SIMULATION AND ENERGY EFFICIENCY EVALUATION OF A LOW-ENERGY BUILDING

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Abstract – The paper presents the results of the simulations made for the one of the low energy houses built in the campus of University Politehnica of Bucharest. The aim of the simulations was to emphasize the role of the solutions applied in order to achieve "the passive house" standard. Some of these solutions can be easily adopted by old buildings. They refer to a special architecture, materials with improved thermal properties, systems requiring renewable sources of energy and heat recovery of the exhausted technologies.

Keywords: thermal load, heat recovery, TRNSYS simulation, passive house.

1. INTRODUCTION

The residential sector is an important energy consumer in all the countries. For this reason people became more interested in finding solutions to reduce both thermal and electrical consumptions of the buildings. In many countries the energy efficiency of buildings is promoted by implementing national programs. After the energy crises in the 70s, due to the price of the fuels and the depletion of energy sources, the low energy building became a standard for the new buildings. There are many solutions which can be applied to both new and existing buildings. A special architecture, a certain orientation, a low ratio of surface to volume are adopted by new buildings [1]. Materials with low thermal resistance and low permeability are used by both types of buildings. There are a lot of studies that showed the impact of the envelope materials on the building energy consumption [2]. Technologies based on renewable sources of energy, capable to maintain the parameters characteristic to buildings environment at desired value, are among these options.

The employment of the renewable energy for space heating leads on one hand to the reduction of primary energy consumption and on the other hand to the reduction of the greenhouse gases emissions.

In the European Union countries, space heating is responsible for more than 50% from the total energy consumption and about 10% are provided by renewable energy sources [3]. In the USA and Asia the situation concerning the energy consumption of buildings is similar [4,5]. In the 90s, an institute from Darmstadt, Germany developed a new concept called "passive house". The passive house is a building created for the central European climate with certain standards referring to the energy consumption: 15 $kWhm^{-2}year^{-1}$ thermal energy consumption and 120 $kWhm^{-2}year^{-1}$ total energy consumption [6]. There are also other requirements referring to the overall heat transfer coefficients of walls, windows, to the number of air changes per hour. Since the first passive house built in 1991, more than 27000 houses were built in Europe [7].

In order to improve the energy performance of the buildings, in May 2010 the European Directive on Energy Performance of Buildings was adopted [8]. The EU Member States agreed to apply a "Net Zero Energy Program". A general definition says that a net zero-energy building (ZEB) is a building that over a year does not use more energy than it generates. But this is not the only definition of this building. There are four definitions for the ZEB depending on different points of view: the aim of the building project, the intentions of the investors, the energy expenses and the impact on the environment [9]. A complete definition should emphasize the importance of using renewable sources of energy but also the energy efficiency of buildings. According to this directive, by December 31st 2020, all new buildings must be nearly zero-energy buildings and after December 31st 2018, new buildings occupied and owned by public authorities must be nearly ZEB.

The newest building concept is "the positive energy house". The positive energy house is a building that generates energy more than its consumption. The users and the management of this building have a very important influence in achieving the standard.

In Romania, the majority of buildings have a mean thermal energy consumption of 300 $kW.m^{-2}.year^{-1}$. This value is double compared to the values specific for European countries buildings. The economical potential to improve the energy efficiency was estimated to 30%-50% for residential field and 13-19% for public field [3].

In developed countries, economical and environmental reasons stimulated the low energy buildings construction. Taking into account these premises, a new project was developed by the University "Politehnica" of Bucharest. The aim of this project was to promote the energy efficiency of buildings in Romania.

2. PROJECT DESCRIPTION

The building comprising two houses is located in the campus of the University Politehnica of Bucharest and it has a total surface of approximately 2x140 m^2. Each house includes a hall, a living room, a kitchen, a small bathroom and a technical room on the ground floor and two bedrooms, two bathrooms, an office and a hall on the first floor. To take advantage of the solar energy, the building has a special architecture and a southern orientation (Fig. 1). The building has very large windows on the southern side and small windows on the north, used only for lighting.

(a)

(b)

Fig. 1 - Politehnica Houses:
(a) southern side; (b) northern side

One of the houses has an eastern orientation (called "East House") while the other has a western orientation (called "West House"). The study presented in this paper was carried out for the East House. In order to realize an optimization of the space, the living and the kitchen have a southern orientation, and the bedrooms are oriented to east. Each bedroom and the office have only one eastern window. Materials such as mineral wool and polystyrene, which are among the best insulation materials, were used to insulate the envelope of the house. Due to these materials with very good properties (table 1), the heat losses are extremely low compared with those of a standard house.

Table 1. Properties of the insulation materials

Wall type	Insulation material	Thickness [mm]	Thermal conductivity [$W.m^{-1}.K^{-1}$]
Roof	mineral wool	400	0.034
Outside walls	mineral wool	300	0.034
Floor slab	mineral wool	150	0.034
	XPS polystyrene	180	0.04

The house has triple glazing windows with glass covered with a low E layer and bio cleaner, very low heat transfer coefficient and a very low solar heat gain factor (U=0.7 $W.m^{-2}.K^{-1}$, g=0.5). The space between the glass layers is filled with argon (90%) and air (10%).

The Politehnica House is very well insulated and has a very tight envelope. In this case, due to the high level of insulation, there is no air leakage and the outside air does not enter the house uncontrollably. A mechanical ventilation heat recovery system (MVHR) is absolutely necessary to supply the fresh air and to remove the exhausted air.

To reduce energy consumption for heating, the air is preheated in two steps (Fig. 2): first in the ground heat exchanger and second in the heat recovery unit which can save even more than 91% from the energy of exhausted air.

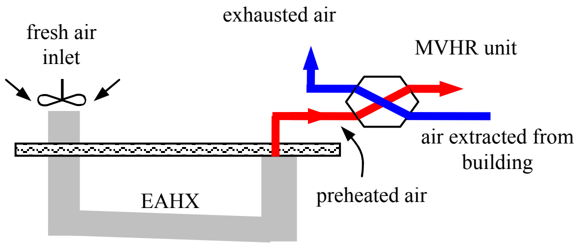

Fig. 2 - Scheme of the EAHX-MVHR system

The role of the earth to air heat exchanger is to preheat the required ventilation air in the heating season and to cool it in the summer. The fresh air is drawn from outside and then flows through the ground heat exchanger.

In the cooling season, the condensate is discharged through a tower. The condensation tower is placed at the lowest point of the system and is fitted with an airtight cover at ground level to prevent false air infiltration into the ventilation system.

The material chosen for the geothermal collector is a high density polypropylene. This is called Awaduct Thermo and is provided by Rehau. In order to prevent the bacteria growth on the inner surface of the collector, very small particles of silver are incorporated during a special process. As it is known, the silver particles have an antimicrobial effect.

The chosen pipe has an outer diameter of 200 mm and a wall thickness of 7.8 mm. The tube has an enhanced thermal conductivity (0.28 $W.m^{-1}.K^{-1}$) to ensure a better heat transfer between the air and the ground.

After passing through the geothermal collector, buried at 2 m below ground surface, the fresh air enters the heat recovery unit. A volume flow (165 $m^3.h^{-1}$) is drawn inside the geothermal system by a fan. This air flow assures an air change rate of about 0.5 h^{-1} that guarantees a proper ventilation of the house.

In order to find the optimum value of the EAHX length, a thermo-economic criterion was applied. The algorithm is presented in detail in [10]. An optimal pipe length of 38 m corresponds to the highest thermal efficiency of the EAHX system.

The MVHR unit installed in the experimental house consist of two fans and an air to air heat exchanger. One

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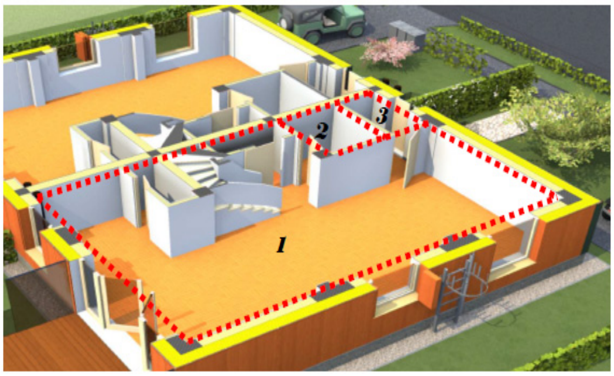
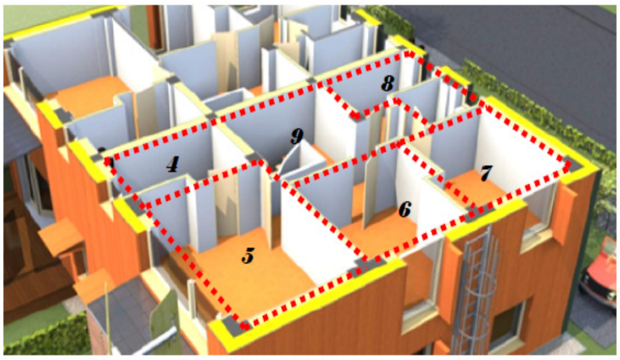
fan supplies new air to the living, bedroom and working rooms and in similar way the other one extracts the polluted air from kitchen and bathrooms. The two air streams flow in a cross-current direction inside the plate heat exchanger. After the MVHR unit, the fresh air temperature increases due to the energy received from the exhausted air. To reach the desired temperature, the air is electrically heated after the MVHR unit. The fresh air and exhausted air volume flows are equal to prevent the discomfort generated by pressure differences.

2. TRNSYS PROJECT OF POLITEHNICA HOUSE

The first step in accomplishing the simulations was to divide the building into 10 thermal zones (Fig. 3). As it can be seen, a thermal zone is represented by one room or a group of rooms. Each thermal zone has a certain volume and a certain thermal air capacity.



(a)



(b)

Fig. 3 - Thermal zones of the house (ground floor/ first floor)

1) living + kitchen + bathroom; 2) technical room 1; 3) entrance hall; 4) bathroom 1; 5) bedroom 1; 6) office; 7) bedroom 2; 8) bathroom 2+ technical room 2; 9) hall; 10) space between roof and ceiling

The simulations were carried out with TRNSYS software that is a complete and extensible environment for the transient simulation of systems including buildings. The simulation of the entire house requires a higher number of parameters. Every thermal zone consisting in one room or a group of rooms has a certain air volume. A minimum value of 20 ºC for the inside air temperature is set for the entire year. Due to the very good tightness of the house envelope, the air leakage/infiltration is considered zero.

3. SIMULATIONS RESULTS

The first simulation was carried out with a simple flux ventilation system. The fresh ventilation air was the outside air temperature. The first step (Fig. 4 - case 1) was to add walls with half of the actual insulation thickness and regular windows with high overall heat transfer coefficient and high solar heat gain ($U=2.8\ W.m^{-2}.K^{-1}$, $g=0.76$). In order to find out the influence of the insulation on the energy consumption of the building, the envelope insulation was changed to different values. As expected, the energy consumption decreases with insulation thickness increasing. In our simulation, the thermal load decrease is about 7% for insulation thickness increased with 50%.

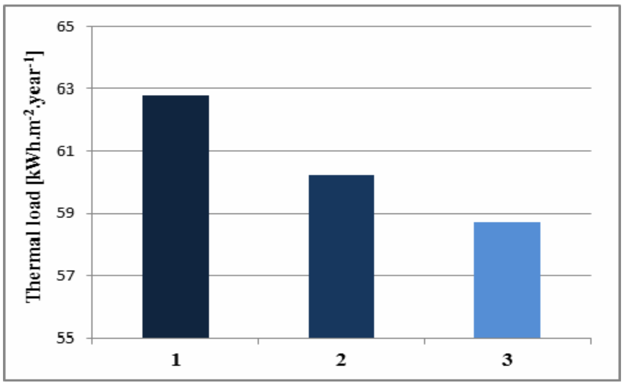


Fig. 4 - The influence of the insulation thickness on the thermal load

1) 50% of insulation thickness; 2) 75% of insulation thickness; 3) 100% of insulation thickness

The value of the heat flux, P ($W.m^{-2}$), corresponding to the case of the real insulation thickness (100%) is about 31.1 Wm^{-2} (Fig. 5).

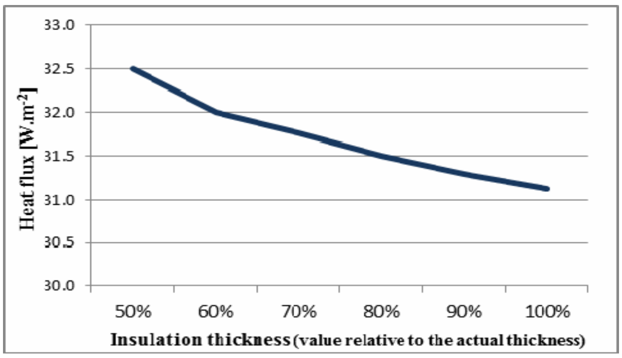


Fig. 5 - The influence of the insulation on the heat flux

Another important design factor is the type of the window chosen for the house. During the simulations, the geometrical characteristics were kept constant and only the thermal properties of windows were changed. For this purpose, three types of windows existing on the market were considered. The third type of the window is the one installed in the house. As it can be seen in Fig. 6, the thermal properties of the windows have a significant impact on the thermal energy consumption. Compared to the first case, the third one has the energy consumption lower with more than 60%.

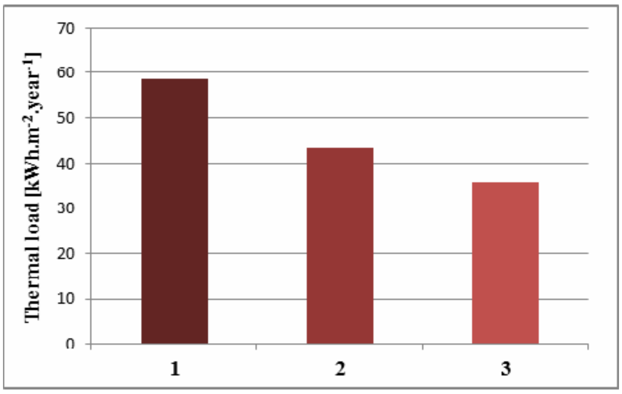


Fig. 6 - The influence of the windows properties on the thermal load
1) U=2.8 W.m^{-2}.K^{-1}, g=0.76; 2) U=1.4 W.m^{-2}.K^{-1}, g=0.59; 3) U=0.7 W.m^{-2}.K^{-1}, g=0.5

The influence of the type of the windows installed is also reflected in the heat flux lost to outside (Fig. 7).

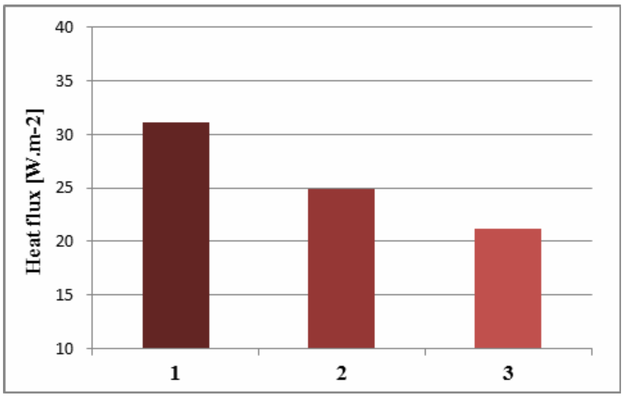


Fig. 7 - The influence of the windows properties on the heat flux
1) U=2.8 W.m^{-2}.K^{-1}, g=0.76; 2) U=1.4 W.m^{-2}.K^{-1}, g=0.59; 3) U=0.7 W.m^{-2}.K^{-1}, g=0.5

After installing the high efficiency windows, the thermal load of the experimental house is about 36 kWh.m^{-2}.year^{-1}. This value can be further reduced.

All the new types of buildings adopt technologies such as the air-to-air heat recovery. Both Politehnica houses have implemented double-flux mechanical ventilation system based on heat recovery (MVHR). The next step in performing the simulations was to add the MVHR unit. The most important part of the MVHR unit is the air to air heat exchanger. The heat exchanger is made of corrugated plastic plates that separate the two air streams (fresh air / exhausted air).

In order to obtain more energy savings and also to meet the hygiene and comfort conditions, the MVHR unit is connected to an earth to air heat exchanger (EAHX). The fresh air is taken from the outside of the building and is introduced inside the EAHX where it is preheated in the winter and cooled in the summer. After this, the air is further heated in the MVHR unit.

After the introduction of the MVHR unit, a significant reduction of the thermal load can be observed (first case in Fig. 8). The decreasing of energy consumption is even more important after coupling MVHR unit to the EAHX.

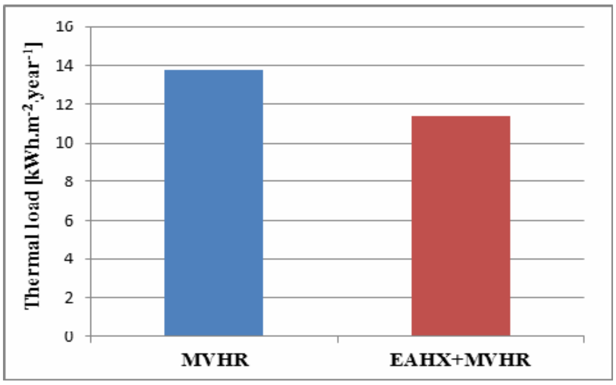


Fig. 8 - The influence of the EAHX and MVHR unit on the thermal load

According to the results of the simulation presented in Fig. 8 the thermal load of studied house is about 11.4 kWh.m^{-2}.year^{-1}, due to the ventilation system which comprises the geothermal component (EAHX) and the heat recovery unit. The value obtained is in accordance with the one of the requirements of the passive house standard, according to which the energy demand for space heating must not exceed 15 kWh.m^{-2}.year^{-1} [4].

The combination made between MVHR unit and EAHX system has also an important influence in reduction of the heat flux. Fig. 9 shows a reduction of over 20% after coupling EAHX to the MVHR unit, compared with MVHR unit operation only.

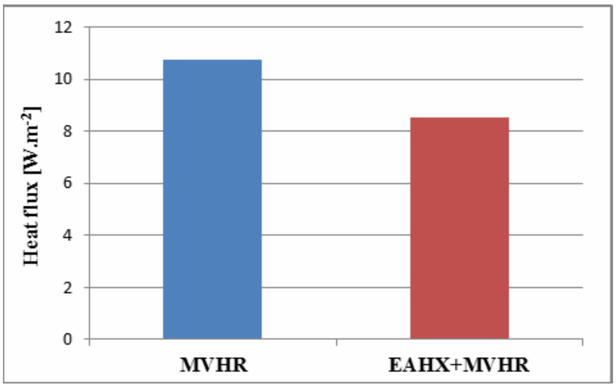


Fig. 9 - The influence of the EAHX and MVHR unit on the heat flux

As the cumulative thermal load shows (Fig. 10), the heating season starts in November and ends in April. Fig. 10 also illustrates thermal demand variation (in W.m^{-2} with a time step of 1 h) with peak load around 8.5 W.m^{-2} achieved in December and January at the lowest temperatures.

The house was built for a family of four occupants. The rate of the heat gain from the occupants is about 100W. Schedules were created for the most important thermal zones (living, bedroom 1, bedroom 2, office).

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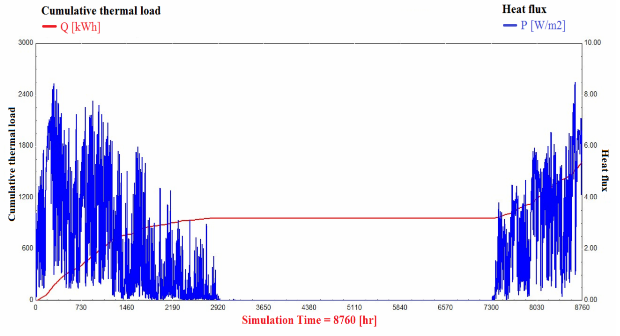
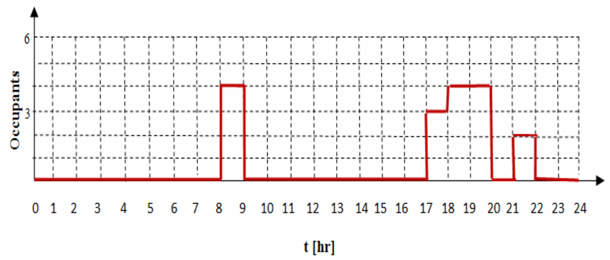
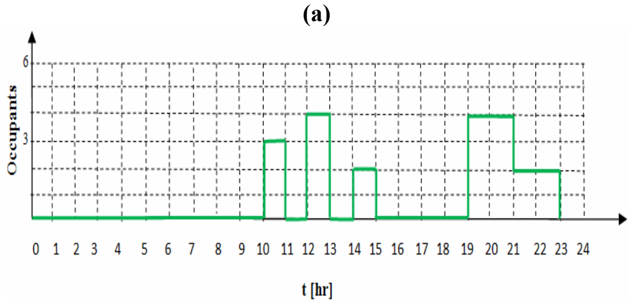


Fig. 10 - Variation of thermal load and cumulative thermal load

Two different schedules for living occupancy are represented in Fig. 11: one for the week days (a) and the second one for the weekend (b).



(a)



(b)

Fig. 11 - Living schedule
(a) week days; (b) weekend

There are eight different schedules for the four thermal zones. The heat rate of the household appliances, the lighting system and other equipment are taken into consideration. Table 2 contains the values of these heat rates [11].

Table 2. Heat rates

Thermal zone	Type	Heat rate [kJ/h]
living+ kitchen	TV	540
	household appliances	720
	refrigerator	60
office	PC	140

Schedules were also created for the electric equipment from table 2 excluding the refrigerator assumed to run all day.

In Fig. 12 and 13, the influence of the heat rates produced by humans and all other electrical devices on the thermal loads and heat flux are presented.

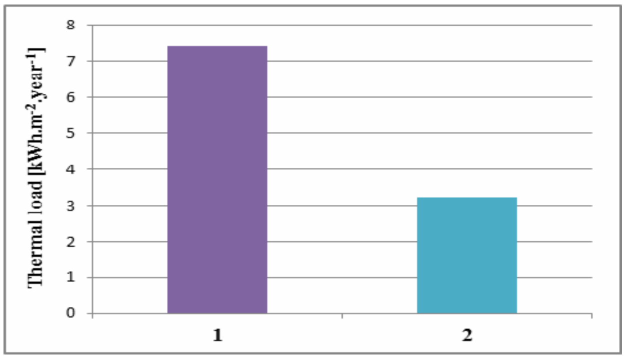


Fig. 12 - The influence of the internal heat rates on the thermal loads
1) human heat rates, 2) all types of internal heat rates

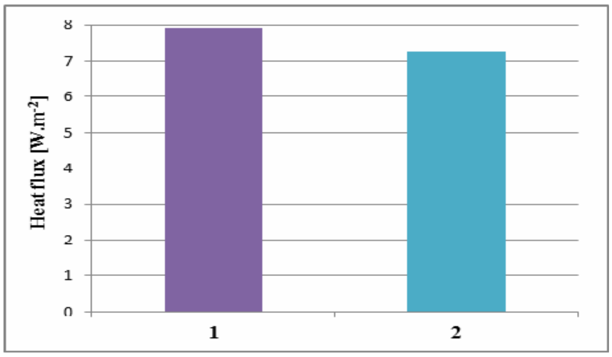


Fig. 13 - The influence of the internal heat rates on the heat flux
1) human heat rates, 2) all types of internal heat rates

During winter, the electrical heater placed after the MVHR is turned on. In order to achieve the control of this auxiliary heater, a thermostat is added to the scheme of the system and it is connected to the house.

In order to assure the thermal comfort in all rooms of the house, the fresh air temperature after the electric heater is settled to 30 ºC.

Comparing the power consumption of the house used as laboratory to the house inhabited by a family of four persons, there is a noticeable difference (Fig. 14).

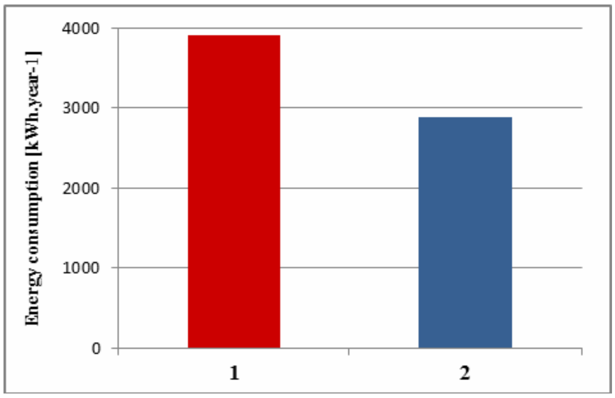


Fig. 14 - Electrical energy consumption of the house

1) house used as a laboratory; 2) house used as a home for a four persons family

The lower energy consumption of the inhabited house is due to the internal heat gains provided by the electric equipment and humans.

4. CONCLUSION

Inside the campus of University Politehnica of Bucharest, two low energy houses which are intended for passive house certification were built. To reduce the primary energy consumption for heating and cooling the ventilation air, one of these houses is equipped with an earth to air heat exchanger (EAHX) coupled with a double flux mechanical ventilation heat recovery system (MVHR).

The orientation plays an important role in the heating process of the house. During the winter when the sun is lower in the sky, this allows the building to capture the free heat coming from the sun. In the summer, when the sun is higher on the sky, the building is able to reject the solar heat. The walls and windows orientation of each thermal zone was set from the beginning and it was not changed during the simulations.

The simulations of the thermal behaviour of the house were carried out step by step and every time a new element was added to the house in order to find out its influence on the thermal load. The simulations show the energy benefits achieved with the insulation materials adopted by Politehnica House.

These simulations also show that the impact of the windows is even greater than the one of the insulation. Not only the heating demand but also the cooling demand can be easily manipulated with the help of the windows properties (one of the properties is the shading factor).

After introducing the EAHX and the MVHR unit, a very important reduction of the annual heating energy consumption was recorded. The obtained value satisfies one of the passive house concept requirements which, theoretically, can qualify the house to obtain the certification.

Acknowledgements

The work has been co-funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection through the Financial Agreement POSDRU/88/1.5/S/61178.

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