U.P.B. Sci. Bull., Series C, Vol. 78, Iss. 4, 2016 ISSN 2286-3540

ACHIEVING HIGH ENERGY PERFORMANCE FOR LOW ENERGY BUILDINGS IN ROMANIAN CLIMATE USING GREEN ENERGY

Alexandra DANU[1], Vladimir TANASIEV[2], Mihail-Bogdan CĂRUŢAŞIU[3], Adrian BADEA[4]

The European Union is promoting renewable sources by searching new ways of saving energy in order to minimize the impact on the environment of the conventional power plants. The research focuses on the importance of renewables in energy balance of the Passive House during warm season. Secondly, it was analysed the influence of the environment on the behaviour of the low energy building. For study, it was analysed the Passive House located in the University Politehnica of Bucharest campus. The monitoring system installed acquires information about indoor comfort level and energy balance between house, grid and photovoltaic system.

Keywords: climate conditions, green energy, low energy buildings, energy consumption, energy balance

1. Introduction

The society development stage reached today is directly related to the usage of the electrical energy in all activity sectors. Worldwide, electricity production has increased in the last two decades, reaching 23132 TWh in 2013, which represents more than double compared with the year 1990 [1]. The continuing development of the world made the energy requirements to grow at a rapid base. Electricity production in Europe represented 21.0% of the total world energy production between 1990 and 2014. In the EU (European Union), both consumption and electricity production followed the same upward trend. The energy produced from renewable sources increased between 1990 and 2013 from 12.8% to 33.0% [1,2,3] and was largely supported by policies of promoting clean energy sources.

1 PhD Eng., Faculty of Energetics, University POLITEHNICA of Bucharest, Romania, e-mail: alexa.danu@gmail.com
2 Lecturer, Faculty of Energetics, University POLITEHNICA of Bucharest, Romania
3 PhD Eng., Faculty of Energetics, University POLITEHNICA of Bucharest, Romania
4 Prof., Faculty of Energetics, University POLITEHNICA of Bucharest, and President of Academy of Romanian Scientists, Bucharest, Romania Romania

In Romania, the electricity production followed a constant trend over the last two decades. Moreover, the production of electricity from renewable sources increased from 11 TWh/year in 1990 to 25 TWh/year in 2014 [4]. At the same time, the energy consumption decreased by the end of 2014 to 49 TWh from 60 TWh in 1990 [4].

According to directive 2012/27/EED of the European Parliament and of the European Council [5] the energy production from renewable sources shall represent 24% from the total energy production by the end of 2020 in Europe. At the end of 2014 Romania reached the target with more than 35.0% share of renewable energy sources [2].

In Romania, the energy provided by the PV (photovoltaic) panels in 2014 was 1295.3 GWh and represented 2.1% of the total energy production, an increase with 874.9 GWh compared with 2013 [6]. The energy produced by wind turbines was 4720 GWh and by microhydro plants 18990 GWh in 2014 [6].

The energetic strategy of the EU aims to reduce the energy consumption in all activity sectors. The residential and tertiary sector is the largest end-use energy consumer, responsible with more than 40% of the total primary energy [7]; thus, the Directive 2002/91/EC of the European Parliament and of the Council of Energy Performance of Buildings was issued in 2002 [8]. The objective of the directive is *‘to promote the improvement of the energy performance of buildings within the Community, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness’* [6]. The Energy Performance of Buildings Directive requires all new buildings to be nearly Zero Energy Building (*nZEB*) by the end of 2020 and all new public buildings to be nZEB by 2018 [9]. The 2013 progress report from the Commission [9] stated that EU countries should increase their efforts in order to meet the deadlines for new buildings to be nZEBs. In October 2014 was published an overview of Member States information on nZEBs that shows a clear improvement, both quantitatively and qualitatively of the information submitted to the European Commission compared to year 2013. Until the report was published all Member States submitted the national plans. Romania has made a significant progress regarding the definition of nZEB which include both numerical target of primary energy use and the share of renewable energy sources [9].

The definition proposed by Romania for nZEB is: *'Nearly zero energy buildings are characterized by low consumption of energy from fossil sources and use renewable (non-fossil) sources of energy, in a proportion established through the procedure defining the minimum requirements in accordance with the provisions in Articles 4 and 5 of Directive 31/2010/EU'*. The national plan for nZEB reflects the adaptation of nZEB in line with local climate, economic and cultural conditions, including strategies and policies for specific building categories [9]. Therefore, in 2012 the 'Green house' program was implemented in the national Romanian plan for energy efficiency as a start for building rehabilitation [10]. In nZEB roadmap, Romania had established that beginning with year 2018 all new building purchased or built by the public sector should be very low energy buildings [10].

The certifying procedure of a nZEB starts from the moment of its design when a PHPP (Passive House Planning Package) is used [11,12]. According to Passive House Institute from Darmstadt a building can be certified as a passive house if the specific energy required for heating does not exceed 15 kWh/m^{2}year and the total primary energy demand does not exceed 120 kWh/m^{2}year for all services (heating, cooling, hot water and appliances) [13,14,15] and in the same time maintaining the interior comfort standards imposed by individual countries. Also, the air exchange between the interior and the exterior of the building should not exceed 0.6 h^{-1} at a difference of 50 Pa, as the blower door test for passive houses' airtightness requires. Moreover, in order to evaluate if a construction is a nZEB or not is necessary that the building to be monitored across one year minimum and the compare the results with the above criteria. The Passive House criteria states that a part or all of the energy consumed by a nZEB must be obtained from renewable sources.

2. Establishment description

The Passive House built in the campus of University Politehnica from Bucharest (UPB) consists of two identical buildings with a total treated area of 140 m^2 each (Fig. 1). The two houses are designed for minimal energy losses according to Passive Houses standards. The U-values for the opaque elements varies between 0.10 W/m^2/K and 0.12 W/m^2/K. The U-value of the exterior triple glazing windows is 0.6 W/m^2/K and total solar absorbance coefficient of 50% [16].

In order to achieve the energy requirements [16] imposed by the Passive House Institute, the East House - "Laboratory House" house from UPB campus was equipped with a EAHX (earth-to-air heat exchanger) and a heat recovery unit coupled with the ventilation system. For peak periods, it is used an electric air heater. The house is connected to the national grid and also a 3.0 kW PV power system supplies a part of the electrical energy used. The PV system is composed of 13 PV panels and an inverter. The PV panels are South oriented and are tilted at 15° and have a nominal efficiency of 13.4%. The 15° tilt was chosen respecting the slope roof in order to avoid its overloading with metal structures and to avoid the tightness destruction of the house. The passive house uses solar collector for domestic hot water.

The studies conducted so far [17,18,19,20,21,22] showed that the low energy building concept is applicable in Romanian climate conditions, achieving high energy performances and good interior comfort. Carutasiu et al. investigated the behaviour of UPB Passive House during winter conditions and indicated that the energy consumption, in order to maintain the interior comfort, was of 14.88 kWh/m^{2}year for heating. The interior comfort and the low energy consumption levels were obtained by applying different scenarios varying the usage of the electrical air heater and modifying the air flow rate in order to achieve the required interior temperature. Moreover, the article 'Reducing energy consumption in low energy buildings through implementation of a policy system used in automated heating systems' [17] analyse the same house presented in this study, but in the heating period (November 2013 – April 2014). The article conclusions [17] were used to obtain a large view of the Passive House UPB energy balance over a year.

The passive house has a data acquisition system, which provides information about the interior comfort, the exterior environment and the energy balance. The monitoring system measures through its sensors the inside and the outside temperature, HVAC (heating, ventilation and air conditioning) air flow, inside CO_2 concentration, humidity, luminosity, solar radiation, energy consumption and PV production. The interior temperature is measured using five wireless sensors (W1-W5). The air temperature through HVAC system is measured using 8 wired sensors (T1-T8) placed as shown in Fig. 2. The solar radiation is monitored by a pyranometer mounted on the roof at 15° tilt. The energy consumption is harvested using 7 wattmeters: EC1 – lights, EC2 – living room (radiant panel and appliances), EC3 – kitchen appliances, EC4 – monitoring system, EC5 – electric resistance, EC6 – MVHR (mechanical ventilation heat recovery) unit (inside fans) and EC7 – bathroom (radiant panel).

Fig. 1. Passive House, UPB, southern view

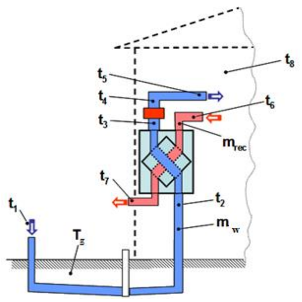

Fig. 2. HVAC sensors position [20]

3. Monitoring results and discussions

The data chosen - 1st May 2014 and 31st October 2014 - gives a full characterization of the Passive House UPB location in the warm season in terms of energy balance, interior comfort and exterior environment.

3.1. Outside environment and interior comfort

The solar radiation and the exterior temperature from UPB campus were measured during a period of 3 years (2012-2014). During monitored period the average temperature was 13.27°C with a minimum average of -0.31°C in January and a maximum average of 25.37°C in July. The total solar yearly radiation was 1428.13 kWh/m^2 with a minimum of 30 kWh/m^2 in January and a maximum of 195.52 kWh/m^2 in July.

Fig. 3 gives a perspective on the variation of daily average exterior temperature and solar radiation in the warm season using the data collected between 1st May 2014 and 31st October 2014 in order to have a base for the energy production of the photovoltaic and for the interior temperatures from Passive House UPB. The maximum daily average of the outside temperature was 29.08°C, and the highest daily average solar radiation was 557.73 W/m^2. The solar radiation has a big influence on the inside temperature due to large windows mounted on southern façade.

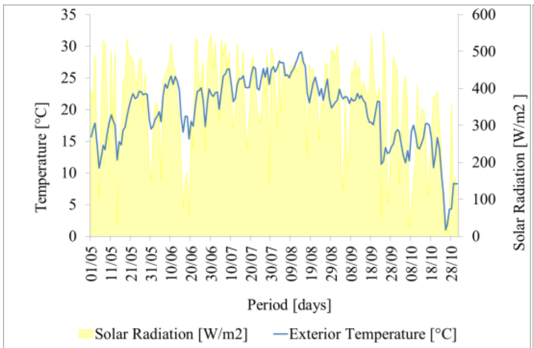

Fig. 3. Solar radiation and outdoor temperature (daily average from 1st of May 2014 to 31st of October 2014)

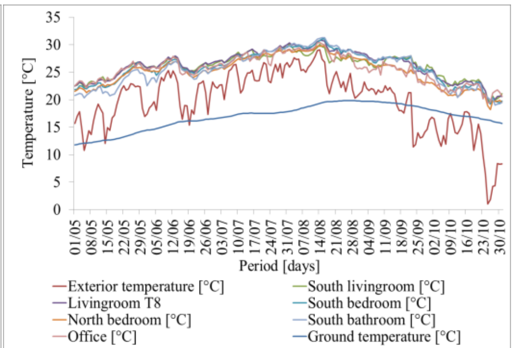

Fig. 4. Variation of interior temperature of Passive House and exterior temperature (daily average from 1st of May to 31st of October)

The fresh air was supplied using EAHX. The ground temperature had a variation between 11.79°C and 19.84°C and the interior temperature fluctuated in limits required by inhabitants. Fig. 4 shows the daily variation of average exterior and interior temperature for entire period. The inside temperature slowly follows the fluctuation of the exterior temperature to the entire observed period, without taking in consideration the end of October when electric air heater was turned on in order to obtain the interior temperature comfort in the cold season.

Spring and autumn were characterized by average differences of 7.6°C between inside and outside temperature. This difference was a result of high thermal properties of the thermal envelope and outside climate condition.

A closer view over the variations of the interior and HVAC temperatures during 24 hours shows the influence of the high materials thermal performances on the temperature in the house (Fig. 5 and Fig. 6). In Fig. 6 the distribution of the temperatures describes the importance of the HVAC system and the influence of a very good insulation level.

The average exterior temperature during that summer day was 26.46°C. The solar mean radiation was 406.53 W/m^2 and influenced the interior temperature through the large windows mounted on the building's South facade. Between 8:00 and 20:00 the outside average temperature was 30.49°C and the inside mean temperature was 28.40°C. The air was cooled using only the ground temperature. During the day, the air flow was set at low rates in order the air to have time to exchange heat with the ground; it can be observed that the air enters in the house with lower temperatures compared with outside thermic conditions, showing a good efficiency of the EAHX system.

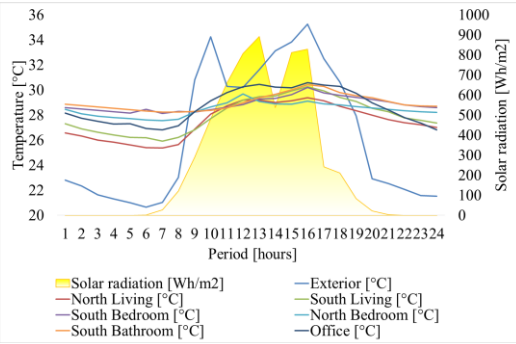

Fig. 5. Evolution of the interior and exterior temperature on 22nd of July 2014 [24]

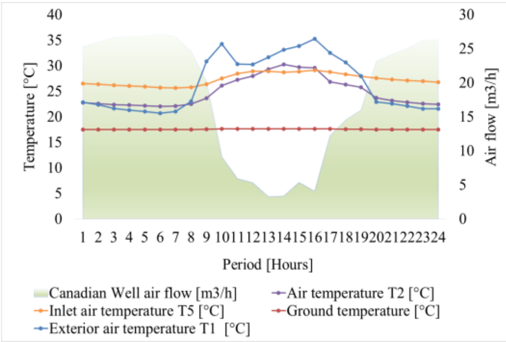

Fig. 6. Evolution of the HVAC temperatures on 22nd of July 2014 [24]

Before entering the house, the exterior air exchanged heat with the ground and reached an average of 24.83°C (measured by the sensor T2). The air introduced in the house had an average of 27.31°C (T5). After ventilating the house, the exhausted air had a mean temperature of 28.40°C.

The air flow rate was varied between 2.24 m^3/h during day time and 27.19 m^3/h in the night. During the time when the exterior temperature recorded high values, the flow rate had an average of 7.00 m^3/h and in the night, the average flow rate was 24.7 m^3/h in order to cool the air from the house. This scenario allowed the temperature across the day to be maintained in a comfort zone.

In the summer (June, July and August), the outside temperature had an average of 23.39°C, with a minimum of 15.37°C and a maximum of 29.08°C. The highest temperature was 31.12°C registered in the South bathroom on 14th of August.

Comparing the ground and the exterior trendline temperatures from Fig. 6, it can be observed that the difference of degrees has a big potential for cooling the house by absorbing the heat from the air that flows through the EAHX. The average difference is 4.20°C.

3.2. Energy Consumption

The energy consumption in the analysed (May - October 2014) period was 473.68 kWh and in winter the energy requirement was 4786.50 kWh. In the analysed period, the energy used for lighting was only 39.01 kWh due to the low-energy light bulbs and to the large glazing surface from South facade. The highest energy consumption was recorded in the living room, responsible of 188.09 kWh. For ventilating the house 166.08 kWh were needed.

In table 1 is detailed the energy consumption for each month of the analysed period.

Table 1

Energy consumption

Month	Kitchen [kWh]	Lights [kWh]	Living [kWh]	Ventilation [kWh]	Air heater [kWh]	Consumption [kWh]
May 2014	2.64	18.61	43.95	57.17	0.00	122.36
June 2014	2.77	4.99	31.47	19.91	0.00	59.14
July 2014	1.71	3.02	30.27	24.92	0.00	59.91
August 2014	1.30	3.84	11.23	40.59	0.00	56.96
September 2014	0.65	2.75	28.89	16.96	0.00	49.25
October 2014	1.65	5.80	42.29	6.53	69.79	126.06
Total [kWh]	10.72	39.01	188.09	166.08	69.79	473.68

The lowest energy consumption was registered in September, 49.25 kWh; 34% of this energy was used for ventilation (EC6) and 59% was used in the living room (EC2). The highest energy used in the house was registered in October when the heating system was turned on. The monthly average energy consumption was 78.95 kWh. The ventilation system of the Passive House is designed to function all year, in order to supply fresh air and at the same time to cool and heat the house. The total energy required for ventilation was 166.08 kWh, which represents 1.19 kWh/m^{2}year over the analyzed period. In the next table are detailed the average energy consumption and air flow rate from 1st May to 31st October 2014.

Table 2

Energy consumption and air flow rate

Period	Energy consumption [kWh/day]	Air flow rate for heat recovery unit [m^3/hour]	Air flow rate for EAHX [m^3/hour]
1st May - 10th June	1.84	157.43	179.75
11th June - 3rd July	0.09	155.42	219.60
4th July -12th August	0.92	161.80	134.92
13th August-10th September	1.47	160.68	254.41
11th September-25thOctober	0.09	164.32	431.85
26th -31st October	0.7	178.42	326.51

3.3. Energy balance

The double energy flow allows the system house - PV system - grid to exchange energy depending of the energy needs of the house and on PV panels availability to produce energy. Fig. 7 shows the PV energy production and the house energy consumption difference for every month of the monitored period. From May to October 2014, the PV panels produced 1054.05 kWh and 441 kWh between November 2013 and April 2014 [17]. This represented more than the energy consumed by the building' systems in the warm season. The rest of 580.37 kWh were inserted into the grid. The 'PV production' represents the energy produced by the photovoltaic system and the 'Passive House consumption' represents the energy consumed by the appliance from the house.

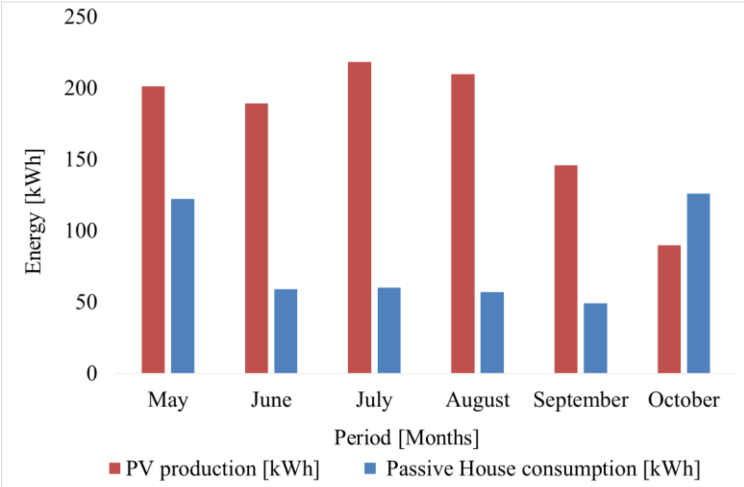

Fig. 7. PV production and energy consumption 1st of May 2014 to 31st of October 2014

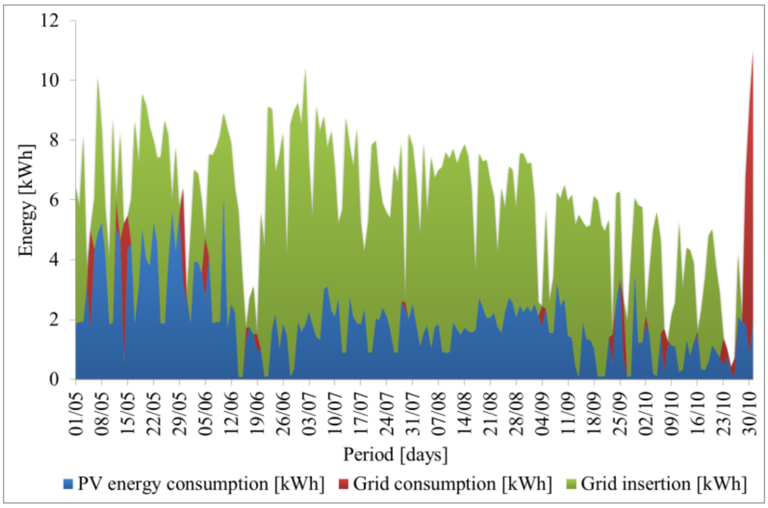

Fig. 8. Source of energy consumption of the house and grid injection energy 1st of May 2014 to 31st of October 2014

'PV energy consumption' represents the energy consumed by the appliance from energy produced by the PV system, 'grid consumption' represents the energy extracted from the grid and 'grid insertion' represents the energy produced by the PV system and inserted into the grid.

In this analysed period, in 160 days from 184 the PV system produced more energy than the house consumed (Fig. 8). The maximum surplus was registered on 22nd of June when 98.97% of the produced energy (9.12 kWh) was inserted into the grid. The minimum energy consumption covered by the PV system was registered on 26th of October when only 26.12% of the house energy needs were covered by photovoltaics.

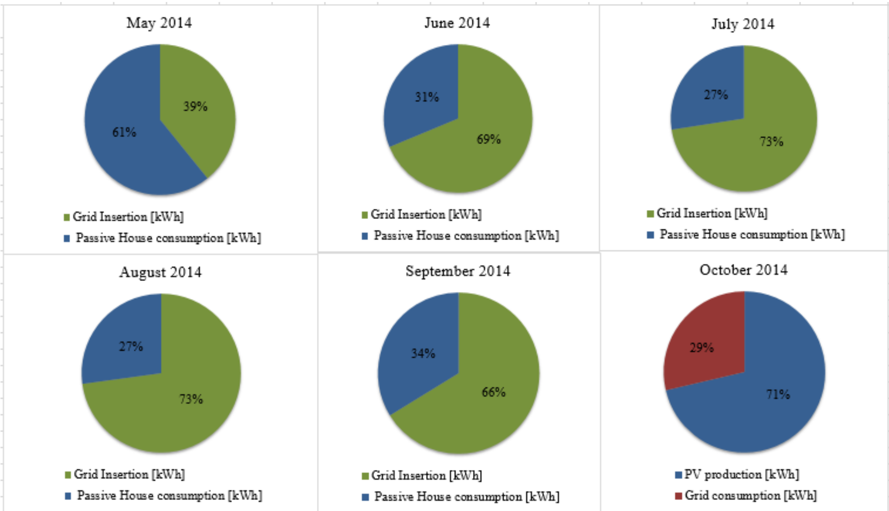

Fig. 9. Monthly energy balance

In summer months 71.47% of the produced energy was inserted into the grid. In June, July and August, the photovoltaic panels produced 617.06 kWh. July was the most productive month even if in August was registered higher solar radiations and higher temperatures. The temperature plays an important role in energy production by the photovoltaic systems. The cell temperature influences the intensity of the current. Optimal function of a photovoltaic cell was recorded to be at 25°C. For a higher cell temperature than 25°C, the Joule losses increase with every degree. In July, the photovoltaic system produced 218.31 kWh with a daily average of 7.04 kWh. Fig. 9 presents the energy balance for each month.

The most productive day of this period was 2nd of July, when the PV panels provided 10.43 kWh. A percentage of 82.26% of the energy was injected into the grid. 0 presents the energy flow between grid, consumer and photovoltaic system. The energy consumption was constant in the night and extracted energy from the grid at a 0.144 kWh rate. The most productive hours was recorded between 14:00 and 15:00 pm. The PV system produced 2.31 kWh from which

2.00 kWh were injected into the grid. It can be observed that during 7:00 and 20:00, the energy required for operating the house is provided by the PV system. In 0 is given the photovoltaic energy repartition for 2nd of July.

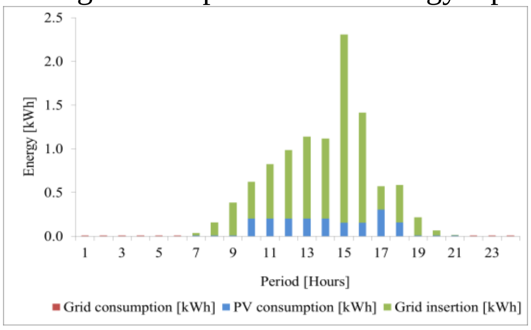

Fig. 10. Energy flow on 2nd of July 2014

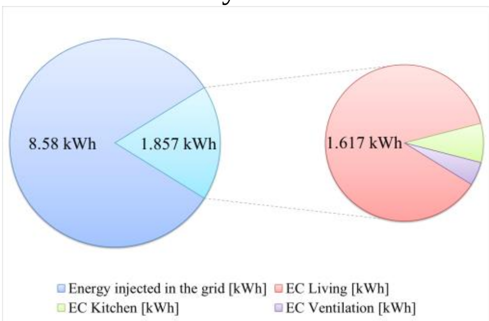

Fig. 11. Energy distribution on 2nd of July

During the operating time the photovoltaic panels had a peak power production of 2484.3 W corresponding to 1163.51 W/m^2 solar radiation and 10.90 A for the electrical current at 14:04.

4. Conclusions

The article describes a case study about the behavior of a low energy building in Romania climate during the warm season. Applying scenarios like reducing the flow rate when the temperature and the solar radiation are high and maximizing it in the night conducts at obtaining comfortable interior temperatures levels.

In Romania, the specific energy consumption for buildings must be within 57 to 111 kWh/m^2/year in order to be considered a nZEB [25,26,27,28]. The total energy consumption recorded in the warm season was 473.687 kWh. In an entire year (November 2013 - October 2014) the total final consumption was 5260.287 kWh, meaning 37.57 kWh/m^2/year (as the total treated area of the house is 140 m^2).

The photovoltaic system inserted in the grid 55% of the energy produced from May to October 2014. Moreover, the presented study shows that in the warm season, the energy balance of the house is positive and the grid can be considered an infinite energy storage capacity for satisfying the consumption needs of the house when the photovoltaic system does not produce energy. Over an entire year, the photovoltaic panels supplied 26% of the total electrical energy needs of the house.

This study for the warm season and the study of the low energy behavior of the same house in the winter demonstrate [17] that the implementation of nZEB in Romanian climate conditions is an achievable goal regarding the renewable energy consumption through the view of the Passive House UPB. But the most important thing to consider is educating the people in saving energy and protecting the environment. Changing energy behavior of the final consumer is an important step for the necessity of saving the resources for the future generation, is an aspect that shall to be followed.

Acknowledgment

The work has been funded by the Sectorial Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/134398.

This paper work was funded by program "Parteneriate" in priority areas – PN II carried out by MEN-UEFISCDI, project No. 47/2014 and Erasmus+ through financial agreement 2014-1-RO01-KA203-002986.

The low-energy house form U.P.B. campus was built during a research project developed through a partnership between the Institute for Studies and Power Engineering (ISPE), University POLITEHNICA of Bucharest (UPB), University of Architecture and Urbanism "ION MINCU" (UAIM), Technical University of Civil Engineering Bucharest (UTCB), Academy of Romanian Scientists (AOSR), Electro-Technical Research Institute (ICPE) and a private company (AGECOM)

R E F E R E N C E S

[1]. Global Energy Statistical Yearbook 2014 https://yearbook.enerdata.net/#energy-primary-production.html;
[2]. National Conference for Energy Efficiency and Passive House, 25 June 2015, Bucharest, Romania, http://www.eventbrite.com/e/eficienta-energetica-si-casa-pasiva-tickets-17077522329?utm_source=eb_email&utm_medium=email&utm_campaign=email_attendees&utm_term=event;
[3]. http://www.solar-magazin.ro/energie/33-din-energia-electrica-produsa-in-ue-provine-din-surse-regenerabile.html;
[4]. Regulatory Authority for Energy, http://www.anre.ro/ro/energie-electrica/legislatie/surse-regenerabile/rapoarte-garantii-certif-verzi, March 2015;
[5]. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2009.140.01.0016.01.ENG
[6]. National Institute of Statistics, http://www.insse.ro/cms/ro/content/resurse-de-energie, March 2015;
[7]. Commission of the European Communities, Proposal for a Recast of the Energy Performance of Buildings Directive (2002–91-EC), SEC(2008) 2865 Commission of the European Communities, Brussels (2008);
[8]. EUR-Lex, Access to European Union law, http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0091, april 2015;
[9]. European Commission, Energy, http://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings;
[10]. Building performance institute Europe, http://bpie.eu/low_energy_buildings_east_eu.html#.VTgDC_mUf_G;

[11]. http://passiv.de/en/04_phpp/04_phpp.htm;
[12]. http://www.passivehouse-international.org/index.php?page_id=188
[13]. Plus Energy Houses - POLITEHNICA Plus Energy Building, A. Badea, CIEM 2011, Bucharest, 2011;
[14]. Passive House Institute, Passive House requirements, http://passiv.de/en/02_informations/02_passive-house-requirements/02_passive-house-requirements.htm;
[15]. http://www.energ.pub.ro/cercetare_passive_house.html;
[16]. An international standard, http://www.passivehouse-international.org/upload/ipha-brochure;
[17]. *M. B. Carutasiu, V. Tanasiev, C. Ionescu, A. Danu, H. Necula, A. Badea*, Reducing energy consumption in low energy buildings through implementation of a policy system used in automated heating systems, Energy and Buildings, Volume 94, 1 May 2015, Pages 227–239;
[18]. *A. Badea, T. Baracu, C. Dinca, D. Tutica, R. Grigore, M. Anastasiu*, A life-cycle cost analysis of the passive house “POLITEHNICA” from Bucharest, Energy and Buildings, Volume 80, September 2014, Pages 542–555;
[19]. *B. Carutasiu, V. Tanasiev, C. Ionescu, A. Badea*, Nearly zero energy buildings in temperate continental climate – a case study for Romania, Colloque Franchophone en Energie, Environment Economie et Thermodynamique–COFRET, Paris (2014);
[20]. *G. Vlad, C. Ionescu, H. Necula, A. Badea*, Simulations of an air heating/cooling system that uses the ground thermal potential and heat recovery U.P.B. Scientific Bull. Series C, 75 (3) (2013) ISSN 2286-3540;
[21]. *C. Ionescu*, HVAC solutions for the Passive Houses from University POLITEHNICA of Bucharest, International Energy-Environment Conference (CIEM) (2011);
[22]. *V. Tanasiev, B. Carutasiu, A. Badea*, Dynamic simulation of energy consumption for a passive house in Romanian climate conditions: a case study, International Conference on Energy and Environment – CIEM, Bucharest (2013);
[23]. *G. E. Vlad, C. Ionescu, H. Necula, A. Badea*, Simulation of an air heating/cooling system that uses the ground thermal potential and heat recovery, U.P.B. Sci. Bull., Series C, Vol. 75, Iss. 3, 2013 ISSN 2286-3540;
[24]. *A. Danu, V. Tanasiev, L. A. Negrea, H. Necula, A. Badea*, Improving thermal and visual user comfort in very low energy buildings, , World Renewable Energy Congress, 9-12 June 2015, University Politehnica of Bucharest with the article, www.wrec.ro;
[25]. Passipedia, Basics http://passipedia.passiv.de/passipedia en/basics;
[26]. *W. Feist, J. Schnieders, V. Dorer, A. Haas*, Re-inventing air heating: convenient and comfortable within the frame of the passive house concept, Energy Build. 37 (11)(2005)1186–1203;
[27]. *C. Ionescu*, HVAC solutions for the Passive Houses from UPB, International Energy-Environment Conference (CIEM), 2011.
[28]. MDRAP, nZEB Romania, http://www.mdrap.ro/userfiles/metodologie_calcul_performanta_energetica_iulie2014.pdf