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ENERGETIC MONITORING AND OPTIMIZATION OF A "SOLAR HOUSE"

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Abstract: *Into the European Energy Performance of Buildings Directive context the "Solar House" is one of the first building in Braşov area intended to rich the status of net zero energy building. Once the building erected and Heating, Ventilation and Air Conditioning (HVAC) system completed a monitoring period was establish. A set of adjustments was performed focused on the indoor thermal comfort of the occupancy and on the efficient use of energy in order to reach a minimum level of the annual energy demand. This amount will constitute the design load for a future photovoltaic system, which will assure de energetic autonomy of the "Solar House".*

Key words: *energetic autonomy, net zero energy building, heat pump, energy efficient system, building commissioning, climate protection.*

1. Introduction

Reducing energy consumption and eliminating wastage are among the main goals of the European Union (EU) [1]. EU support for improving energy efficiency will prove decisive for competitiveness, security of supply and for meeting the commitments on climate change made under the Kyoto protocol. With 40% of energy consumed in buildings, the EU has introduced Energy Performance of Buildings Directive (EPBD) to ensure that they consume less energy. This directive was recast in November 2009 when the EU institutions have reached a political agreement on the revision of the EPBD. The aim of the recast is to clarify, strengthen, and extend the scope of the current directive, as well as to reduce the large differences between Member States' practices in the building sector. By 1 January 2021, all new buildings, including existing buildings undergoing major renovation, will have to supply a significant proportion of their energy requirements from renewable energy generated either on site or nearby. According to the new directive, public authorities have an exemplary role to play by ensuring that all new buildings they own or occupy meet the nearly zero energy standards as of 1 January 2019.

Romania has adopted appropriate measures to implement the directive through the law 372/2005, [2] that is the transposition of EPBD into national law. A methodology was introduced to evaluate the energy performance of buildings [3]. This methodology takes into account available CEN standards. In addition, alternative calculation methods for heating

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and cooling processes, based on Romanian research activity, have been included. The certification objectives are to save energy, while ensuring comfortable conditions and acceptable indoor air quality and to reduce CO_2 emissions. Certification is obligatory for new buildings with a building permit after 1 January 2007. For public buildings, a certification is needed from 1 January 2007. Residential buildings, when rent or sold, must have an energy performance certificate from 1 January 2010.

The research activity in *Transilvania* University of Braşov fits in this context too. As a first step, a "Solar House" was built in 2009. The design objectives of this building were to develop a low energy building with reduced CO_2 emissions, integrated with its surroundings and providing a high level of individual control and comfort for occupants.

This study, as a part of the above mentioned research activity, has the following goals:

A. Energetic analysis of the building and its facilities concluded with an energy performance certificate.

B. Establish a monitoring algorithm for the building and HVAC system response in different situation.

C. Performing a monitoring period closely followed by result analysis.

D. Optimizing the system in order to obtain a minimum amount of annual energy demand, without affecting comfortable conditions and indoor air quality.

The result of research, the annual energy demand, will be used to design a future photovoltaic system, which will assure de energetic autonomy of the "Solar House".

2. Building & HVAC System Description

"Solar House" is a tertiary building, built in 2009, emplaced in Braşov, into the fourth climatic zone of Romania characterized by a conventional outdoor design temperature of –21°C [2] and monthly mean outdoor air temperatures as presented in Table 1.

Monthly mean temperatures [4] Table 1

Month	Mean temperature [°C]
January	–4.9
February	–2.5
March	2.6
April	8.5
May	13.3
June	16.1
July	17.5
August	17.0
September	13.4
October	7.9
November	2.8
December	–1.9

The "Solar House" is situated on the top of University's Hill as presented in Figure 1 where can also be observed the Heat Pump Laboratory and the area where the Geothermal Horizontal Coil is displaced.

Fig. 1. *Emplacement of the "Solar House"*

The architecture of the "Solar House", Figure 2, is based on passive solar design. A non-traditional egg shape metallic structure with a curved roof insures the natural ventilation both in heating and cooling period providing energy savings.

Fig. 2. *Photo of the "Solar House"*

The "Solar House" has a 290 sqm built surface area from which 240 sqm are heated corresponding to a volume of 777 m^3. The area of the exterior building element surfaces are presented in Table 2.

Exterior building elements area Table 2

Exterior building part	Element surface [m²]
Walls	131.53
Doors and windows	155.64
Plafond	114.86
Floor above exterior air	22.90

The layout of the building is designed to make best use of natural lighting and, in winter, maximum solar gain for passive heating. The large, double-glazed facades cover 50% of the floor area (against the normal 10-15%). Energy-optimized windows with slender profiles and 2-layer, low-energy pane with a U value of 0.3 W/m²K were used.

The plafond is constituted by a light metallic structure covered with insulated panels outwards and plasterboard inwards with a low global transmittance coefficient.

The heating and the cooling load is covered by a HVAC system whose schematic is presented in Figure 3. High-efficiency ground coupled heat pump, which utilizes the geothermal energy throughout horizontal coils, supplies heated water to a hot water tank. From this tank, by the mean of three ways diverter valves are alimented successively: underfloor heating system (max. 35 °C), fan coil heating system (max. 45 °C), and domestic hot water cylinder (max. 45 °C).

A gas fired condensing boiler supplies the remaining heating requirement not covered by the heat pump system.

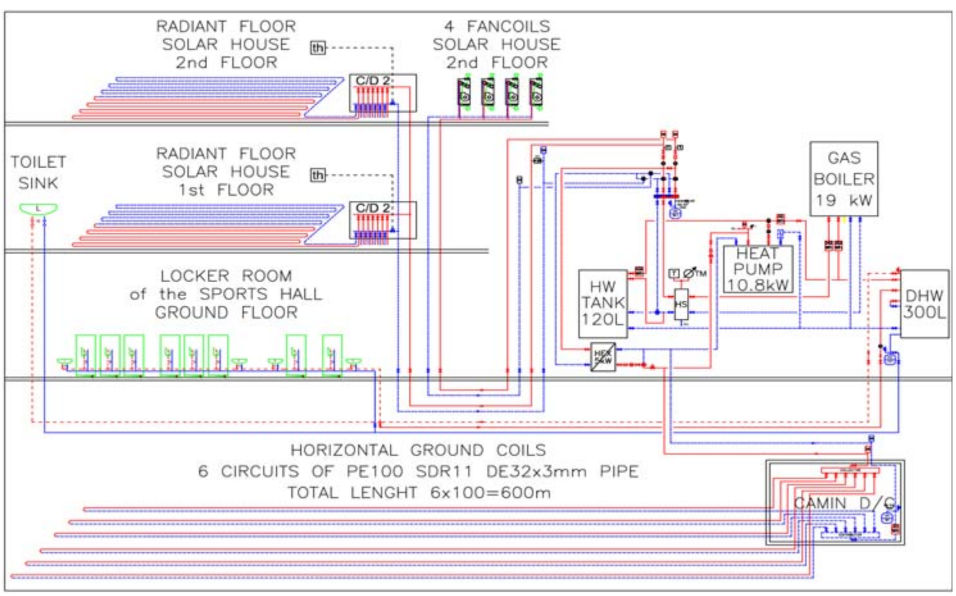

Fig. 3. *Schematic of the HVAC system*

3. Annual Energy Demand of the "Solar House"

Annual energy demand for the "Solar House", covering energy needs for space and hot water heating, cooling, ventilation and lighting, was determined using the methodology from [4] and [5].

Using Mc-001 thermal resistance corrected with thermal bridges R' for the exterior building elements was calculated and the results are presented in Table 3.

Exterior building elements area Table 3

Exterior building element	**Thermal resistance [m²K/W]**
Walls	3.270
Doors and windows	0.331
Plafond	2.190
Floor	2.446

With the same methodology the energy flows through exterior building components were determined and theirs total amount and distribution are shown in Figure 4.

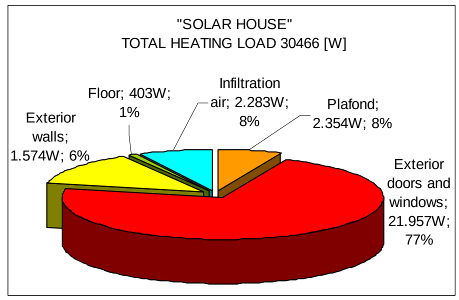

Fig. 4. *"Solar House" energy flows through building components*

Annual specific energy demand and the classification for the "Solar House" are presented in Figure 5.

Buiding energy performance	**Energetic note: 90.87**	
Calculation methodology for the energy performance of the building elaborated applying Law 372/2005	Real building	Reference building
High energy efficiency		
A		
B	B	
C		
D		D
E		
F		
G		
Low energy efficiency		
Annual specific energy consumption [kWh/m²year]	196.15	326.52
Equivalent emission factor CO_2 [kgCO_2/m²year]	33.46	57.35

Annual specific energy consumption for:	[kWh/m²year]	Energetic class: Certificated building	Energetic class: Reference building
Heating:	98.38	B	D
Domestic hot water:	39.10	C	C
Air conditioning:	-	-	-
Mechanical ventilation:	-	-	-
Artificial Lighting:	58.67	C	C
Annual energy consumption, renewable energy sources [kWh/m²year]:			149.21

Fig. 5. *"Solar House" energy performance*

This analyze was accomplished based on the certification criteria from [4] in order to reflect the actual energetic situation of the "Solar House" and contains information about specific thermal energy consumption related to heating, hot water installations, lighting, ventilation, and acclimatization. Based on the calculated value of annual specific energy consumption [kWh/m^{2}yr], the building is classified into a category of performance from A to G. At the same time, a benchmark for energy efficient usage is calculated. The real building is compared with a reference building having the same values for the envelope units and thermal resistance but whose energetic note is not affected by the penalty coefficient or by the use of renewable source of energy.

4. Data Acquisition, Monitoring and Optimization of the HVAC System

The main parameters of the HVAC system are monitored through data acquisition system. Ultrasonic heat meters are used to measure the power, flow rate, return and flow temperature. The levels of temperature in essential points of the systems are measured with PT100 thermoresistances. Data logger allows reading out, displaying, and storing these parameters in such a manner that it can be use at any time. The system is provided with a logbook function; different events are recorded and read out using specialized software. This enables diagnosis of rarely occurring faults. Events, operating states, and changes to the unit are recorded for a long time and made transparent. This permits uninterrupted system monitoring and a detailed technical analysis of the system states and mode of operation. The ground temperature, in the area wherefrom the geothermal energy is extracted, is monitored too in order to survey the variation during the heating and recharging periods. The monitored parameters are displayed in real time on a dedicated PC monitor in the Heat Pump Laboratory as shown in Figure 6.

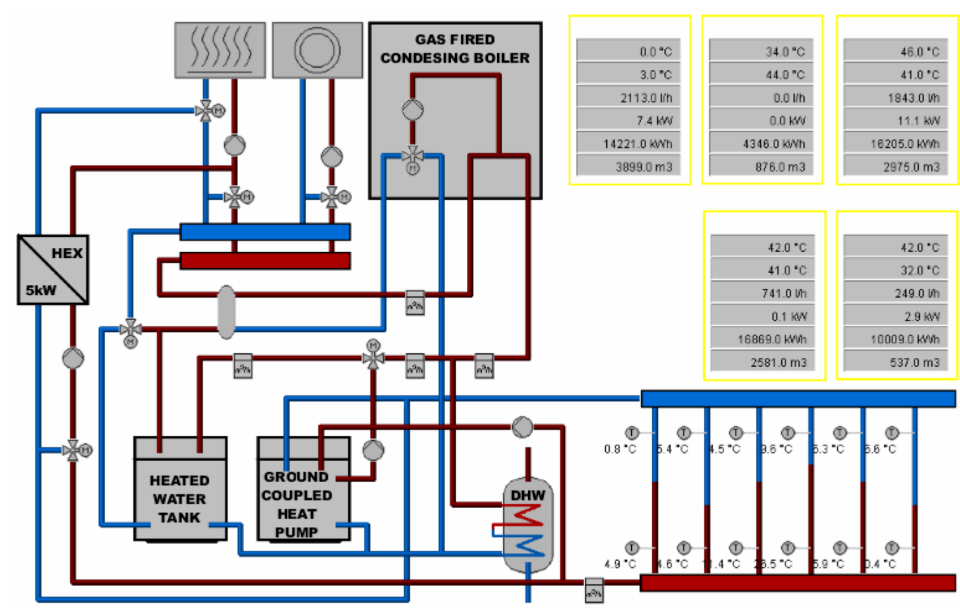

Fig. 6. *Data acquisition system*

In Figure 7, the hourly variation of the mean indoor and outdoor air temperature together with the global and diffuse horizontal solar irradiance are presented for a continuous function of HVAC system without any commissioning during the 11th week of 2010. The HVAC system was set to keep, for each day of the week, different indoor temperature between 15 °C and 18 °C in order to monitor the dynamic building response.

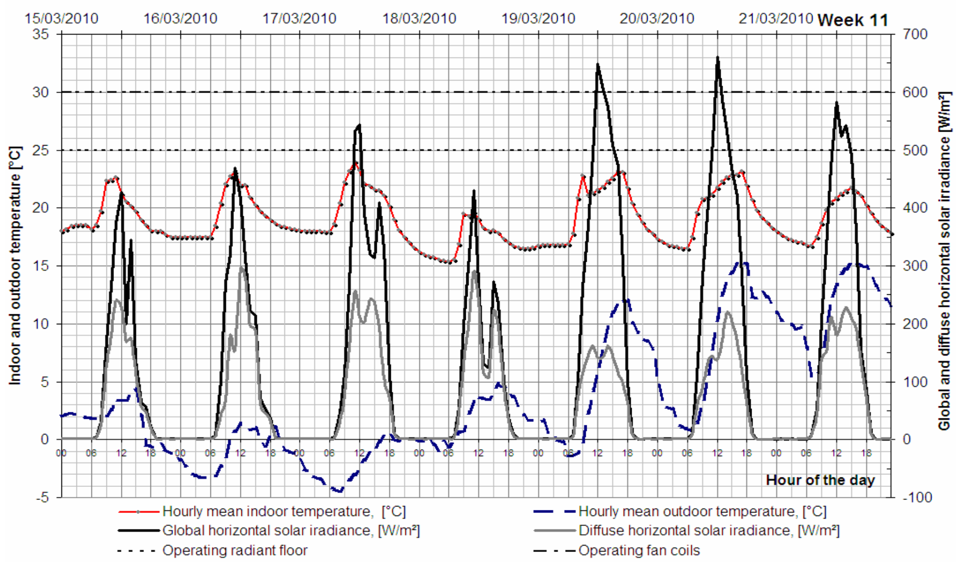

Fig. 7. *The monitored parameters' variation for 11th week - continuous function of HVAC system without any commissioning*

Due to the continuous function mode of the heat pump, correlated only with the outdoor air temperature without any indoor temperature feedback, increased indoor air temperature was registered during the daytime period. This was due to overlap of the heat pump operation with important heat gain from solar radiation. As can be see in Figure 7, for 16th march 2010 the indoor air temperature was set at 18 °C. During the night, the heat pump managed to maintain this indoor temperature even for negative outdoor air temperature lowered to –5 °C. In the morning, the increasing levels of solar radiation determined a fast growth of the indoor temperature to 24 °C, which was too warm for room occupants. The heat pump was on too due to the negative outdoor temperature. Immediately after noon, the decreasing levels of the solar radiation led to decreasing indoor air temperature. A first way to correct this consists in setting the indoor temperature at 15 °C which was reflected in the next day indoor temperature which rises only up to 20 °C, but, because of lower solar radiation in the afternoon the indoor air temperature drops to 17 °C which was too cold. For the next two days, the indoor temperature was set to 17 °C and based on the solar radiation the indoor temperature increased up to 22-23 °C. The indoor temperature was appreciated as acceptable but the continuous function of the heat pump leads to a weak coefficient of performance (COP), smaller than 2.00.

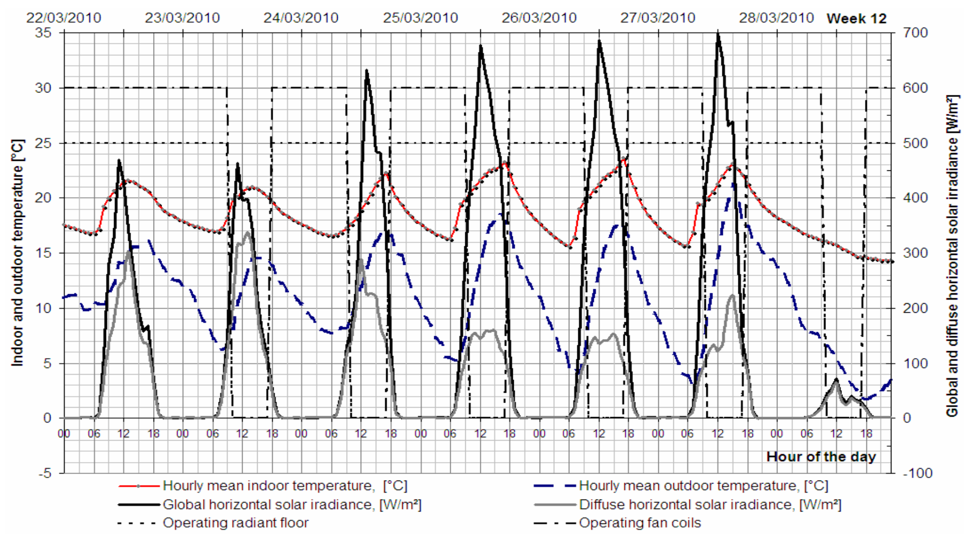

Fig. 8. *The monitored parameters' variation for 12th week - commissioned HVAC system*

COP, calculated as ratio between the electric energy used to drive the heat pump and thermal energy provided, for vapor compression heat pump have values between 3 and 6 depending on source and sink temperatures.

As a conclusion, after the first week of monitoring, the adjustment of the heat pump according only to external temperature cannot provide a good COP reflected in higher energy consumption.

For the 12th week of 2010, the heat pump was stopped between 10:00 and 17:00 in order to increase the COP. As it can be observed in Figure 8, the solar radiation assured acceptable indoor temperature levels between 18 °C up to 23 °C during the working time.

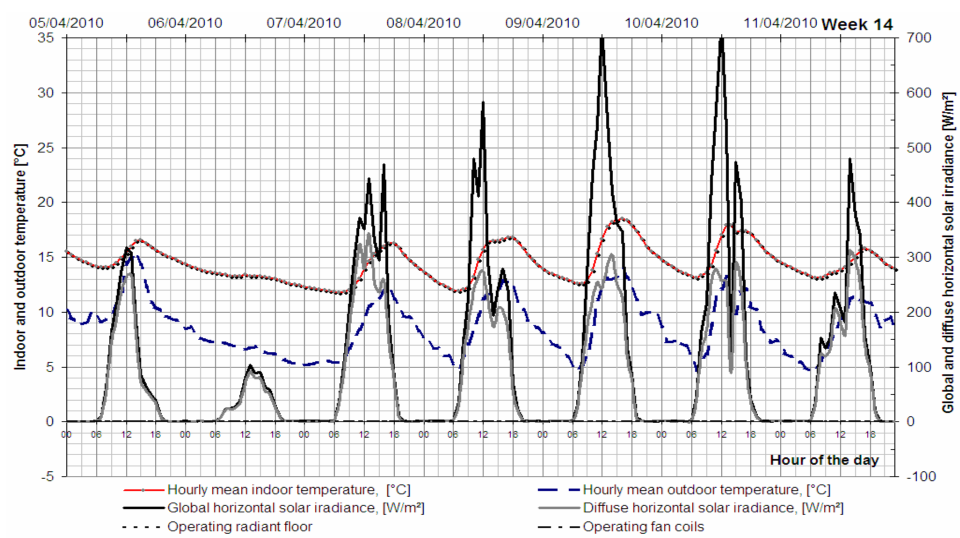

Fig. 9. *The monitored parameters' variation for 12th week - stopped HVAC system*

For the 14th week of 2010, during Easter vacation, the heat pump was completely stopped and the variation of monitored parameters are presented in Figure 9. The greenhouse effect came out in evidence, with positive effects during the daytime but negative in the night because of low thermal inertia of the building.

5. Conclusions

The goals of the research study have been achieved as follows:

A. Using the methodology from [3] an annual energy demand for a "Solar House" of 48 MWh/year resulted, covering energy needs for space and hot water heating, cooling, ventilation and lighting. In comparison, an ordinary house with windows surface of 15% of utilizable floor area, will need only 37 MWh/year.

B. A monitoring algorithm consisting in the measurement of necessary parameters was established.

C. A monitoring period was started beginning with 11th week of 2010. After each day of the week the results was analyzed.

D. Based on obtained results sets of adjustments of the HVAC system was performed in order to reach the minimum level of energy demand.

This value for annual energy demand will constitute the design load for a future photovoltaic system, which will assure de energetic autonomy of the "Solar House". This system will convert the solar energy into electricity which will be inserted into the national grid and when will be necessary the "Solar House" will use as much electricity as needed for installations, household and lighting.

Is in focus also the summer period when the unshielded windows do not protect the indoor environment against hot summer sun. Passive solutions will be considered like the use of exterior sun screening as an active facade, which automatically controls the amount of light and heat transmitted through the windows. Its effects can be supplemented by the provision of thermal mass in the walls and ceilings in conjunction with night ventilation. In addition, a natural ventilation system to provide fresh air for the "Solar House" throughout the summer is needed. Sensors must control this system so ventilation is optimized. The use of natural ventilation instead of a mechanical ventilation system provides energy savings. In winter, fresh air must be supplied by an on-demand system, which recycles heat from the exhaust air.

For more relevance, the research will be extended on a minimum one-year period.

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