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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^{2}year) and a total primary energy demand of less than 120 kWh/(m^{2}year) (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

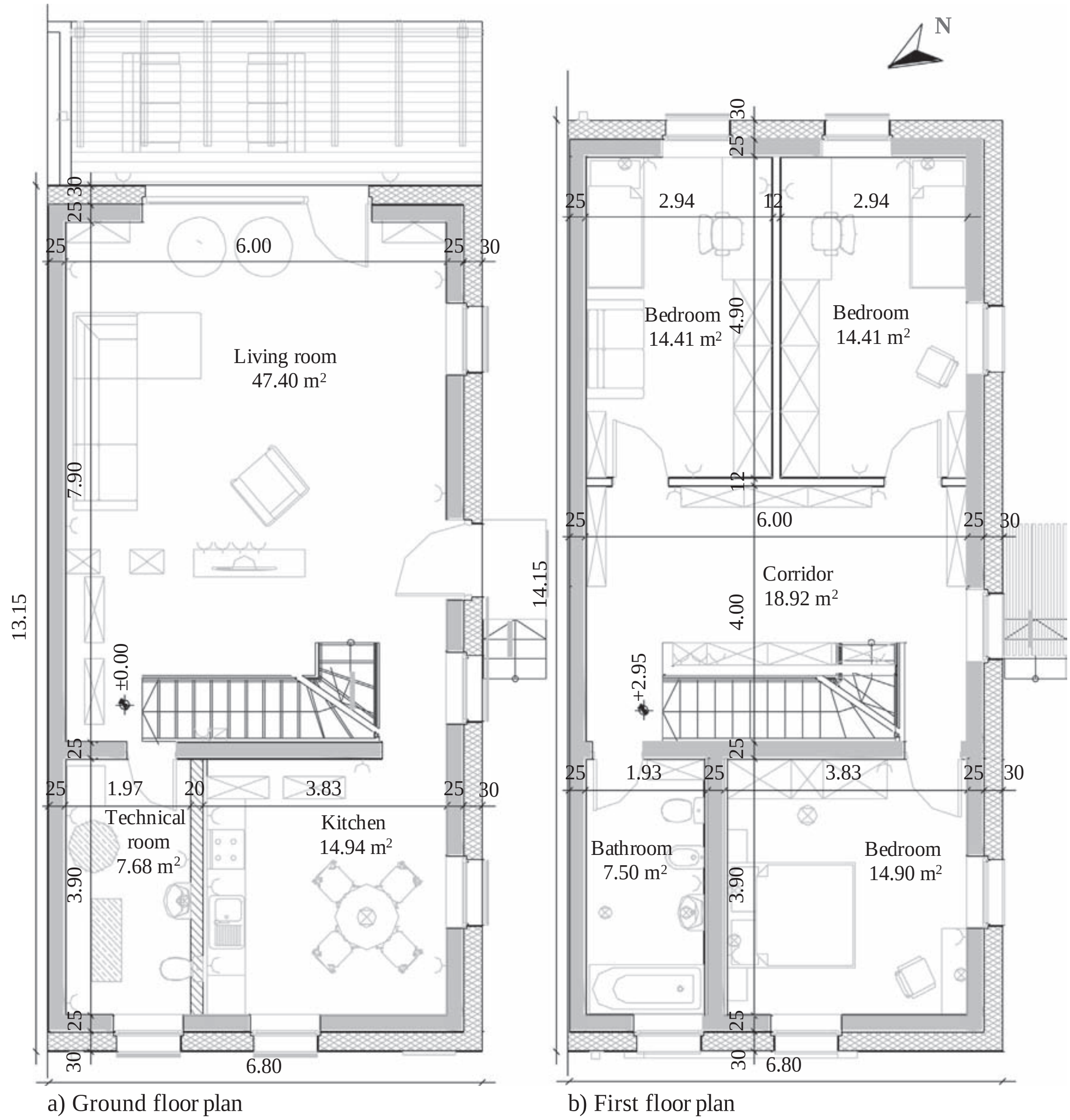


Fig. 1. Architectural plans of the studied passive house.

with a slope of 2%, which incorporates 425 mm thick thermal insulation (Fig. 2).

The thermal bridge free design was verified through numerical analyses using a dedicated software of thermal transfer calculation ANTHERM (Anon.). For all the analysed details, the linear thermal transmittance coefficients (ψ-values) were ≤0.01 W/(mK) and even negative, allowing to neglect them in the energy demand calculation (Passive House Planning, 2007).

The infrastructure system of the house consists of isolated concrete blocks connected with foundation beams to comply with the seismic building requirements and to preserve an envelope free of thermal bridges. The foundation system reduces the amount of concrete used and facilitates the thermal insulation of the entire ground floor, the polystyrene plates being applied from the foundation beams upwards (Fig. 2).

The over-structure was designed to conform to the P100/2006 (2006) Romanian standard, which is a stricter version of European code EN 1998–1 (EN 1998-1). Based on these requirements, the structure was designed for a peak ground acceleration of ag = 0.16 g. More details of the research programme developed at Politehnica University of Timisoara were presented in Stoian et al. (2013). Fig. 3 presents a series of photos taken during construction of the house.

The airtightness of the building was verified through a Blower Door test procedure at pressure of 50 Pa. The airtightness test indicated an air change rate of 0.60 h^{-1}.

Besides the careful planning and execution of the building's envelope, other challenging aspects in obtaining an energy efficient house are related to the building services. The studied house has a complex system providing heating, ventilation, and domestic hot water. The scheme presented in Fig. 4 illustrates how the building equipment of the investigated house operate. The key components of the system are a heat recovery ventilation unit that features an underground heat exchanger for fresh air input, an air-to-water heat pump, and a solar collector. The house is equipped with a hot water boiler and a heating buffer for thermal energy storage. The heat is distributed throughout the rooms through fan convectors installed in the ceiling. Table 1

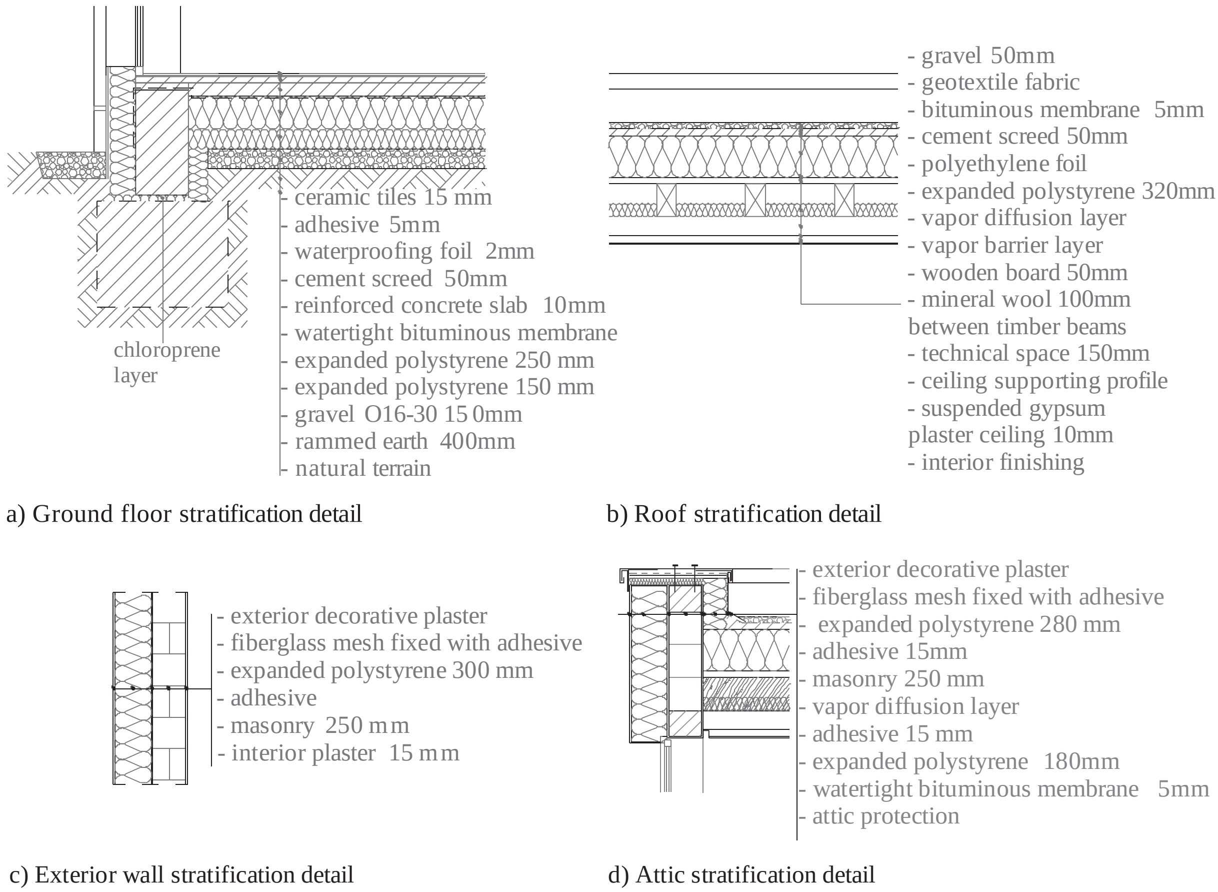


Fig. 2. Detail and stratification of the envelope elements.

shows the characteristics of the ventilation system. The effective heat recovery efficiency value of the heat recovery unit was provided in the technical information of the equipment. Additional heat necessary to maintain the indoor climate is sourced by the air–water heat pump that has performance coefficient of 2.7. The heat pump is also useful to provide domestic hot water when the solar collector does not cover the needs entirely.

Energy use evaluation

The energy demand evaluation in the design phase of the house was performed using Passive House Planning Package software and also the DOSET PEC software, which is a Romanian programme used for evaluating the energy performance of buildings. The main advantage of the Passive House Planning Package software is that all components for the thermal envelope and the building services can be optimised to achieve the entire maximum technical potential of the respective component (Certified European Passive House (CEPH)). The Romanian software DOSET PEC is commonly used in Romania for determining the building energy performance class. The corresponding building energy performance class (A–G) along with the corresponding CO_2 emissions are presented on the energy performance certificate. The calculation procedure is described in the Romanian national Energy Performance of Buildings Calculation Methodology MC 001 (Mc 001-2006).

The calculations with the two programmes were made using two different sets of climate data: climate data provided by METEONORM weather database (http://meteonorm.com/); the conventional climate data from the Romanian national Energy Performance of Buildings Calculation Methodology MC 001 (Mc 001-2006). In order to identify the impact of passive house design compared to the common energy-efficient design encountered in Romania, two design variants of the discussed house were analysed with PHPP and DOSET PEC: the house designed following the passive house required design principles (H1); the house designed following the actual energy efficiency criteria and requirements for the Romanian building sector (H2) (C107/2005). Besides the thermal envelope characteristics, the differences between the two design types are also related to heating, ventilation, and DHW systems (Table 2). All the simulations were performed using an interior temperature of 20 °C. The results of the calculations are presented in Table 3. The differences between the results obtained with the two calculation programmes are relatively low, which confirms the tendency to apply the same models and methods in evaluating the energy use, methods that are certified at European level by measurements, but also highlights the use of alternative Romanian calculation methods following the research determined in this area, for example, the heat transfer through building elements in contact with the ground. A small difference is identified regarding the conversion factors for primary energy and CO_2 emissions.

Life-cycle cost analysis

The design and construction of a house following the passive house design principles imply a higher initial investment, so it is important to verify the cost performance over a period of time. Life-cycle cost analysis is a valuable technique for assessing and comparing different building designs in terms of initial cost increase versus long-term operational cost benefits (Miro et al., 2013). Currently, there is no internationally accepted common methodology or structure for the life-cycle cost assessment, but several guidelines, standards, and handbooks have been

Fig. 3. Phases of the construction process.

developed (Guidelines for life-cycle cost analysis, 2005; International Standard ISO, 2008; Fuller & Petersen, 1995).

The life-cycle cost analysis model adopted in this paper uses the discounted costs method. A comparative life-cycle cost evaluation was performed for the house designed following the passive house design principles (H1) and the house designed following the actual Romanian energy efficiency criteria (H2), which is basically the same house but has a different thermal envelope and building services.

The relevant cost categories considered in this analysis are initial investment costs, energy costs, and maintenance costs. The differences between the two design variants, in terms of initial investment, consist of the thermal system, window quality, and mechanical systems and building equipment. The initial investment for H1 was evaluated at 92.600 € and the initial investment for H2 was evaluated at 73.000 €. The life-cycle cost calculation was completed for a period of 20 years. The analysis period was determined by an estimated renovation cycle of the building, which represents the time after which the building is subjected to a series of major renovations and overall improvement (European Commission, 2012). In order to take into account the time value of money, a discount rate and price escalation rate must be considered. For Romania, according to the "Guide to Cost–Benefit Analysis of investment projects" (European Commission,

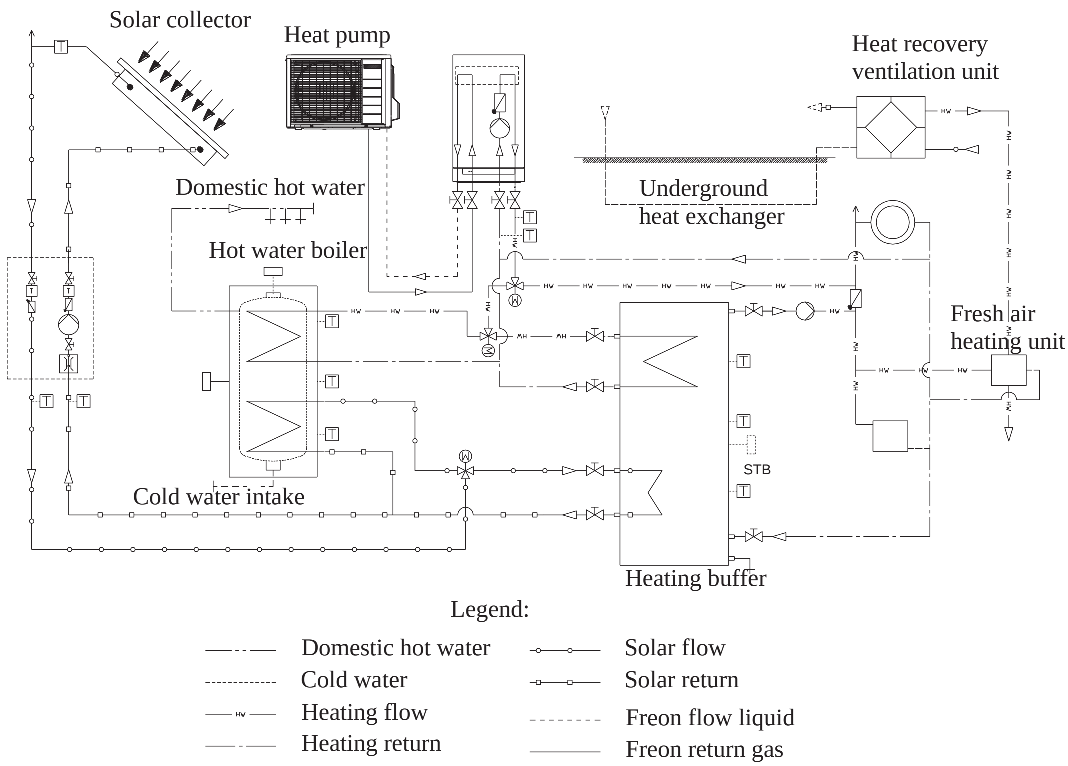


Fig. 4. Schematic representation of the building's heating and ventilation systems.

2008), a discount rate of 5% is recommended. Estimating future price escalation rates for energy and maintenance costs implies a high degree of uncertainty. The analysis was performed using the average of the annual price escalation rates for electrical energy for the last 10 years in Romania, which is 4.2%, calculated using data provided by the statistical office of the European Union EUROSTAT (http://ec.europa.eu/eurostat/web/main).

Along with the life-cycle cost assessments, the payback time was determined, which is the time required to recover the supplementary investment in H1 compared to H2. As shown graphically in Fig. 5, after 13 years, the cost of H2 overcomes the cost of H1, meaning the payback time was achieved. The payback time and results of the life-cycle cost analysis are strongly dependent on the growth of energy prices and present a certain risk due to the degree of uncertainty when estimating the evolution of future costs. However, past experiences prove that in the long term, prices have the tendency to increase rather than to remain constant or decrease; this is especially true in case of energy prices, which are extremely relevant for this analysis.

Table 1
Parameters of the ventilation system with heat recovery.

Component	Effective efficiency [%]
Heat recovery unit	81.2
Subsoil heat exchanger (SHX)	19

Monitoring system

In order to obtain a monitoring system with minimum costs, several turn-key solutions were evaluated. Although on the market there were available ready-made monitoring systems, the decision was to create a system based on components that were available separately, with the disadvantage of a higher labour of its assembly and implementation. The components of the systems were chosen based on the need to make data available online and on the type and number of parameters that were to be monitored. The resulted composition of the system is as follows.

Table 2
Thermal envelope characteristics and building services.

	Thermal transmittance of the envelope elements [W/m^{2}K]							Ventilation system	Space heating and DHW
	Exterior walls	Partition wall to neighbour	Ground floor	Floor over air	Roof	Windows	Exterior door		
Passive house requirements Feist et al. (2007); Passive House Planning (2007)	All opaque envelope elements must have U-values ≤0.15					≤0.85	≤0.85	Mechanical ventilation system with heat recovery	Examples: Compact heat pump unit; air/soil/water–based heat pump; direct electricity; biomass heating
H1	0.10	0.10	0.087	0.10	0.08	0.90	0.90	Mechanical ventilation system with heat recovery	Air to water heat pump and heating fans, solar collector
H2	0.55	0.55	0.22	0.20	0.20	1.29	1.20	Natural ventilation	Electricity/gas central heating with radiators

Table 3
Simulation results of the analysed house.

Design concept	Climate data	Heating energy demand [kWh/m^{2}year]		Total primary energy [kWh/m^{2}year]		Total emissions CO_2- equivalent [kg/m^{2}year]	
		PHPP	DOSET PEC	PHPP[a]	DOSET PEC[b]	PHPP[a]	DOSET PEC[b]
Passive house design—H1	Weather database METEONORM (http://meteonorm.com/)	14	13.5	104	73.5	26.2	14.6
	Romanian methodology MC 001 (Mc 001-2006)	16	15.6	109	79.2	27.6	15.8
Actual Romanian energy efficient design—H2	Weather database METEONORM (http://meteonorm.com/)	92	96.5	223.7	253.8	52.9	48.2
	Romanian methodology MC 001 (Mc 001-2006)	96	105.1	228.4	265.2	54.1	50.3

[a] Total primary energy. Primary energy conversion factors: 2.7 (electricity) and 1.1 (gas). CO_2 emission factors 0.680 kg/kWh (electricity) and 0.250 kg/kWh (gas) (Feist et al., 2007).
[b] Primary energy for HVAC, DHW, lighting. Primary energy conversion factor: 2.8 (electricity) and 1.1 (gas). CO_2 emission factor 0.557 kg/kWh (electricity) and 0.205 kg/kWh (gas) (Mc 001-2006).

Central unit

The central unit is commercially available under the Web Energy Logger (WEL) name. The WEL collects measurements from the sensors every minute and posts the data to a webserver provided by the manufacturer of the unit. The service offers the possibility to display trend graphs for collected data and to download all data in spreadsheet-friendly form. The need to provide a low-cost option for commercially available router featuring a USB port that was in turn connected to a 3G WWAN access modem offering a flat rate internet access. The router in turn provides an Ethernet connection to the WEL. The module is configured to reset the power to the router anytime a connection time-out is detected and also provides local data display, very useful during the setup of the system (Fig. 6).

In addition to storing the information, the interface unit stores minimum, maximum, and average values that are reported every minute as the bus is polled. The unit is also programmed with a threshold value that enables certain ranges of data to be protected from overwriting until access to the unit is possible and the locally stored data can be downloaded and further analysed.

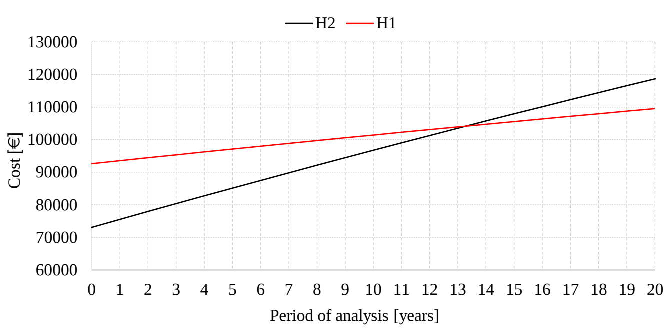


Fig. 5. Life-cycle cost calculation over 20 years.

Measuring components—Sensors and energy metres

Among the measuring components, the most relevant for this study are temperature sensors, air humidity sensors, solar radiation metres, CO_2 concentration sensors, and electrical energy metres. The most relevant monitored parameters can be visualised online (http://

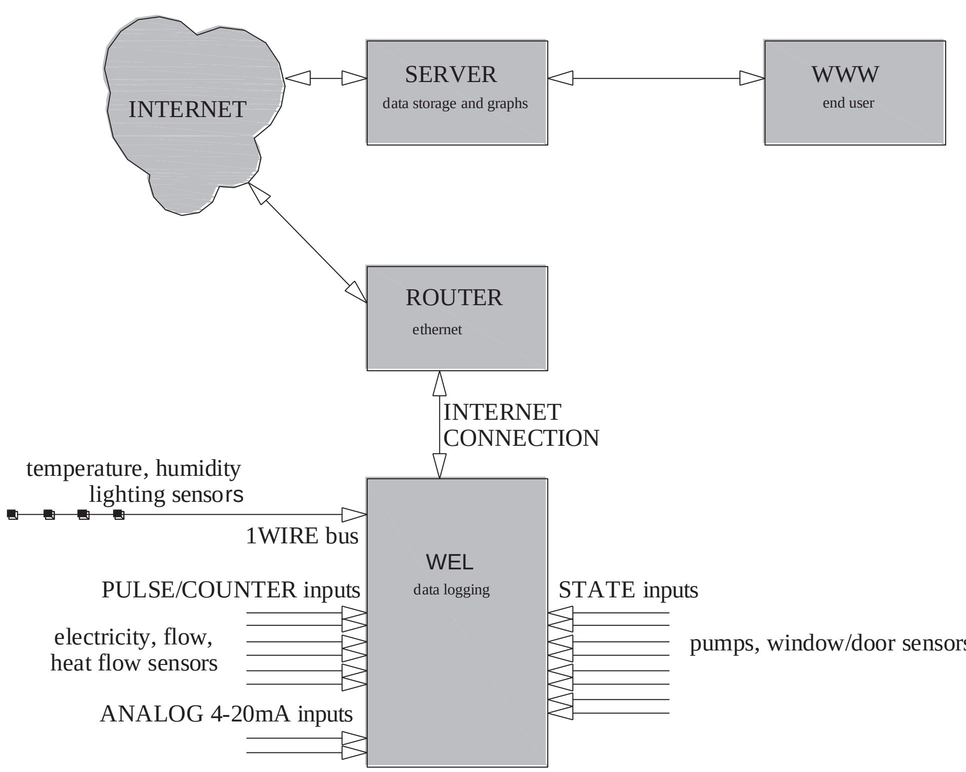


Fig. 6. Schematic representation of the monitoring system.

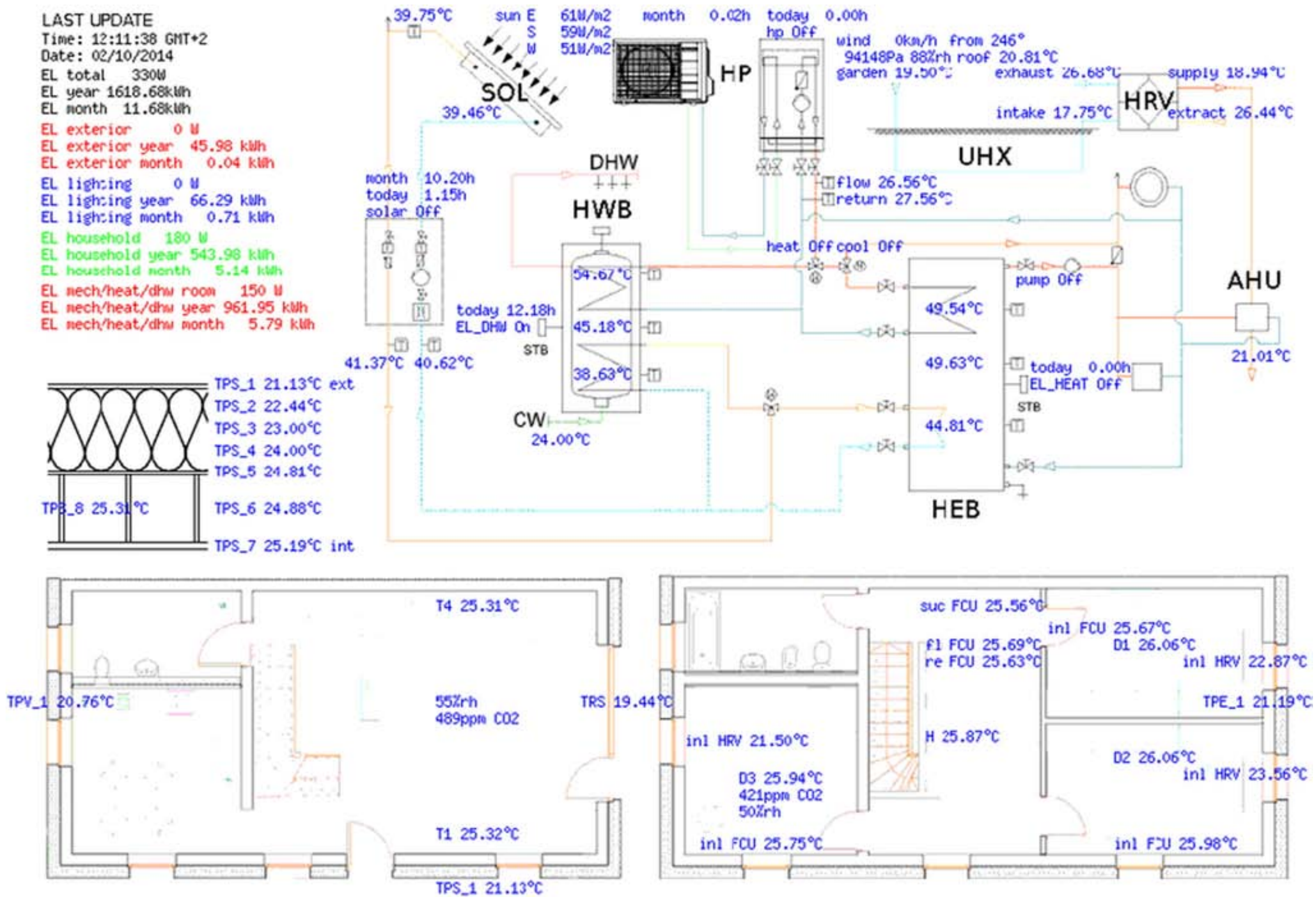


Fig. 7. Interface of the online, real-time monitoring system (an example from 02 October 2014).

www.sdac.ro/site/archives/796) where a monitoring scheme is provided (Fig. 7) and also graphs for collected data.

The temperature sensors used in the study are low-cost sensors that were readily available and have a measuring range from −55 to 125 °C with a precision ±0.5 °C. The multitude of temperature sensors measure various temperatures (air, envelope elements, cooling/heating, ventilation system, water, underground heat exchanger). The humidity sensors have a measuring precision of ±3.5% for measuring range from 0% to 100% RH. For solar radiation measurements, silicon pyranometers with amplified output are used that provide a 1% linearity up to 3000 W/m^2 and the measurements are made with an error of ±5%. The electrical energy consumption is measured through several electrical energy metres in order to obtain the energy consumption broken down by consumer categories (Table 4).

Analysis of monitored data

The monitoring process was initiated at the end of 2011 even if for that moment not all the measuring components were available such as solar radiation, sensors that indicate equipment operation and some water temperature sensors. Since complete sets of climate data are available starting with May 2013, the real energy performance of the building will be evaluated for two seasons, meaning June 2013 to May 2014 and June 2014 to May 2015.

Table 4
Electrical energy consumption monitoring—consumer categories.

Recorder ID	Electrical energy consumer
EL_1	House hold appliances
EL_2	Lighting
EL_3	Heating, ventilation, hot water
EL_4	Exterior

Indoor air temperature and humidity

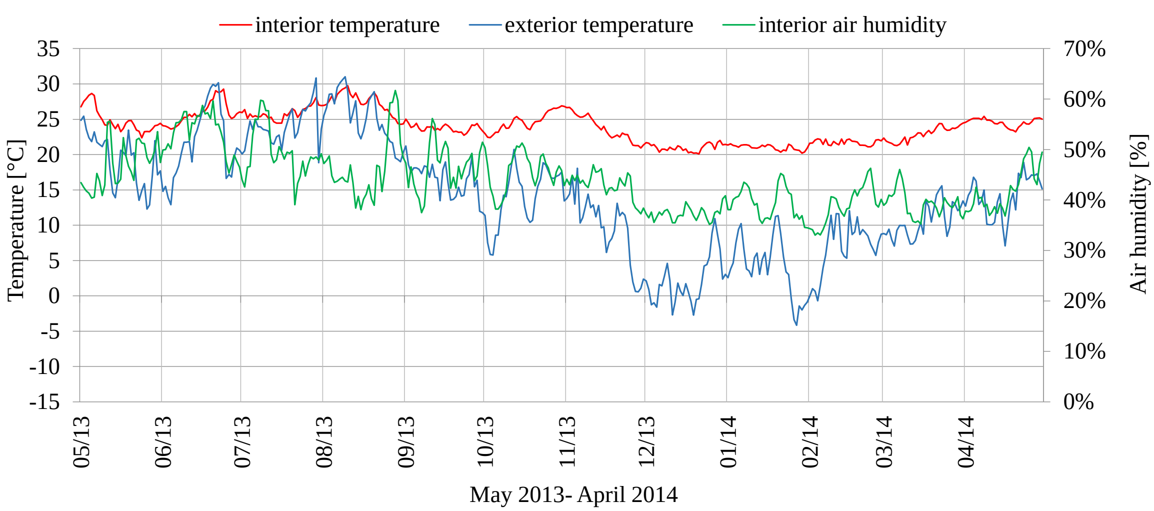
The main purpose of residential buildings is to offer their occupants a comfortable environment where hygienic conditions are met and the occupants can optimally conduct their activities during the entire year. The south orientation of the windowed façade and lack of an active cooling system, as it is specific to passive houses, might lead to overheating during summer if passive cooling techniques such as strategic shading or night cooling (windows opening) are not considered. The Passive House Institute recommends a limit for the frequency of summer overheating events when indoor temperature is higher than 25 °C. Thus, it is recommended that the frequency of overheating to be less than 10% of the total number of occupied hours in a year. According to EN ISO 7730 (Thullner, 2010), the recommended design temperature for winter is from 20 to 24 °C, and for summer from 23 to 26 °C, in order to keep the amount of dissatisfied occupants below 10%. In order to provide an indicator of the overheating period, for this study, the frequency of overheating was calculated at 25 and 26 °C limit using two methods. The first method consists in PHPP simulations that were made using the climate data registered by the monitoring system in the seasons May 2013–April 2014 and May 2014–April 2015 (Table 5). The overheating period was also determined based on the monitoring of the interior temperature, expressed as a percentage of the total hours of the year (May 2013—September 2013, May 2014—September 2014) when the temperature inside the house overcame the value of 25 and 26 °C (Table 5). The temperature sensors registered the interior air temperature at every minute. In order to obtain the number of hours, the number of minutes with interior temperature

Table 5
Frequency of overheating determined through monitoring.

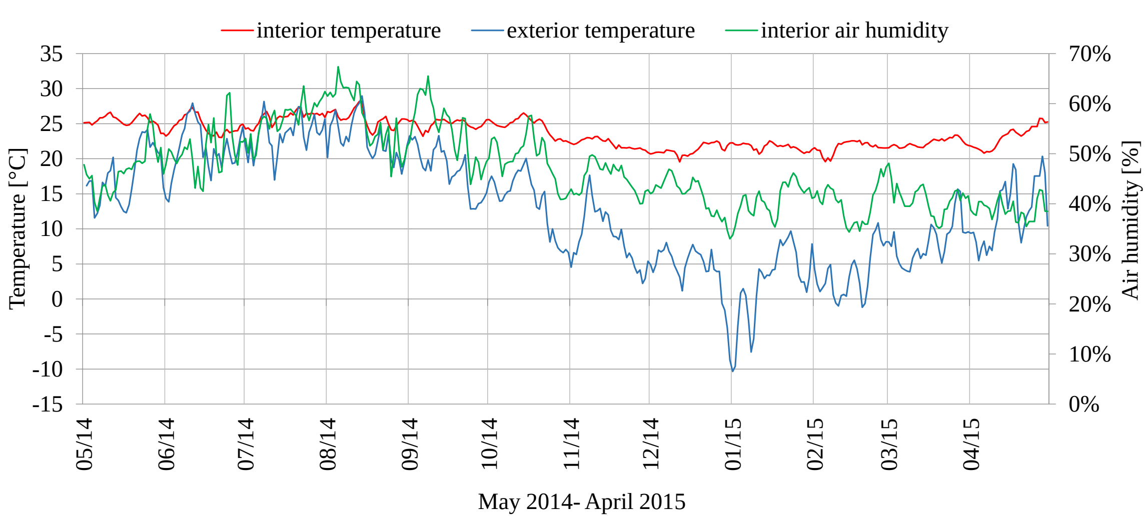
Climatic year	Frequency of overheating at 25 °C		Frequency of overheating at 26 °C	
	PHPP -simulation	Calculated	PHPP-simulation	Calculated
May 2013–April 2014	31.4%	25.3%	25%	16.3%
May 2014–April 2015	25.7%	24.3%	20.6%	11.4%

higher than 25 °C, respectively, 26 °C was counted and converted into hours (Table 5).

Fig. 8 shows diagrams of the monitoring campaign May 2013–April 2015. These graphs show the daily mean temperature inside the house and the daily mean exterior temperature for the period of monitoring. Also, the graphs present the interior air humidity registered in the monitoring period. According to ISO 7730 (ISO 7730-2006), humidity influences the thermal comfort of the human body (heat balance). This influence is rather limited at temperatures below 26 °C and moderate activity levels. For higher temperatures and activities, humidity has a greater influence on thermal comfort. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) (ASHRAE 62-1999) provides guidelines that recommend a relative humidity of 30–60%. Levels less than 30% in the winter and greater than 60% in the summer should be unacceptable. Analysis of the graph in Fig. 8 a) and b) shows that the interior air temperature is maintained at values between 20 and 22 °C for the winter months, indicating adequate thermal comfort. As we can see, for the winter months, the thermal envelope of the house, along with the heat recovery ventilation system and heat pump, is able to maintain an internal temperature corresponding to thermal comfort needs. Yet for the summer months, there were days when the daily mean temperature was higher than recommended, as indicated by the frequency of overheating events during the sunny summer days. The causes of the overheating are the lack of shading systems for the windows and of an active cooling system, the house being cooled solely during the night through windows opening. Despite the overheating of the house during the summer days, the users of the house did not claim any major discomfort.



a) Monitoring campaign May 2013 – April 2014



b) Monitoring campaign May 2014 – April 2015

Fig. 8. Temperature and air humidity measurement over the monitoring period.

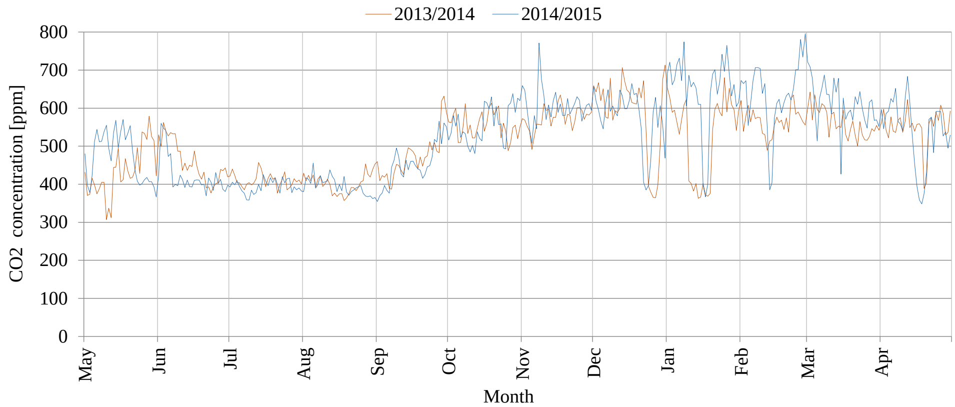


Fig. 9. CO_2 concentration measurement over the monitoring period.

CO_2 concentration measurement

Indoor air quality in houses depends of many factors such as the number of persons and time of occupation, emissions from activities, emissions from furnishing, construction materials, cleaning products, etc. (EN 15251, 2006). Among the pollutants in the indoor air that represent a health risk are nitrogen oxides, formaldehyde, carbon monoxide, radon, and ozone (Passivhaus Dienstleistung GmbH, 2012). The CO_2 concentration can be used as an indicator for the degree of indoor air quality in buildings where people are the main pollution sources. According to European Standard 15251 (EN 15251, 2006), new buildings should have the CO_2 concentrations lower than 500 ppm above the outdoors for most of the time. For the studied house, CO_2 sensor was mounted in the living room. Even though the house occupancy was not monitored, it is known that the house is constantly inhabited/used by 3 persons and the number of people increases occasionally during guests' visits. The measured CO_2 concentration for the living room over the monitoring period is presented in Fig. 9. With the average outdoor concentration in Timisoara of 350 ppm, it can be noticed that the indoor CO_2 concentration has an acceptable level during the year, lower than 800 ppm.

Simulated and measured energy use

The energy use of the house is continuously monitored through a series of electric data recorders. All equipment installed in the building uses electricity, which facilitates an accurate and clear evaluation of the building's total energy use. Using the data registered with the electric recorders, the actual energy use of the building is obtained, broken down by consumer categories.

PHPP simulations were performed using the real environmental conditions registered by the monitoring system from May 2013 until April 2015 in order to make a comparison between the estimated energy requirements using real environmental conditions and the real energy use of the house measured by the monitoring system in the considered period (Table 6). The comparison between the real registered energy use of the house and the results provided by PHPP shows small differences that highlight the PHPP software's ability to provide reliable results.

Table 6
Real energy performance using monitoring data.

Parameter	Tool	Period	
		2013–2014	2014–2015
Heating energy demand [kWh/m^{2}year]	PHPP simulation[a]	12	14
DHW energy demand [kWh/m^{2}year]		23.1	22.6
Cooling energy demand [kWh/m^{2}year]		15	13
Heat pump and auxiliary electricity [kWh/m^{2}year]	PHPP simulation[a]	23.6	25.1
	Measured	23.2	29.5
Household electricity [kWh/m^{2}year]	PHPP simulation[a]	13.1	13.1
	Measured	10.5	10.9
Primary energy[b] [kWh/m^{2}year]	PHPP simulation[a]	99	103.1
	Measured	94.4	113

[a] PHPP simulations were performed using the monitored interior temperature in the heating season: 22.7 °C for 2013–2014 and 22.5 °C for 2014–2015.
[b] Primary energy conversion factor 2.7 (electricity).

Conclusions

One of the most relevant methods of promoting new energy-efficient buildings in the real estate market is to build pilot projects that could transparently show whether a solution such as a passive house or nearly-zero-energy building can be successful in the local conditions. Romania, as a member of the European Union, implemented national regulations regarding the energy efficiency of buildings. The national current regulations adopt approaches similar to other European countries but are not very restrictive when it comes to energy efficiency and renewable energy use in buildings.

The first part of this study shows the main differences between two design variants of a residential building. The passive house design leads to a reduction of the heating energy demand of approximately 84% compared to the actual energy efficient design in Romania. Consequently, the total primary energy demand is 53% lower and the CO_2 emissions 50% lower.

In case of the building studied in this paper, the initial investment in the house designed applying passive house measures (H1) is approximately 26.7% higher than the investment in the house designed considering the minimum energy efficiency requirements in Romania (H2). The difference between the two investments is considerable, emphasising the weak requirements in terms of energy efficiency for buildings in Romania and also the costs still very high for qualitative thermal insulation, windows and energy-efficient building equipment in the Romanian market. The life-cycle cost analysis results are strongly dependent on energy prices and the interest rate. Further studies and sensitivity analyses are needed to examine the life-cycle cost of such investments.

The results from assessing the energy performance for the studied building, using PHPP and the Romanian calculation methodology, demonstrate the capability of the Romanian calculation methodology and specialised computer programmes to determine the energy performance of buildings according to European standards.

The second part of the study concentrates on evaluating the real performance of the house through monitoring. The interior temperature and humidity indicate adequate comfort during all seasons, with overheating in the summer season. The CO_2 concentration remained at acceptable levels, with a slight but acceptable increase in the winter season. As a future improvement and increase of thermal comfort during the summer sunny days, additional shading devices are considered and also the use of the air–water heat pump as an active cooling system when is needed.

For the purpose of this paper, the total energy use of the house was evaluated using the monitoring registrations in 2 years. The PHPP simulations using the exterior environmental conditions registered by the monitoring system and also the real interior temperature adopted by the users show that the studied house is meeting the passive house design target of total primary energy less than 120 kWh/m^2year and energy demand for heating below 15 kWh/m^2year. Considering that the monitoring system registers data at every minute, energy simulations with dynamic models are expected to be developed in order to more accurately assess the energy performance of the building. Although building performance was evaluated only as a function of winter heating energy use, it is absolutely necessary to also consider the cooling energy use in the summer.

The experience with the monitoring process led to the conclusion that a monitoring system with an accessible web interface is an efficient solution that offers enough transparency to monitor the behaviour of the building in terms of energy consumption and comfort parameters.

The energy-efficient house built in Timisoara is a promising experiment and invites further development in the field; multiple values of heating energy demand must be considered as a function of the indoor conditions adopted in the design phase of the PH standard because practice shows that users generally adopt higher interior temperatures during the winter than conventional assumptions; additional years of monitoring will provide more reliable data about the energy performance of the house. Decisions to improve the energy performances of buildings have long-term consequences, and more pilot projects are needed to promote efficient solutions in buildings and to evaluate user satisfaction. Energy-efficient buildings, built using passive house details, could be an alternative solution for temperate climate areas such as the Romanian territory.

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