University of Banja Luka
Faculty of Mechanical Engineering

# DEMI 2021

## 15th International Conference on Accomplishments in Mechanical and Industrial Engineering

# PROCEEDINGS

Banja Luka, 28 - 29 May 2021

University of Banja Luka
Faculty of Mechanical Engineering

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# DEMI 2021

*Banja Luka, May 2021*

# 15th INTERNATIONAL CONFERENCE ON ACCOMPLISHMENTS IN MECHANICAL AND INDUSTRIAL ENGINEERING

# DEMI 2021


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**CONTENT**

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# Possibility for energy saving in Serbian building with photovoltaic-thermal collectors

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**Abstract** *In the last few decades, buildings have been recognized as large energy consumers, so it is necessary continuously implementation of different measures for improving energy efficiency of existing and construction of energy efficient new buildings. The use of renewable energy sources is essential, and solar energy represents the most promising and most reliable source of energy. This paper analyzes the energy consumption in a single-family residential building with photovoltaic/thermal (PV/t) collectors. Electricity in the building is used for space heating, lighting, DHW system and electrical appliances. The system with photovoltaic/thermal collectors generates heating energy, which is used to prepare hot water in the buildings DHW system, as well as electricity which is used for other needs. The rest of the energy needs are compensated by purchasing energy from the electricity distribution system. Energy consumption and energy generation data were obtained based on simulations performed in the EnergyPlus software, while building, i.e. a house for a family of four, was designed in Open Studio plug-in for Google Sketch Up. The considered facility is positioned in the city of Kragujevac. This analyzes show the possibility for energy saving in heating energy and electricity from by photovoltaic thermal collector in residential Serbian building.*

**Keywords** *building, photovoltaic/thermal collector, simulation, generated energy, energy saving*

## 1. INTRODUCTION

Serbia is one of the countries with extremely low energy efficiency. The reasons for this are the use of outdated, energy inefficient technologies in industry, construction and infrastructure, inadequate legislation and insufficiently developed environmental awareness of the population.
Building sector in a world is a large energy consumer with amount of even 40 % of total energy consumption. Serbia has about 300-400000 energy inefficient buildings, without thermal insulation - energy inefficient homes, with an annual energy consumption of 220 kWh/m$^2$, while the European average energy consumption is 60 kWh/m$^2$, so energy consumption in buildings in Serbia is at the level of even 50 % [1, 2]. That is why it is very important to build energy efficient buildings that involve renewable energy technology. Systems of renewable energy can generate the energy (electricity, thermal energy) to partially or completely satisfying building energy needs. These buildings have reduced energy consumption, a longer life cycle and contribute to environmental protection through lower greenhouse gas emission [3, 4].
Solar energy is the most promising renewable energy source because it does not bring pollution, which is disproportionately large compared to the use of fossil fuels. In conventional solar systems, solar energy is converted into electricity or heat. A special type of solar technology is the joint use of photovoltaic modules and solar collectors in

photovoltaic-thermal or PV/t collectors (hybrid systems). It is expected that PV/t technology, as renewable energy technology, become competitive with conventional energy production and has a significant potential for domestic use in the future [5].

This paper analyzes the energy consumption and possibilities for energy saving in a single-family residential building with a PV/t collector. Electricity in the building is used for space heating, lighting, electrical appliances and for the domestic water heating. The PV/t system generates thermal energy, which is used for water heating, as well as the electricity for space heating, lighting, electrical appliances, etc. The rest of the energy needs are compensated by purchasing energy from the electricity distribution system. Energy consumption data were obtained by simulations performed in the EnergyPlus software [6]. Previously, a building model was designed in Open Studio plug-in for Google SketchUp software. The considered facility is positioned in the city of Kragujevac.

The analyzes show various parameters such as total energy consumption, energy consumption in DHW system, heating energy consumption, and generated energy by PV/t collector.

## 2. MATERIALS AND METHODS

### 2.1 Model of analyzed building

The modelled single-family residential building is shown in Figures 1 and 2. It is one-store building and it has 6 conditioned zones (living room, kitchen, hall, bathroom and two bedrooms).

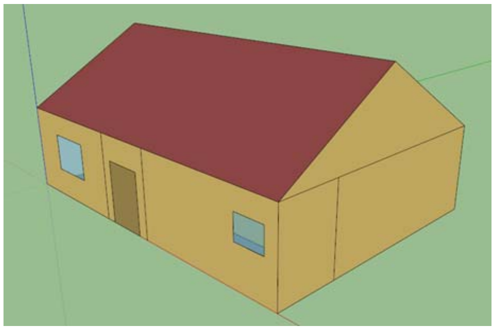

**Fig. 1.** Modeled building in EnergyPlus - south facade

The total floor area of the building is 88 m$^2$. The windows are double glazed with the air gap of 15 mm, with total area of 5.85 m$^2$, and the U-value of 2.72 W/(m$^2$K). Inward opening side-hung windows are implemented in modelled buildings.

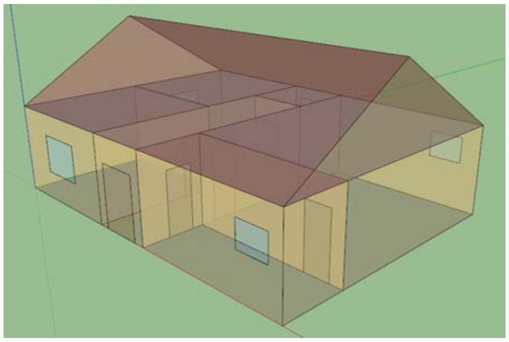

**Fig. 2.** Modelled building in EnergyPlus - X ray view

The building envelope and roof are thermally insulated by polystyrene (thermal insulation thickness - 0.15 m). The building has the south-north oriented roof with a slope of 32$^0$. The external wall consists of brick, heavy concrete, insulation, air space and gypsum board, with U value 0.177 W/(m$^2$K). The inner wall consists of two layers of gypsum boards between which there is air space. The floor construction consists of lightweight concrete, air layer and acoustic plate, with U value 0.517 W/(m$^2$K). The ceiling consists of lightweight concrete, air space and an acoustic plate. Above the ceiling is the attic zone (non-conditioned zone).

The building was simulated through a year, when heating system operates from October 15 to April 15, which is a common practice in Serbia. Every conditioned zone in the building is equipped with an electric baseboard heater. Air temperatures in the heated rooms are set to 20$^0$C from 07:00-09:00 and from 16:00-21:00, and to 15$^0$C from 09:00-16:00. The simulation time step is 15 min.

### 2.2 Location and Climate

The investigated building is located in the city of Kragujevac, in Sumadija region which is in the central part of the Republic of Serbia. Its average height above sea level is 209 m. Its latitude is 44$^0$10 N and longitude 20$^0$55 E. The time zone for Kragujevac is GMT+1 h. Kragujevac has a moderate climate, with warm and humid summers (with temperatures as high as 37$^0$C). The winters are cool, and snowy, with temperatures as low as -12 $^0$C [7].

The EnergyPlus uses weather data from its own database file. Input file in EnergyPlus contains a large variety of parameters for solar radiation calculating for every day in the year. Daily average solar radiation for Serbia is different in different parts of country – it is about 1,1 kWh/m$^2$ at the north of Serbia and 1,7 kWh/m$^2$ at the south of Serbia in January; in July it is about 5,9 kWh/m$^2$ at the north and 6,6 kWh/m$^2$ at the south of Serbia. Annually average solar radiation in Serbia is from 1 200 kWh/m$^2$ for north-west to 1 800 kWh/m$^2$ at the south of Serbia, while in Central Serbia, where the analyzed house is located, this value is 1550 kWh/m$^2$ [8].

### 2.3 Model of PV/t collectors

Four photovoltaic/thermal collectors are installed on the south-oriented part of the roof (slope angle of 32$^0$). Thermal efficiency of PV/t collectors is 30 % and cell efficiency of PV panel is 15 %.

The input object in EnergyPlus software SolarCollector:FlatPlate:PhotovoltaicThermal provides a simple PV/t model that is provided for quick use during design or different studies. The user can set up values for a thermal efficiency and the incident solar heats the working fuild. This model of PV/t collector is water-based model and it is a part of plant loop with nodes connected to a plant loop and the plant operating scheme determines flows. No other details of the PVT collector's construction are required as input data [6].

In these investigations, temperature of the water heating in solar loop is limited to 65$^o$C. Main tank has volume of 250 l while instantaneous tank has volume of 80 l. Monthly hot water consumption is 14 m$^3$, and total monthly water consumption is 25 m$^3$.

## 3. BUILDING ENERGY CONSUMPTION

Total finally energy consumption $E_F$ in a building is related to the electricity. Electricity in a building is consumed for heating (eh), lighting (el), domestic hot water (DHW) and appliances (eq).

$$E_F = E_{eh} + E_{el} + E_{DHW} + E_{eq}$$

where:

- $E_{eh}$ - electricity consumption of the electric heating,
- $E_{el}$ - electricity consumption for lighting,
- $E_{DHW}$ - electricity consumption for DHW system and
- $E_{eq}$ - electricity consumption for the appliances (electric equipment).

Generated energy $E_{GEN}$ in a building, by PV/t collectors is equal to sum of generated electricity $E_{GEN, PV}$ and generated thermal energy $E_{GEN, THERMAL}$, i.e.

$$E_{GEN} = E_{GEN, PV} + E_{GEN, THERMAL}$$

Net-energy consumption in building with PV/t collectors is:

$$E_{NET} = E_F - E_{GEN}$$

## 4. RESULTS AND DISCUSSION

The aim of presented investigation is to show the possible energy saving in building with photovoltaic/thermal collector. Comparisons of two identical single-family residential buildings were made, one without and the other with a PV/t collector on the roof. At the end, there is provided a comparison of the obtained results.

### 4.1 Case 1 – Building without PV/t collector

The results of the energy consumption in the building without PV/t collector are given in the Table 1.

The largest part of energy consumption is related to the electrical heating system (29.188 GJ), then to the domestic hot water heating (20.93 GJ). Electrical appliances consume 4.37 GJ of electricity, while lighting consumes 0.23 GJ. All data are obtained for building energy simulation through one year, so total yearly building energy consumption is 54.718 GJ.

**Table 1.** Energy consumption in building without PV/t collector (Case 1)

| **Energy consumption (GJ)** | **Case 1** |
|---|---|
| Heating | 29.188 |
| Lighting | 0.23 |
| Electric equipment | 4.37 |
| DHW system | 20.93 |
| **Total energy consumption** | **54.718** |

Figure 3 shows the distribution of annual building energy (electricity) consumption, in GJ and %, in the building without PV/t collector. As it can be seen, the largest share of energy, 53%, is spent on heating, then 38% on DHW system. Electrical equipment and lighting spent 8 % and 1 % of total energy consumption, respectively.

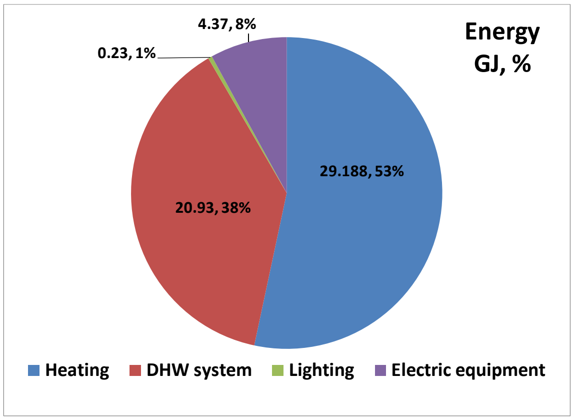


**Fig. 3.** Schematic presentation of energy consumption for building without PV/t collector

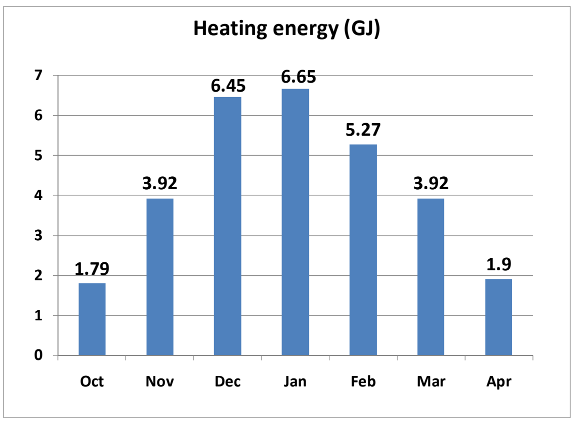


**Fig. 4.** Monthly heating energy consumption for building without PV/t collector

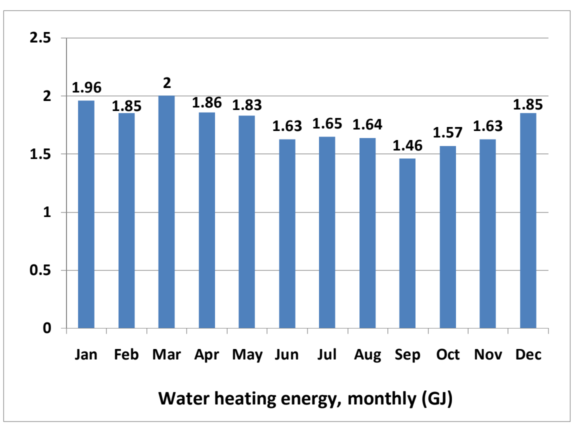


**Fig. 5.** Monthly energy consumption for DHW system, in building without PV/t collectors

Figure 4 shows monthly heating energy consumption in GJ, for building without PV/t collectors. Heating energy consumption for January has the greatest value – 6.65 GJ.

Fig. 5 shows monthly energy consumption in DHW system in the case without PV/t collectors, and the greatest value is for March – 2 GJ.

### 4.2 Case 2 – Building with PV/t collectors

The results of the energy consumption in the building with PV/t collectors, and generated energy are given in the Table 2.

**Table 2.** Energy consumption and generated energy in building with PV/t collector (Case 2)

| **Energy consumption (GJ)** | **Case 2** |
|---|---|
| Heating | 24.42 |
| Lighting | 0.23 |
| Electric equipment | 4.37 |
| DHW system | 10.34 |
| **Total energy consumption** | **39.36** |
| Generated electricity | 4.768 |
| Generated thermal energy | 10.59 |
| **Total generated energy** | **15.358** |

The largest rate of energy consumption is related to the heating system (24.42 GJ), then to the DHW (10.34 GJ). Appliances and lighting consume same energy amount. Total yearly building energy consumption is 39.36 GJ.

Figure 6 shows the distribution of building energy consumption, in GJ and %, in the building with PV/t collectors. Heating system has share of 62% in total building energy consumption, and DHW has share of 26% in total building energy consumption. Electrical equipment and lighting spent 11% and 1% of total energy consumption, respectively.

Yearly generated thermal energy with PV/t collectors is 10.59 GJ and generated electricity is 4,768 GJ, i.e. their sum is 15.358 GJ. This value represents energy saving in building, achieved by PV/t collectors. Total generated energy by PV/t is 15.892 GJ - 10.595 GJ of energy related to thermal energy and 5,297 GJ is electricity

(4,768 GJ of electricity is directly used, while 0.529 GJ is sold to the utilities).

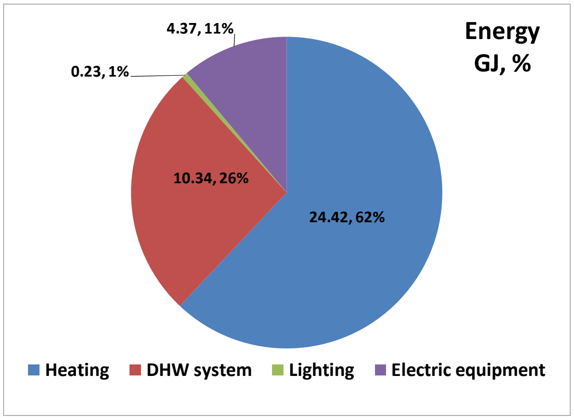


**Fig. 6.** Schematic presentation of energy consumption for building with PV/t collectors

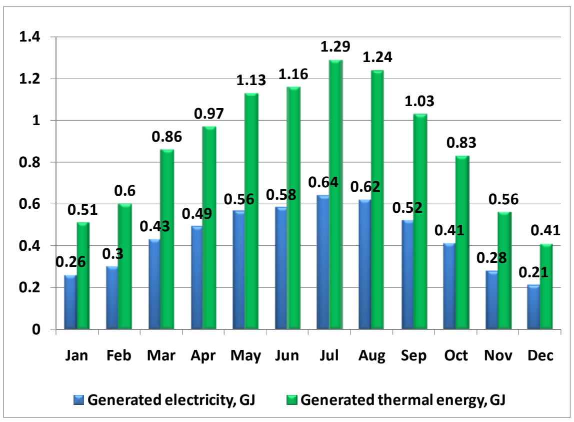


**Fig. 7.** Generated energy (electricity and thermal) with PV/t collectors

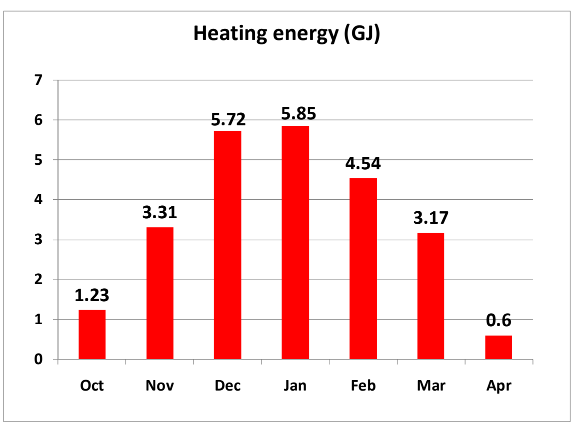


**Fig. 8.** Monthly heating energy consumption for building with PV/t collector

Figure 7 shows monthly generated energy by PV/t collectors, which generate a larger amount of energy during the summer period. The highest generated amount of both, electricity and heat is in July and amounts 1.29 GJ of thermal energy and 0.64 GJ of electricity**.**

Figure 8 represents monthly heating energy consumption in GJ, for building with photovoltaic/thermal collectors. It can be concluded that heating energy consumption for January has the greatest value – 5.85 GJ.

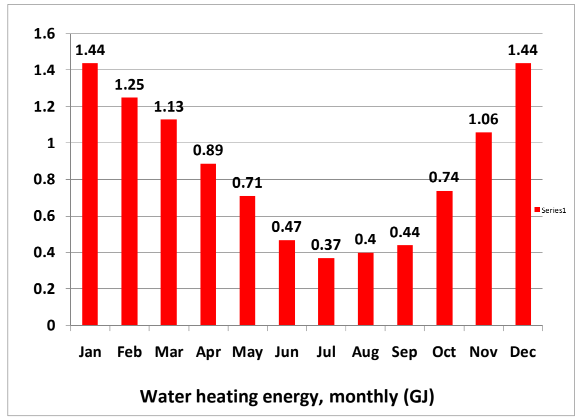


**Fig. 9.** Monthly energy consumption for DHW system, in building with PV/t collectors

Figure 9 shows monthly energy consumption in DHW system, for building with PV/t collectors. It can be concluded that it has the greatest value for January and December, 1.44 GJ, and the smallest value in July, 0.37 GJ. Smaller values of energy consumption for DHW system are in summer months, when PV/t collectors generate a significant amount of electrical and thermal energy.

### 4.3 Comparison of the obtained results

Based on the obtained research results, it can be concluded that installation of PV/t collectors can significantly improve building energy efficiency. If the total annual energy consumption in building is compared for two analyzed buildings, Case 1 and Case 2, it can be achieved energy saving of 15.358 GJ in building with installed photovoltaic/thermal collectors. Expressed as a percentage, that is the amount of even 28 %. This fact clearly shows the importance of implementation PV/t collectors in buildings.

Zondag, in his review paper [9], gave the analysis of PV/t collectors and their applications in different climate, and concluded that possible energy saving with this solar systems can be 23-38 %, depending on climate conditions.
Next figure (Figure 10) shows comparison of monthly energy consumption for Case 1 and 2.

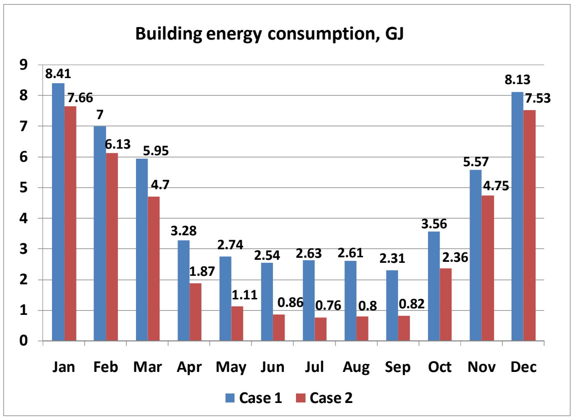


**Fig. 10.** Monthly building energy consumption for building without and with PV/t collectors

Building with PV/t collectors on the roof has lower energy consumption through whole year, especially in summer months. In those months, a great amount of solar energy is available, and PV/t collectors generate significant amount of electricity and thermal energy. This fact is according to the Figure 7.
Due to the large amount of generated thermal energy in the summer months, the energy consumption in the DHV system is lower in the building with PV/t collectors (Figure 11).

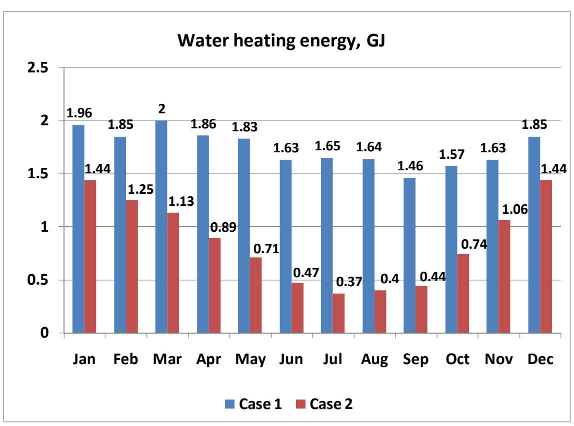


**Fig. 11.** Monthly building energy consumption for water heating in DHW system, for building without and with PV/t collectors

During the winter months, there is a possibility of electricity generation by PV/t collectors during the sunny days. The amount of generated electricity is not huge but it certainly presents energy saving (Figure 12).

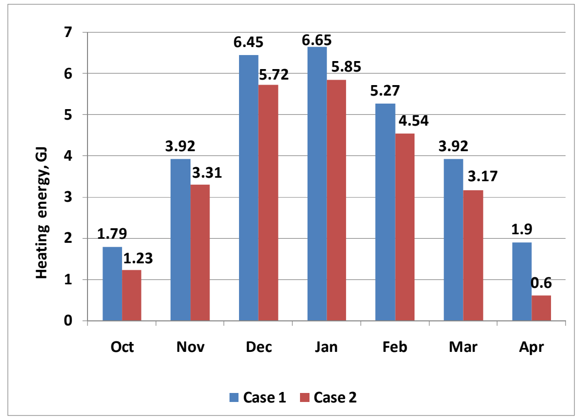


**Fig. 12.** Monthly consumption of heating energy, for building without and with PV/t collectors

## 5. CONCLUSION

In buildings, solar energy can be directly used by installation of photovoltaic/thermal collectors. PV/t collectors can improve building energy efficiency and they are representing renewable energy technology with high potential for great energy savings, due to simultaneous generation of electricity and thermal energy.
Single-family residential building, located in the city of Kragujevac, Republic of Serbia, is analyzed in this paper. Simulations were conducted for the same building – with and without installed PV/t collectors.
Annual energy consumption in building without PV/t collectors is 54.718 GJ, while in building with PV/t collectors, it is 39.36 GJ. Results obtained by simulation in EnergyPlus software show annual energy saving of 15.358 GJ, i.e. 28 %. Generated energy by PV/t is 15.892 GJ - 10.595 GJ of energy related to thermal energy and 5,297 GJ is electricity.
In addition to high energy savings, i.e. economic saving, that can be achieved by various solar systems, we should not neglect their very small detrimental impact on the environment.

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