Renewable energy sources used for a low energy University building

Popescu Razvan[a], *Popescu* Lelia[a], *Catalina* Tiberiu[a], *Lungu* Catalin[a],

[a] Technical University of Civil Engineering, Faculty of Building Services Bucharest, razvan22@yahoo.com

Abstract. Nowadays, the renewable energy sources have to be implemented in every new building. This paper describes the case study, and related simulations, of a university building in Romania, that has to become zero energy. Ground source heat pumps (GSHP) are ideal to be implemented in new buildings, being able to produce either heating and cooling. A good insulation is important too, to reduce the cooling and heating energetic needs. Asides active cooling, the passive cooling should be taken into account because it can lower the cooling consumption. For the domestic hot water (DHW), solar panels are taken into consideration to reduce at least 60-70% of the energy consumption, for DHW only. To be able to accomplish the goal of a near zero energy building, photovoltaic solar panels are taken into consideration, placed on the terrace of the building, the system being off-grid type. For all the dynamic simulations Designbuilder software was used, a powerful simulation tool which is able to model all renewable energy sources above mentioned. Also very detailed yearly energetic consumption is presented for all types of consumers from the building: heating, cooling, lighting, ventilation, heating, cooling and domestic hot water. Concerning ventilation, a recovery heat exchanger is used in simulations, having a 80% efficiency, also to reduce the energy consumption. The energy between building and heat pump is using fan coils in all the occupied areas,. Finally, regarding the results of the simulations, after a good insulation of the building and the implementation of the geothermal heat pump, heat recovery unit, solar thermal and solar photovoltaic solar panels, a zero energy building has been obtained. The simulated building had initially a poor energy efficiency, without proper insulation but also with old heating and cooling systems. For the characteristics of the soil measurements with thermal response test (TRT) method from Bucharest were used. Dynamical simulation is one of the best methods to simulate as accurate as possible energy consumption for several case studies, varying insulation type and thickness and different heating/cooling systems.

Keywords: Building simulation, Designbuilder, dynamic models, passive building, renewable sources
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1. Introduction

Because of outdoor pollution and greenhouse gasses that are increasing continuously, major concern is in all the world for improvements in the building sector.

A major sector concerning energy consumption the building one, either residential or the tertiary one. Some buildings are old with poor energy efficiency, other newly constructed and better from the energetically point of view. There are many studies nowadays to improve energy efficiency, in many countries from EU [1].

In Romania for new buildings only NZEB (Nearly Zero Energy Buildings) are accepted by the authorities, since the beginning of 2021, being a novelty in the construction sector. This is the reason why studies are very important to find out optimal measures to achieve this goal. In the European Union the building sector is a very important energy consumer, having around 40% of the total energy consumption, therefore the huge interest in this area to improve energy efficiency. There are studies that show how many buildings in EU should be improved soon, to lower the energy consumption [2].

Because of the increasingly prices of fossil fuels in the last halt year, the transition to clean energy sources should be taken into consideration soon, EU would like to achieve 32% till the year of 2030 [3].

Romania is trying to achieve EU goals concerning energy efficiency by implementing NZEB in every sector of the building sector. Studies, especially dynamic simulation should show how this goal can be achieved. Renewable energy sources like geothermal heat pump, solar energy either thermal or electric ones, heat recovery units, are very important to be simulated and optimised [4-6]. Another important result that should be accomplished after building rehabilitation is to reduce CO_2 emission, being an important condition to achieve NZEB building [7]. As known, one of the most efficient type of building is the passive house [8], and maybe in the future this should be built more frequently because of its benefits. There are only some few passive buildings in Romania, in the Faculty of Building Services from Bucharest there are two passive buildings, that have been simulated in Romania as well as other climates [9]. Therefore dynamic simulation software are very important to present final or primary energy as well as renewable energy production [10].

2. Description of the case study

This paper presents dynamical simulations for a tertiary building which is located in Bucharest, capital of Romania. The activity inside the building is mainly of student activity with laboratories and offices of the teachers. A short description of the building is presented as follows:

- total surface 501 m^2;
- height regime: underground, ground floor, and 1$_{st}$ floor;
- the building is poorly insulated not being according to the present regulations;
- the heating is produced with an old boiler and the Domestic Hot Water (DHW) with an electric accumulator;
- the cooling is produced using split type devices;
- destination: educational building with 10 permanent persons;
- Height of the building: 8m

The purpose of this research is to be able to find which are the measures to achieve a passive house using the following equipments:

- ground source heat pump (GSHP) for heating;
- passive and active cooling to obtain a low cooling load;
- photovoltaic panels to cover the electrical consumption;
- solar thermal collectors to produce DHW;
- heat recovery unit for fresh air intake.

Case study 1- initial case building

As presented briefly the building envelope need major improvement concerning energy efficiency. That's the reason why this study is very important to reduce as much as possible the energy costs after major renovation.

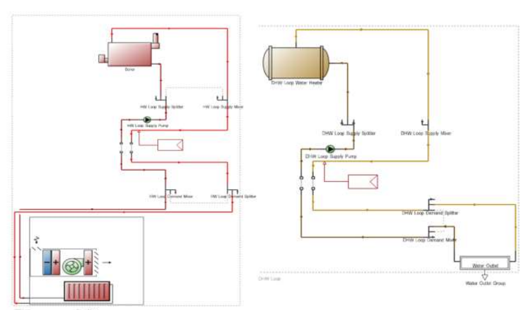

Fig. 1- Initial case with classic heating system and electric DHW

In Fig.1 the initial case from Designbuilder software is presented with an old gas fired boiler with low efficiency and radiators, and DHW production with an electric accumulator.

Case study 2- rehabilitated building using renewable sources of energy (RSE)

The building is rehabilitated by improving its envelope, implementing 30cm of insulating material (polystyrene having a thermal conductivity of 0.04 W/m K) and new windows. Also the source of energy production, cooling and heating ones are modern, GSHP type. There are two systems used in simulations for interior thermal energy distribution:

heated/cooled floor and fan coil units (FCU), the latter working when the first system can't deliver enough energy. So, passive cooling is working most of the time, with low energy consumption, and only when there are hot days (high outdoor temperature such asa 32-35°C) the active system is turned on, to achieve 26°C setup temperature inside the building during summertime (Fig.2).

For winter time, the conventional outdoor temperature is -15°C and the indoor setup temperature considered is 20°C.

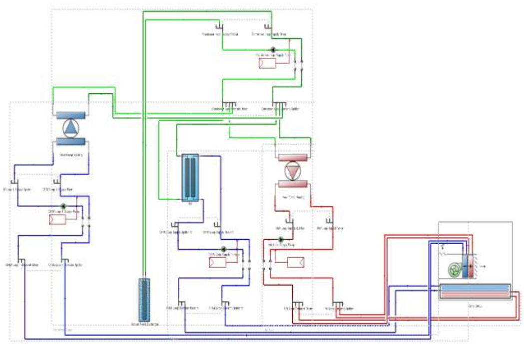

Fig. 2- Ground source heat pump with active and passive cooling

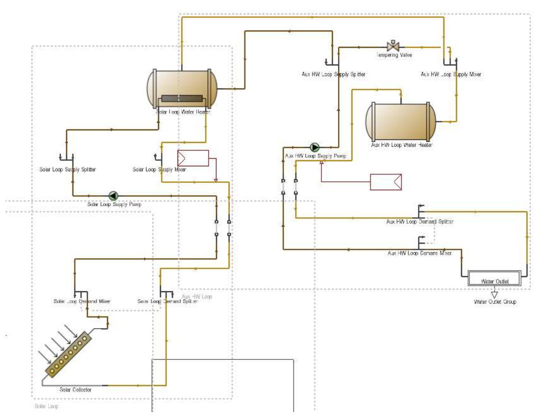

Fig. 3- Solar heating system for DHW production

In Fig. 2 we can find the representation in Designbuilder software for the active and passive cooling as well as the heating system. In Fig. 3 the representation of the solar heating system is presented, with a 3m^2 vacuum panel.

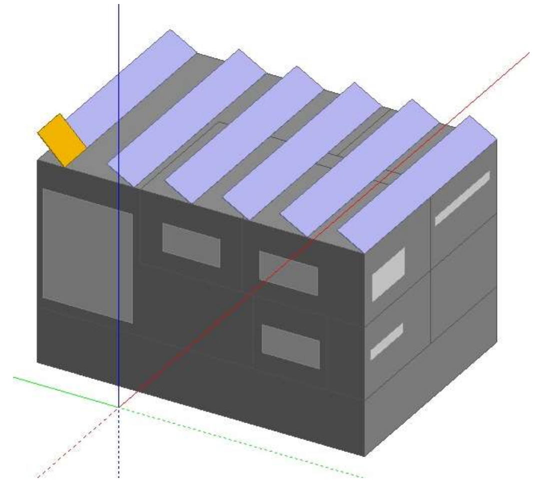

Fig. 4- Representation of the building with solar thermal and photovoltaic panels

In Fig. 4 the representation of the simulated building after rehabilitation is presented. In orange colour is the solar thermal panel, having 45° angle from horizontal plane, and photovoltaic collectors in blue colour, having 35° angle, also from horizontal plane, to achieve maximum energy production, either thermal or electrical. The photovoltaic installed power is 24,1 kW$_p$ with monocrystalline collectors (the electric load of the building is 29209 kWh/year). To reduce fresh air heating and cooling loads, for the rehabilitated building, a heat recovery unit is implemented, with 92% efficiency, compared to the initial case that has important infiltrations, due to old windows mounted in its envelope.

The building has separate thermal zones for each office or chamber inside, with different glazing surface (a total glazing of 103 m^2) and indoor temperatures. The basement is also a distinct zone, without heating or cooling for this area.

The boreholes connected to the heat pump, and simulated in Designbuilder are double U type, of 100m depth. The number of borehole needed is estimated at 7, estimation that is confirmed by Groundloop design software that is dedicated only to this kind of estimation. Also, very important parameters introduced in Designbuilder concern the soil thermal properties:

Tab. 1. Soil thermal properties [5]

Thermal properties	Value	Unit
Soil characteristics		
Conductivity	2.1	W/mK
Heat capacity	2.3	MJ/m3K
Ground temperature	10.5	°C
Ground conductivity	1.7	W/m2
Coolant properties		

Conductivity	0.36	W/mK
Heat capacity	4028	J/kgK
Density	960	kg/m3
Freezing point	-25	°C

The ground temperature is a mean value in the borehole. Designbuilder software has a library with such data.

The thermal properties of the building, are presented, for the two case studies:

Tab. 2 - Building thermal properties of the building, thermal resistance, [m^2 K/W]

Envelope/ R, m^2 K/W	Case study 1	Case study 2
Exteriour walls	0.61	10.4
Ceiling	0.81	9.6
Floor	4.23	10.2
Windows	0.5	1.2

3. Results

The results obtained by means of dynamic simulation software use are shortly presented in Tab. 3. The energy consumptions are presented in as final energy types, but also converted in primary energy consumptions, as a function of fuel type. Also the CO_2 emissions were calculated.

Tab. 3 -Energy consumption and CO_2 emissions.

	Case study 1	Case study 2
Thermal energy consumption [kWh/m^2 year] (1)	357.6	0
Electrical energy consumption [kWh/m^2 year] (2)	65.4	42.1
Conversion to primary energy Natural gas fuel (1) [kWh/ m^2 year]	418.4	0
Conversion to primary energy Electric energy (2) [kWh/ m^2 year]	171.3	110.2
Yearly primary energy consumption Total (1)+(2) [kWh/ m^2 year]	589.7	110.2
Primary energy economy compared to initial case [%]	-	81%
Specific CO_2 emission [kg CO_2/m^2 year]	79.2	3.8
CO_2 emission decrease [%]	-	95%

For the proposed scenario, the building is only using electrical energy as energy type. The results present a primary energy economy between the initial case and the final case of 81%. The carbon dioxide specific emissions were also reduced by 95%. For the final case, the photovoltaic system provides 100% annual coverage of the electric consumption. According to Romanian legislation [11], the initial case of the studied building has a "D" label for total energy consumption. After the retrofit, the building will be labelled with a total energy class "A".

An investment of 272k euro was taken into account for building's envelope and building's services rehabilitation. In Romania, starting with the 2020 year the energy market shifted from a regulated one to a liberalized one. Due to this fact, but also as worldwide energy prices incensement, the price of the kWh of thermal or electrical energy exploded. For example, the natural gas kWh price increased 4 times during the 2021 year, and higher prices are to be expected for the 2022 one. In the view of this facts, the transit from conventional energy use to renewable ones will be faster than expected. The payback time of 10 years was calculated according to Romania legislation [11], less than their life time, but this period will be significantly reduced as the energy price market is in continously increasment.

Tab. 4 - Comparison with the passive house requirements.

	Case study 2	Passive house
Yearly space heat energy demand [kWh/m^2 year]	12.7	15
Yearly space cooling energy demand [kWh/m^2 year]	6.9	15
Renewable primary energy demand [kWh/m^2 year]	42.1	60
Air tightness [changes/hour]	0.5	0.6
Heat recovery system, with efficiency of at least 75%	yes	yes
Mean heat transfer coefficient of windows [W/m^2K]	1.11	0.80
Mean heat transfer coefficient of all opaque building components [W/m^2K]	0.16	0.15
Absence of thermal bridges	yes	yes

4. Conclusions

The initial case for the studied building was poorly thermally insulated (thermal properties of the building are presented in Tab.2) and provided with high energy consumption equipments, only from fossil fuels. The total energy class of the building in accordance with the Romanian legislation for

buildings' energy efficiency [11] was label "D" for the initial case and "A" after the retrofit. Our aim was to obtain a passive building, so the passive house' requirements were considered and accomplished, as proved in Tab.4. A primary energy reduction of 81% was obtained. The final energy reduction between the initial case and the retrofit scenario was 90% and the CO_2 emissions decreased by 95%. The photovoltaic system ensure 100% of the building's electric energy consumption. So, by means of dynamical simulation an existing building was converted in a passive one provided only with "green energy".
Very important is to calculate the payback time for every investment, so also in this case. Not only energy savings are important but also economic aspect. Using the Romanian legislation [11] for building's energy performance, a payback time of 10 years was calculated. Considering that energy costs are increasing continuously, it is expected that this period of time to decrease in the future.

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