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Passive house design—An efficient solution for residential buildings in Romania

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ABSTRACT

In a temperate climate such as that of Romania, due to the high differences between comfort parameters and temperate environmental conditions, energy is needed in order to achieve a comfortable indoor environment in both winter and summer. Yet, due to the higher initial investment cost, in Romania, the new solutions for highly energy efficient buildings are rarely used. In order to increase the awareness of the investors on the long-term advantages of these solutions, pilot projects are necessary that provide real-time monitoring on the energy performance and behaviour of energy efficient buildings.

At the Politehnica University of Timisoara, an experimental programme was developed to demonstrate that applying passive house design principles could be an alternative solution for energy-efficient buildings, reflecting the Romanian local climate conditions, materials, and construction techniques. An energy-efficient house was built following the passive house design principles and was subjected to extensive monitoring. In the design phase, the discussed house is compared to a reference house designed following the energy efficiency requirements in Romania, in order to emphasise the differences in terms of energy demand and life-cycle cost. The life-cycle cost analysis results are dependent on the future growth of energy prices. The study contains the results from the monitoring campaign of the energy efficient house, including the monitoring of the energy consumption as well as of the indoor parameters. The monitoring results indicate that the studied house is meeting the passive house design target of total primary energy requirement of less than 120 kWh/m^2 year.

Introduction

Energy efficiency as a solution for climate change, and climate change-related phenomena represents one of the most important concerns and pursuits of humanity, especially in the economically developed areas of the world, such as the European Union. The EU is currently aiming for a 20% reduction of greenhouse gas emissions, an increase in the share of renewable sources by 20% and a 20% increase in energy efficiency by 2020 (Directive 2010/31/EU, 2010). Thus, the European Commission has proposed several measures to increase efficiency at all stages of the energy chain: generation, transformation, distribution, and final consumption (EU, EUROPE 2020, 2010; European Commission's, 2014). In December 2015, the Paris Agreement under the United Nations Framework Convention on Climate Change was adopted and one of its main objectives is to stop “the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognising this would significantly reduce the risks and impacts of climate change” (United Nations Framework Convention on Climate Change (UNFCCC), 2015). One major opportunity for climate change mitigation is in buildings which use approximately 40% of the total EU energy, according to the European Commission (European Energy Security Strategy, 2014). In Romania, the average annual final energy consumption in the residential sector, for the period 2009–2014, was of 7830 thousand tonnes of oil equivalent, representing 36% of the average annual final energy consumption in Romania in the considered period. Approximately 60% of the potential global savings in emissions are from the building sector (International Energy Agency, 2013), which emphasise the need for a sustainable development of buildings.

Background literature and research strategy

Throughout the world, there are many different concepts of energy-efficient buildings, generally defined as buildings with lower energy demand than common buildings, including passive houses, near-zero-energy buildings, or even active houses. Annunziata et al. (Annunziata et al., 2013) stated that after analysing the design of national regulatory

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frameworks on energy-efficient buildings in European countries, the national building regulations adopt different approaches. Although the energy efficiency concept is implemented in other countries where more residential buildings are built using passive house or near-zero-energy principles, the projects are not monitored enough to validate the design solutions and user satisfaction. This fact was underlined by Mlecnik et al. (2012), Danner (2003), and Hauge et al. (2011), who concluded that post-occupancy evaluation (POE) could be a valuable measurement of the satisfaction of indoor climate in efficient buildings. According to Sartori & Hestnes (2007), operation represents 90–95% of the total life-cycle energy consumption in conventional buildings, and the rest represents the energy embodied in materials and production. Therefore, one way of reducing the environmental impact of a construction project is to improve the energy performance of the building (Kashreen et al., 2009).

Results from Morrissey et al. (Morrissey & Horne, 2011) suggest that the cost savings from higher efficiency standards are significant over 25-year and 40-year time horizons. In another study, Kurnitski et al. (Kurnitski et al., 2011) demonstrate that when compared with passive house standards, the cost optimal value is almost the same as that required for passive houses in the Central European climate. Dall'O' et al. (Dall'O' et al., 2012) presented a comparative study between predicted and real consumption for one residential building in the Lombardy region (Italy). It was concluded that the problem of air conditioning in the summer is much more complex than that of winter heating, due to solar radiation.

Outside of Europe, in USA, Parker (2009) stated that, starting from measured values, the both new and existing very low-energy buildings are fully within our grasp if society deems their achievement a national priority. Zhu et al. (Zhu et al., 2009) analysed two residential buildings built in suburban Las Vegas, using both conventional and newer, efficient solutions. It was found that an insulated slab is effective during the heating season but does not contribute to energy savings during the summer.

To achieve the passive house standard, a building must have an annual heating/cooling energy demand of at most 15 kWh/(m^2year) and a total primary energy demand of less than 120 kWh/(m^2year) (Passive House Planning, 2007). A passive house combines high-level comfort with low energy consumption. Passive components such as insulation, advantageous orientation, heat recovery, and an air-tight envelope are the key elements that reduce the need of actively heating of the house. The small amount of additional heat which needs to be supplied is frequently realised with heat pumps (Ochs et al., 2011). A proper design and execution can lead to a highly energy-efficient building which consistently provides pleasant indoor and surface temperatures. The passive house concept can be adapted to any climate zone; depending on the climatic conditions, the quality and type of components, materials, and equipment may vary.

Currently, the knowledge informing passive house design solutions for buildings located in geographical and climatic areas such as Eastern Europe are not as developed as in Western Europe. In Romania, the passive house concept is relatively new, and most people are sceptical of approaching it, generally because of the higher initial investment. Nevertheless, in recent years, several passive house projects were successfully implemented in different parts of the country. Near Bucharest, a passive office building was built and has been in use since February 2009. The research on this passive building proves that the PH standard applies to heating demand in Romania, but special attention should also be paid to the cooling demand when designing and planning a PH in Romania (Badescu et al., 2011).

This paper refers to a residential house complying with the European PH standard, designed and built in Timisoara. Located in the western part of Romania, Timisoara is the third largest city in the country and economically one of the most important. Unlike Mediterranean and Scandinavian countries, which have to manage mainly one side of the issue (cooling or heating, respectively), Romania is situated in south-eastern part of the European continent and is characterised of a transitional climate between temperate and continental, having large temperature differences between the hot and the cold seasons. Therefore, attention should be paid to both heating during the winter and avoiding excessive overheating in the summer. Moreover, as Romania is a highly active seismic country and because Timisoara is in a zone with peak ground acceleration of $a_g = 0.16$ g, special structural requirements and detailing are imposed by seismic codes at the concept and design stages of a building.

The Passive House Planning Package (PHPP) procedure (Feist et al., 2007; Passive House Planning, 2007) and the Romanian national Energy Performance of Buildings Calculation Methodology MC 001 (Mc 001-2006) were adopted for evaluation of the standard energy performance of the buildings.

To prove the achievement of passive house standards and to assess deviations in the energy performance evaluation procedures, the house was equipped with extensive monitoring instrumentation; thus, the evaluation of the actual performance of the building was made by analysing energy use data during an entire year of occupancy. Costa et al. (2013) presented a possible solution that can increase the energy performance using a monitoring and optimization toolkit.

The aim of the research programme was to assess the real energy efficiency of the building based on measured external climate parameters, underlining the divergences between theoretical and monitored data-based evaluations. The study placed emphasis on validation of the specific details applied in the design of passive buildings located in temperate climate zones and seismic areas.

Design process of the house

Envelope and building services

The design and planning of the house were conducted following the passive house design principles, in such a way as to obtain a high level of energy efficiency at an affordable final price. Therefore, special attention was paid to the details necessary to obtain an efficient thermal envelope, strict control of the air exchange between the interior and exterior environments, and a high-performance HVAC system with heat recovery.

The house was built as a semidetached house and has approximately 140 m^2 of living space, corresponding to the needs of an average family. From an architectural perspective, the energy-efficient house built in Timisoara presents a compact form and has south-facing facades with considerable glazing surfaces (Fig. 1). Triple-glazed windows were used, providing resistance to condensation problems and reducing sound transmission, in addition to saving energy. The south orientation of the windowed facades has advantages during winter through solar heat gains, ensuring passive solar heating, but might represent a disadvantage during summer due to the risk of overheating events in the absence of shading systems. At the moment, the studied house does not have any special shading devices but are taken in consideration for future investment. The compactness of the building is indicated by the thermal envelope surface area to volume (A/V) ratio of 0.89 m^2/m^3 and by the heat loss form factor of 2.77. The heat loss form factor is an alternative to the A/V ratio and describes the ratio of the thermal envelope surface area to the treated floor are. Achieving a heat loss form factor of ≤ 3 is a useful guideline when designing a passive house (BRE Trust).

The house is composed of masonry structural walls of 250-mm-think ceramic hollow bricks, confined with reinforced concrete horizontal and vertical ties to meet seismic regulations. The use of external insulation provides a major advantage in reducing thermal bridges at geometric junctions. The vertical surfaces were complemented with general thermal insulation consisting of polystyrene plates of 300 mm thickness, while only 150 mm of thermal insulation was provided for the upper part of the parapet. The roof system is a non-traffic terrace