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THE INFLUENCE OF THE TROMBE WALL ON ENERGY CONSUMPTION FOR HEATING AND COOLING OF NET ZERO ENERGY HOUSE

Abstrakt: *This paper deals with the influence Trombe wall on heating and cooling net zero energy house. Net zero energy house consists of six rooms that are heated and cooled and is located in the Belgrade area. Trombe wall as a passive solar system is set on the vertical and sloped south side of the house. The basic house does not contain Trombe wall. The simulation was performed for models of houses with vertical Trombe wall, sloped Trombe wall and for a model house with both Trombe walls. Houses, as well as heating and cooling in them, are modeled using the software EnergyPlus. Heating and cooling uses the electricity. To save energy, there are thermostatic valves. The simulation is done for a year. For all the houses, as well as appropriate facilities in them, the temperatures and energy consumption are compared. Simulation finds energy savings of about 15% in the case Trombe wall.*
Keywords: *Trombe wall, net zero energy house, temperature, EnergyPlus*

1. INTRODUCTION

"All the world's oil reserves will be exhausted on October 22nd, 2047., at 20:58 hours," according to the Internet energy portal of the Europe www.energy.eu [1]. Also affected energy source is natural gas, "whose reserves would be exhausted on November 12th, 2068., at 9:25 am. Coal reserves will run out on May 19th 2140., at 20:05" according to the same portal. The statement stresses that such precise timetable was given to the public to warn to the dramatic situation of non-renewable energy sources, and that there is a need for urgent use of renewable energy sources. The main disadvantage of non-renewable energy sources is that the combustion of fossil fuels emit large amounts of carbon dioxide (CO_2) into the atmosphere. From an environmental point of view this is the main problem of the use of fossil fuels.

When renewable energy is mentioned, solar energy is mostly meant. Solar energy can be used actively and passively. The active use of solar radiation means its direct transformation into electricity or heat. This transformation is performed by different devices. The most commonly, solar collectors are used to generate heat and photovoltaic panels to generate electricity. In the passive use of solar radiation, there are no complicated devices and technologies, but use of conventional building materials (concrete, metal, stone, glass, wood, etc.) utilizes the solar energy. The task of passive solar system is to accumulate as much solar energy as possible in a building during the heating season. However, in the summer time, the task of passive solar system is to protect the building of overheating the rooms due to intensive solar radiation.

One way of using passive solar radiation is the application of Trombe wall. Trombe wall is a building construction (mostly brick, concrete) with thickness from 100 to 400 mm. The outer surface of the wall is painted black, which has the ability to absorb the sun's rays. In front of the wall, at a distance of 20 to 100 mm, there is a glass, which can be single, double or triple. The inner surface of the wall is uneven, to maximize the surface area for heat exchange with the appropriate rooms in the building.

Felix Trombe is a French scientist, who has designed a solar house in the Pyrenees in 1956. On the south side of the house raised the massive concrete wall thickness of 40 cm. The wall is glazed and the front painted black. The sun's rays pass through the glass and fall on black colored side walls which absorb them. The wall has a large mass and acts as heat storage, which emits in the room at the end of the day when you need rooms to be heated [11].

Vertical section of a passive solar system with Trombe wall is shown schematically in the following figure:

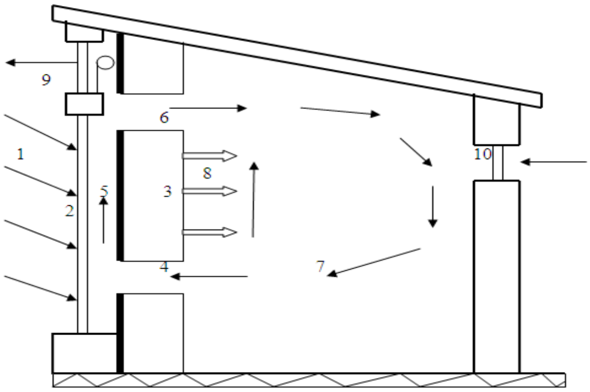

Figure 1. Vertical cross-section of the Trombe wall

Principle of operation of the passive solar system is as follows:

The sun's rays (1) pass through the glass (2) and fall to the dark side of the front Trombe wall (3). Trombe wall is usually made of solid concrete, which is heated. One half of the Solar energy is accumulated by wall, and the other half creates natural circulation of air through the holes (4) and (6), due to the greenhouse effect. On the other hand, Trombe wall radiates heat accumulated in the desired room (8). In order to the Trombe wall stays warm at night, the curtain should be installed (9) between the glass and the wall. At night, when solar radiation ends, the curtain comes down and plays the role of thermal curtains. However, in the summer time the curtain comes down during the day to prevent overheating of the wall and the room. At night, curtain is lifted to allow cooling of the wall by radiation. In this way, the curtain with hot air vents (9) and fresh air (10), performs the process of air conditioning in the summer.

Utilization of solar radiation by using the Trombe wall was studied by many authors. For example Fares has investigated the influence of various components of the Trombe wall on thermal load on houses in Syria, considering the climatic conditions prevailing in that environment [2]. Chel and other authors have investigated the use of the Trombe wall on a warehouse of honey in Gwalior in India [3]. Jaber and other authors have investigated the optimal structure of the Trombe wall in the Mediterranean region [4]. Ellis in his work dealt with the improvement of different typesof the Trombe wall in EnergyPlus [5]. Nwachukwu and Okonkwo have examined different coating the outer surface of the Trombe wall which have a high power absorption and a very low emission of solar radiation [6]. Saadatian studied examples of different types of Trombe wall both form and material components of the oldest and simplest to the more complex modern structure [7]. Shen, and other authors have compared conventional and composite Trombe walls stating that the composite Trombe walls have better thermal performance than the classical [8]. Track and other authors have experimentally investigated the unwanted overheating Trombe wall in warm climates and how shading and ventilation can reduce these side effects [9]. Yilmaz and Kundakci studied the possibilities of renovating and installing of Trombe wall on the south facade to existing residential buildings in Istanbul, and the mandatory installation Trombe wall on the south facade of the new residential buildings because of the large number of sunny days in Istanbul. [10]

This labor presents the results of energy savings through out the year, in a house with Trombe wall in relation to the house without Trombe wall. Electrical energy is consumed for heating, cooling, lighting and furnishings. Depending on the type of observed Trombe wall, energy savings ranges from 3.17% to 14, 84%.

2. SOFTWARE ENERGYPLUS AND SKETCHUP

These two software are connected by Google SketchUp providesa net zero energy house geometry, which is simulated in the EnergyPlus. The EnergyPlus has no graphical user interface for a graphical definition of the geometry and graphical presentation of results, so there is a need to use the programs to construct a net zero energy house and to show the calculation results. For this purpose, the Google SketchUp with the addition OpenStudio and Microsoft Excel have been used.

To simulate the heating, cooling, ventilation, lighting, and other energy flows in the net zero energy house was used in version 7.0.0 and EnergyPlus. This software models the energy use in a particular home. EnergyPlus takes into account all the factors that affect the thermal load of the house, such as electrical appliances, lighting, the presence of people in the house, the influence of solar radiation, wind influence, infiltration, shading open spaces. This software allows us to perform a simulation of the energy behavior of net zero energy house over a defined period of time.

3. THERMAL AND GEOMETRIC DESCRIPTION OF THE NET ZERO ENERGY HOUSE

Modelians are four net zero energy houses. The basic model for the simulation is a house without Trombe wall (MODEL BTrZ). The simulation was performed for models of houses with a vertical Trombe wall (MODEL VTrZ), for a model home with a sloping Trombe wall (MODEL KTrZ) and for a model with both of these Trombe walls (MODEL 2TrZ).

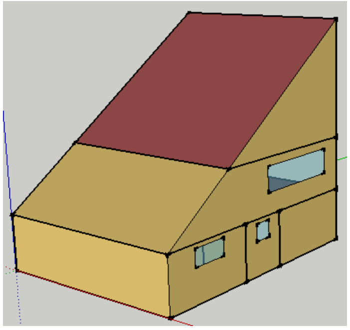

Figure 2. MODEL BTrZ

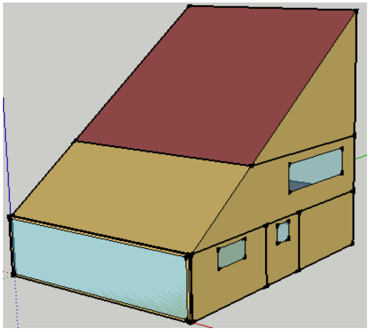

Figure 3. MODEL VTrZ

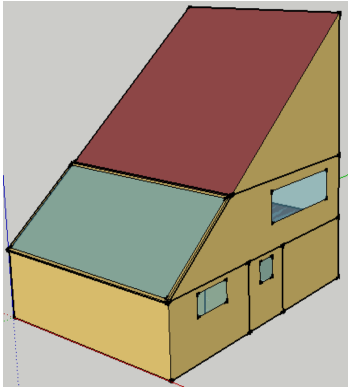

Figure 4. MODEL KTrZ

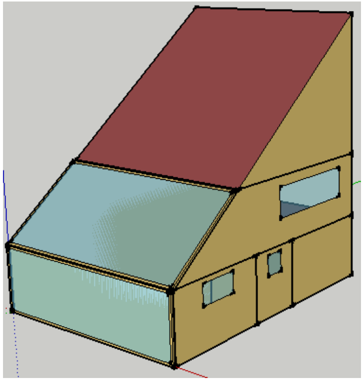

Figure 5. MODEL 2TrZ

Each of the models of net zero energy house consists of six rooms that are heated (living room, two bedrooms, bathroom, hall and floor), and four rooms are cooled (living room, two bedrooms and first floor). The cross sections of the house for the ground floor and upper floor of the house are shown on the following pictures:

Figure 6. Cross section of the ground floor of the house in 3D

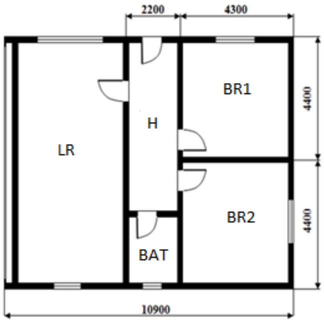

Figure 7. Cross section of the ground floor of the house in 2D

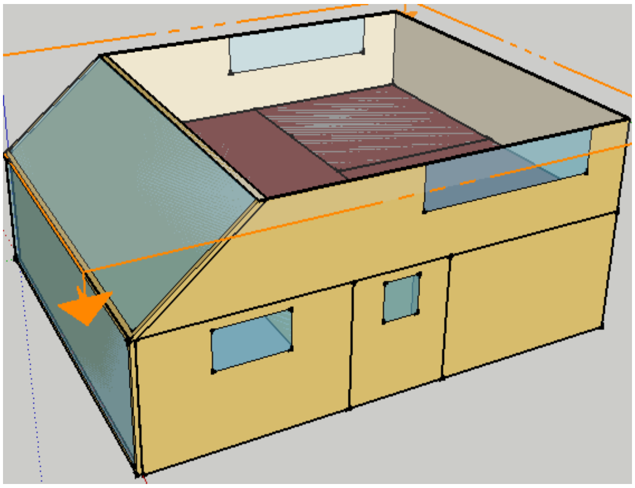

Figure 8. The intersection of the upper floor of the house in 3D

The electricityis used for heating and cooling. Electric heat is done by the Norwegian radiators series ADAX NEO [13]. For cooling are used split air conditioners of LG [14]. At each heating body and room conditioner exist thermostatic valves in order to save energy.

EnergyPlus modeling software allows heating of the building, taking into account all the factors that affect the thermal load of the building and all the factors that affect energy gains. This software provides capabilities for modeling different scenarios for heating buildings. In this labor, the scenario with the gains of the electrical and power equipment, electric bulbs and the presence of people in the premises.

4. THE CONSTRUCTION OF THE TROMBE WALL

Trombe wall consists of solid parts (reinforced concrete), a thickness of 30 cm and a thickness of three-layer glass (4, 18, 4; 13, 4) mm [12]. The glass structure is set at 10 cm of reinforced concrete. The front of reinforced concrete is painted in black.

To reduce winter night cooling of concrete, and in the summer day prevent it from overheating, and thous the rooms of the house, between the concrete and glass is placed blind [15]. It goes down at night in the winter, and in the summer by day. Vertical section of the Trombe wall is shown in the following figure:

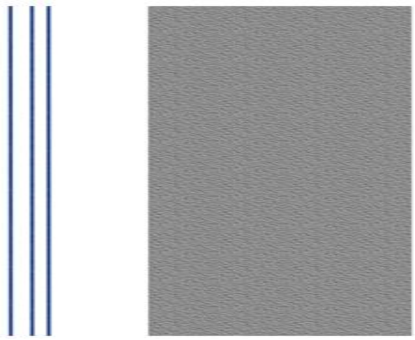

Figure 9. Vertical cross-section of the Trombe wall

5. RESULTS AND DISCUSSION

The simulation is done for the whole year. The heating season lasts from October 15th till April 15th following the calendar year, and the season of cooling from April 15th till October 15th of the same year. The results are presented in tabular HTML file and use of Microsoft Excel. Simulation results are obtained and displayed every 15 minutes.

5.1 Specific consumption of electricity for the entire year

The HTML file gives the total consumption of electricity for heating, cooling, lighting and furnishings.

For the one-year period frame, EnergyPlus simulation software showed that the highest specific energy of total electricity is for the house without Trombe wall (122.41 kWh/m2), then for the house with vertical Trombe wall (118.53 kWh/m2), for the house with a sloping Trombe wall (106.77 kWh/m2) and the lowest total specific consumption of electricity is for the house with 2 Trombe walls (104.24 kWh/m2). These results are shown in Figure 10.

If the basic model is to simulate houses without Trombe wall, then the total energy savings is for the house with 2 Trombe walls 14.84%, for the house with a sloping Trombe wall 12.78% and for the house with vertical Trombe wall 3.17%.

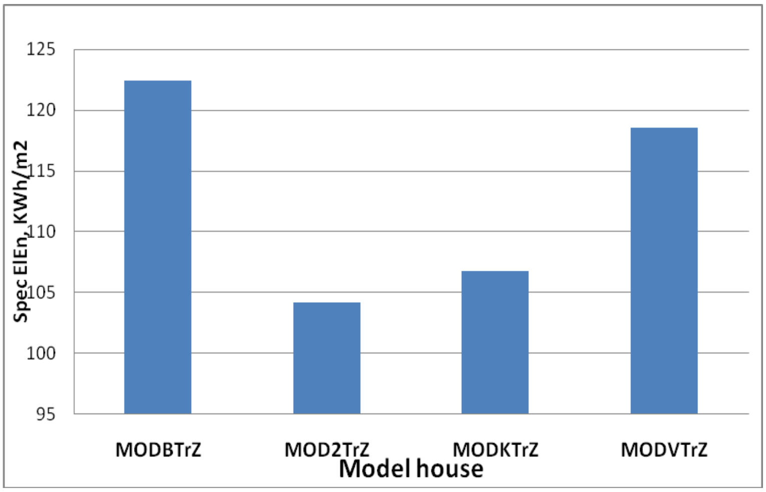

Figure 10. Specific consumption of electricity overall energy for different models

If we consider only the use of electricity for heating, the results are as follows: the highest specific energy consumption for heating is the house without Trombe wall (56.30 kWh/m2), then the house with vertical Trombe wall (51.00 kWh/m2), for the house with a sloping Trombe wall (36.40 kWh/m2) and the lowest specific electricity consumption is for heating the house with 2 Trombe walls (32.83 kWh/m2). The results are presented in Figure 11.

Looking at the house without Trombe wall as the basic model for the simulation, the saving of electricity for heating is for the house with 2 Trombe walls 41.69%, for the house with a sloping Trombe wall 35.35% for the house with vertical Trombe wall 9.41%.

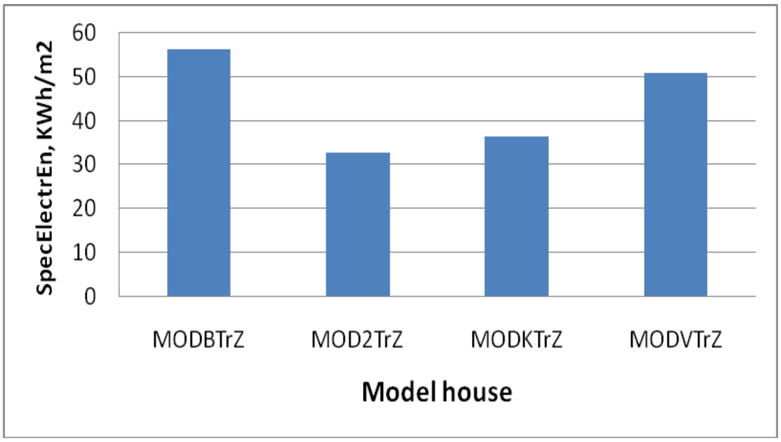

Figure 11. Specific consumption of electricity for heating

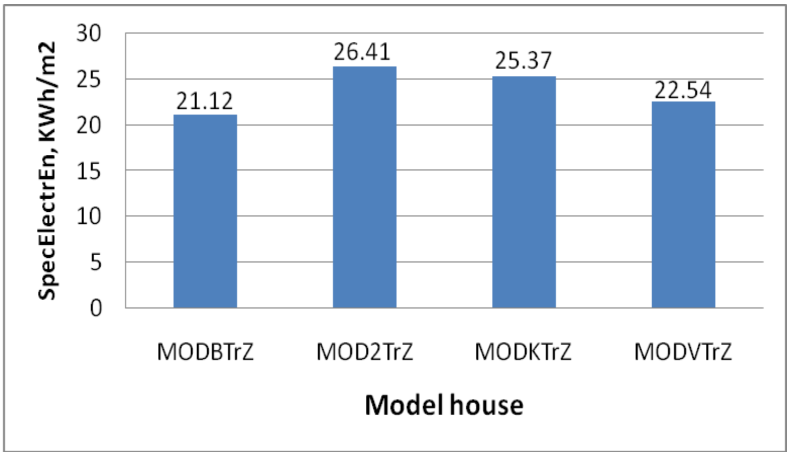

Figure 12. Specific electricity consumption for cooling

If we observe the use of electricity for cooling results are as follows (Figure 12): the highest specific power consumption is for the house with 2 Trombe walls (26.41 kWh/m2), then for the house with a sloping Trombe wall (25.37 kWh/m2), for the house with vertical Trombe wall (22.54 kWh/m2) and the lowest power consumption is for cooling the house without Trombe wall (21.12 kWh/m2), as expected. However, the positive influence of Trombe wall on heating, in the heating season, is much larger than its negative influence on cooling (overheating of the rooms), in the cooling season. This conclusion is confirmed by the following Figure 13, on which is shown the electricity consumption for heating and cooling aggregate for all models of houses.

5.2 The coldest day of the meteorological file

Figure 12 shows the air temperature in the living room for all types of houses for December 24th, which was the coldest day of the meteorological file for Belgrade. The figure shows that the temperature in the living room reaches a constant value when the heater is on. These values are set on the thermostat, in the living room 20^0C. Upon termination of heating, the temperature in the living room decreased epending on their wrapper, i.e. the coefficient of thermal conductivity so that the mean temperature will be lower than the default.

Comparing the temperature in the living room of all types of houses we obtain the following results: the average temperature in the living room of the house with 2 Trombe walls increases by 1.8^{0}C than the temperature in the living room of the basic model for the simulation, in the living room of the house with vertical Trombe wall increases by 1.6^{0}C, and in the living room with a sloping Trombe wall increases by 0.3^{0}C from the basic model of the house.

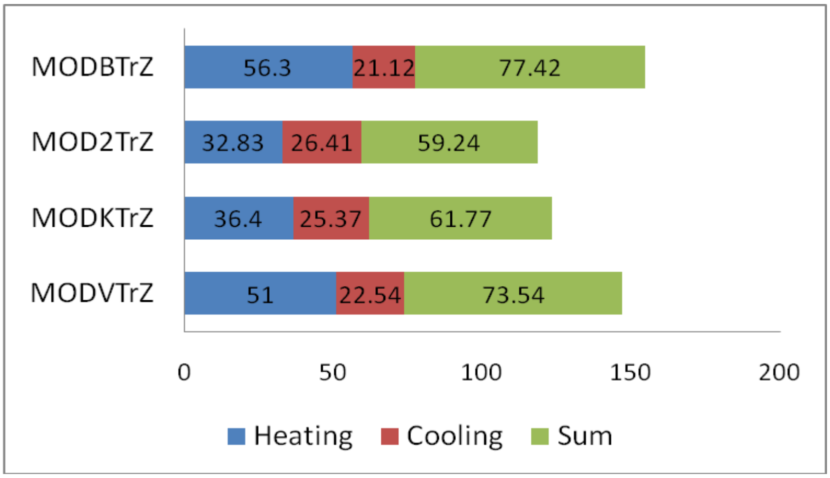

Figure 13. Specific energy consumption for heating, cooling and summary in KWh/m^2

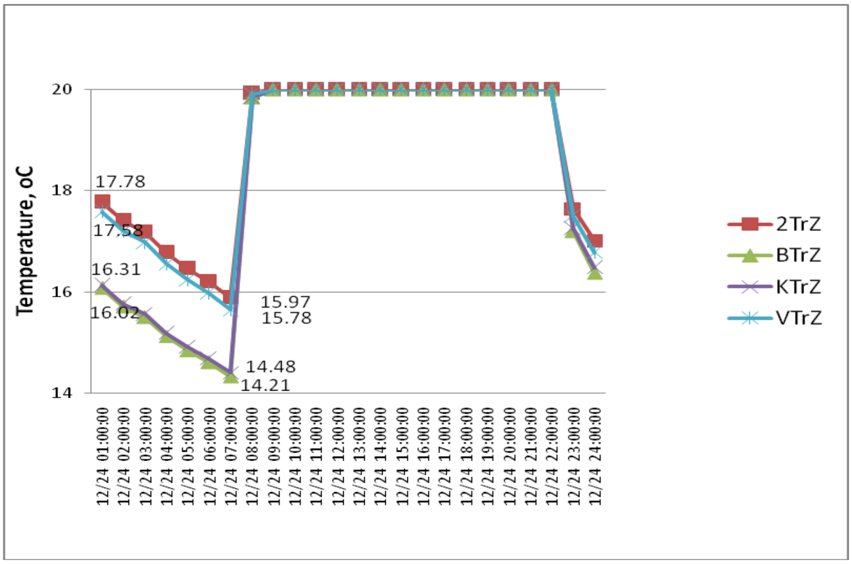

Figure 14. Temperatures in living rooms for the coldest day

Besides temperature, power of heaters can be analyzed in areas of extremely low temperatures, i.e. for December 24th. Figure 15 was used for the analysis, which shows the power of heaters in each room for the model of the house with 2 Trombe walls. It is clearly seen that the heaters start working at 7h and work until 22h . In the first hour of its heating device reaches its maximum power in order to achieve the required temperature. During the day, the oscillation of the power are observed.

When the heaters are off at 22h, the power decreases rapidly. Figure also shows that the highest power of heaters is needed for a room on the first floor, because it is the largest one.

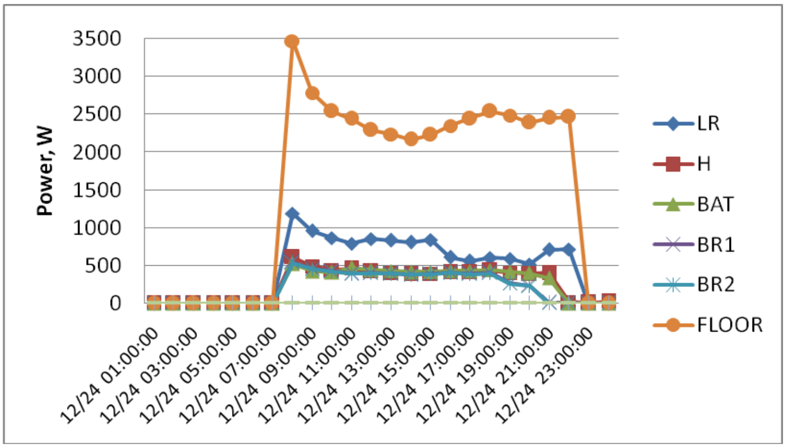

Figure 15. Power heaters for the coldest day for a house with 2 TrZ

5.3 The warmest day of the meteorological file

From the standpoint of cooling is interesting to observe the hottest day of the meteorological file for Belgrade, which is June 15th. Figure 16 shows the temperature in the room of the house with 2 Trombe walls.

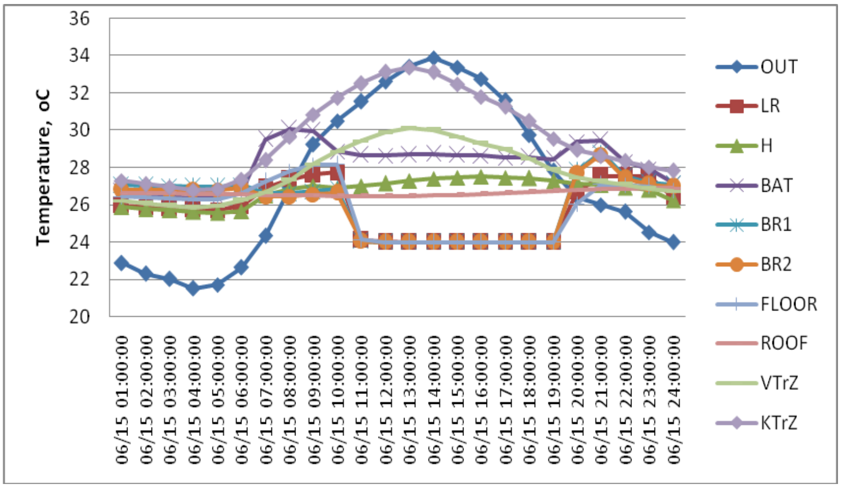

Figure 16. Temperature in the room of the house with 2 TrZ of the hottest day

The figure shows that the air conditioning units turn on at 10:00 and turn off at 19:00, and that the specified temperature of the thermostat from the 24^{0}C is achieved after one hour, i.e. at 11:00. After the exclusion of air conditioning, temperature rises rapidly in the next hour. Of course, this applies to the four rooms that are cooled (living room, two bedrooms and first floor).

Also, it is interesting to observe the engaged air conditioners power during the hottest day of the meteorological file (Figure 17).

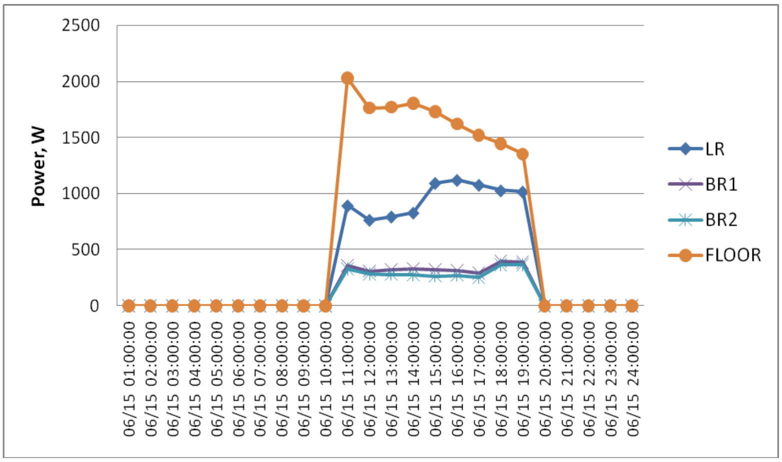

Figure 17. ***Power of air conditioners in each room of the house with 2 TrZ hottest days***

Figure 17 and Figure 16, clearly indicate the working hoursof air conditioner from 10:00 to 19:00. The maximum use of the air conditioner is in the first hour when the air conditioner achieves its maximum power. Later in the day, oscillation of the power of air conditioners can be observed.

6. CONCLUSION

In this labor, the results of the effect of the Trombe wall on electric heating and cooling net zero energy house are shown. On heating and air conditioning bodies are thermostatic valves to regulate the room temperature and energy savings. Heating and cooling of four model houses have been modeled.

In addition to the basic model (house without Trombe wall), heating and cooling simulation was performed for the models of houses with vertical Trombe wall, for the house model with a sloping Trombe wall, for the house model with both Trombe walls. Based on the simulation results it can be concluded that the biggest savings of the total electricity generated with the house model with 2 Trombe walls of 14.84% for the house model with a sloping Trombe wall 12.78%, for the house model with a vertical Trombe wall 3.17%. Energy savings is much higher if one considers only its consumption for heating: the house model with 2 Trombe walls 41.69% for the house model with a sloping Trombe wall 35.35% for the house model with a vertical Trombe wall 9.41% .

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