^2$year, calculated in the design phase. The value of the total energy consumption of the house is not entirely relevant for the energy performance of the building because this consumption may vary depending on the lifestyle of the occupants, appliances installed in the house and so on.

Currently, the studied passive house does not meet the standard imposed by the Passive House Institute in terms of energy consumption for heating and cooling but is a promising experiment for further development in the field. One of the reasons for higher than expected energy consumption for heating and cooling is the fact that the other apartment of the duplex was not inhabited or heated during the monitoring year. Therefore, heat losses occurred through the wall that separates the two apartments which was not sufficiently insulated. An extremely necessary upgrade of the house is the mounting of shadowing elements for the windows, in other to avoid overheating during the summer. Also, in winter days with very low minimum temperatures, the air water heat pump did not functioned properly, registering higher energy consumption. Nevertheless, the house ensures great thermal comfort achieved through well-insulated envelope elements, qualitative windows and an adequate ventilation system with heat recovery.

## AKNOWLEDGEMENTS

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