



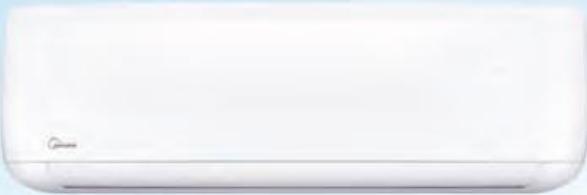
**48. MEDUNARODNI
KONGRES I IZLOŽBA
O KLIMATIZACIJI
GREJANJU I HLAĐENJU**

**Beograd, Sava centar
6–8. XII 2017.**

**48th INTERNATIONAL
CONGRESS & EXHIBITION
ON HEATING
REFRIGERATION AND
AIR-CONDITIONING**

**Belgrade, Sava Center
6–8 XII 2017**

**ZBORNIK RADOVA
PROCEEDINGS**



Midea



Dovoljno pametna klima
da vidi vaše potrebe



WiFi Control



Smart Sleep



Samodijagnostika



elcomtrade

Ekskluzivni distributer za Srbiju, Kosovo i Bosnu i Hercegovinu:

Bulevar Arsenija Čarnojevića 52a, lok. 3
11070 Novi Beograd

Tel: +38111 30 18 118, 30 18 119, 30 15 505

Fax: +38111 30 18 118, 30 18 119, 30 15 505

e-mail: office@elcomtrade.com

Web: www.elcomtrade.com

ZBORNIK RADOVA

**48. MEĐUNARODNI KONGRES O GREJANJU,
HLAĐENJU I KLIMATIZACIJI**



2017

ZBORNIK RADOVA
48. međunarodni kongres o grejanju,
hlađenju i klimatizaciji
(Beograd, 6–8.12.2017)

IZDAVAČ
*Savez mašinskih i elektrotehničkih
inženjera i tehničara Srbije (SMEITS)*
– *Društvo za grejanje, hlađenje i klimatizaciju (KGH) Srbije*
Kneza Miloša 7a/II, 11000 Beograd
2017. god.

UREDNIK
Prof. dr Branislav Todorović, dipl. inž.

RECENZENTI
*Branislav Todorović, Marija Todorović,
Milovan Živković, Slobodan Pejković,
Petar Vasiljević, Bojan Bogdanović*

TIRAŽ
450 primeraka

ŠTAMPA
Paragon, Beograd

ISBN
978-86-81505-85-4

CIP- Каталогизација у публикацији
Народна библиотека Србије

697(082)(0.034.2)
628.8(082)(0.034.2)
621.56/.59(082)(0.034.2)
620.9(082)(0.034.2)

МЕЂУНАРОДНИ конгрес о климатизацији, грејању и хлађењу (48 ; 2017 ; Београд)

Zbornik radova [Elektronski izvor] = Proceedings / 48. međunarodni kongres i izložba o klimatizaciji, grejanju i hlađenju, Beograd, 6-8. XII 2017. = 48th International Congress & Exhibition on Heating, Refrigeration and Air-Conditioning, Belgrade, 6-8 XII 2017 ; [urednik Branislav Todorović]. - Beograd : Savez mašinskih i elektrotehničkih inženjera i tehničara Srbije (SMEITS), Društvo za grejanje, hlađenje i klimatizaciju (KGH) Srbije, 2017 (Beograd : Paragon). - 1 elektronski optički disk (CD-ROM) ; 12 cm

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovnog ekrana. - Radovi na srp. i engl. jeziku. - Tiraž 450. - Napomene i bibliografske reference uz radove. - Bibliografija uz većinu radova.

ISBN 978-86-81505-85-4

a) Климатизација - Зборници; b) Расхладна техника - Зборници; c) Грејање - Зборници
d) Енергетски извори - Зборници

COBISS.SR-ID 253938700

PREDGOVOR

*48. međunarodni kongres i izložba o
grejanju, hlađenju i klimatizaciji*

*Za prilaz zdravim, održivim i rezilijentnim zgradama,
naseljima i gradovima nula emisije CO₂*

Beograd, 6–8. XII 2017.

Ovogodišnji skup je planiran da bude u duhu tema koje danas obuhvataju aktuelne zadatke svetske energetike i očuvanja životnog prostora i da okupi sve profile učesnika u gradnji zgrada i njihovom energetskom opremanju: energetičare, arhitekte kao i građevince koji ujedinjenim naporima stvaraju objekte, posebno one koji u budućnosti treba da budu nula energije. Rukovodeći se naglašenim potrebama za saradnjom svih učesnika u projektovanju i građenju zgrada, u Organizacionom odboru su predstavnici više struka.

Spisak tema je širok kako bi se podstakle sve institucije, obrazovne, projektantske, montažerske, kao i one administrativno-pravnog profila, da svojim nastupom, svaka u svojoj specijalnosti, upotpune celokupnu problematiku energetike koja se odnosi na građevinske objekte. Predviđen je i poseban program za studente visokoškolskih i univerzitetskih institucija.

Kongres i ove godine prati izložba uređaja, sistema, aparata, opreme, koji se ugrađuju i koriste u građevinskim objektima, kao i odgovarajućih instrumenata, materijala i softverskih programa, koji su u vezi sa energetskim potrebama stambenih, javnih i industrijskih zgrada.

*U Beogradu,
novembra 2017.*

UREDNIK

Sadržaj

| | | |
|-----|--|-----|
| 1. | ZELENI STANDARD ZA PROCENU FUDBALSKIH STADIONA ZA FIFA SVETSKI KUP 2018. GODINE <i>Iurii TABUNSHCHIKOV, Marianna BRODACH</i> | 11 |
| 2. | EKSERGIJA KAO MERA ODRŽIVOSTI ENERGETSKOG SISTEMA <i>Peter NOVAK</i> | 19 |
| 3. | PRIMENA GEOTERMALNIH IZVORA ENERGIJE U FUNKCIJI ZAŠTITE ŽIVOTNE SREDINE <i>Miroslav VULIĆ, Kristijan VUJIČIN</i> | 41 |
| 4. | DOPRINOS GEOTERMALNE ENERGIJE URBANOJ TRANSFORMACIJI GRADA UTIKE U SAD, SA ASPEKTA URBANISTIČKOG PLANIRANJA <i>Aleksandar JOVANOVIĆ</i> | 51 |
| 5. | SISTEMI ZA SEZONSKO SKLADIŠTENJE SOLARNE ENERGIJE U ZGRADAMA <i>Uroš STRITIH, Rok KOŽELJ, Urška MLAKAR</i> | 61 |
| 6. | PROVERA INTEGRITETA ANALITIČKIH REZULTATA ČVRSTIH BIOGORIVA <i>Predrag PETROVIĆ, Marija PETROVIĆ</i> | 73 |
| 7. | KOMPRIMOVANI PRIRODNI GAS (CNG) – PROIZVODNJA, TRANSPORT I PRIMENA <i>Marin IVOŠEV</i> | 83 |
| 8. | POVEĆANJE ENERGETSKE EFIKASNOSTI U SKLADU SA EVROPSKOM DIREKTIVOM 2012/27/EU U CILJU SMANJENJA POTROŠNJE ENERGIJE KRAJNJEG KORISNIKA <i>Romanas SAVICKAS, LL. M. Lauryna SAVICKIENE</i> | 97 |
| 9. | CFD MODELIRANJE PROTOKA FLUIDA U POJEDINAČNIM KANALIMA PLOČASTIH RAZMENJIVAČA TOPLOTE <i>Dragan MANDIĆ</i> | 109 |
| 10 | KOMBINOVANI ŠTEDNJAK KAO IZVOR TOPLOTE U SISTEMIMA ETAŽNOG ILI CENTRALNOG GREJANJA <i>Mile S. ŠILJAK</i> | 117 |
| 11. | SISTEM AUTOMATSKE DOPUNE ZATVORENE EKSPANZIONE POSUDE KORIŠĆENJEM TRANSMITERA PRITiska I SENZORA MAKSIMALNOG NIVOA VODE <i>Vojkan ZDRAVKović, Miroljub TODORović</i> | 125 |
| 12. | EKSPERIMENTALNA I NUMERIČKA STUDIJA INDIREKTNOG SLOBODNOG HLAĐENJA U EGZOTERMIČKOJ ZGRADI <i>Yazid KACED, Stephane Le MASSON, David NORTERSHAUSER, Patrice GLUANNEC</i> | 133 |

POTROŠNJA FINALNE ENERGIJE ZA GREJANJE PASIVNE KUĆE (SLUČAJ KRAGUJEVAC)

FINAL ENERGY CONSUMPTION FOR HEATING A PASSIVE HOUSE (CASE OF KRAGUJEVAC)

Aleksandar NEŠOVIĆ*, Nebojša LUKIĆ, Novak NIKOLIĆ,

Katedra za energetiku i procesnu tehniku Fakulteta tehničkih nauka

Univerziteta u Kragujevcu, Kragujevac, Srbija

U cilju minimiziranja potrošnje finalne energije za grejanje objekata, pasivna kuća je prepoznata kao pravac u kom treba da se razvija zgradarstvo. Međutim, u Srbiji je sproveden mali broj istraživanja koji se odnosi na ispitivanje performansi pasivnih kuća. U okviru ovog rada ispitano je kako rad rekuperatora toplotne otpadnog vazduha utiče na potrošnju finalne energije u pasivnoj kući. Od aktivnih sistema grejanja, pasivna kuća koristi podne panele koji su u spremi sa geotermalnom toplotnom pumpom. Analizirana zgrada se nalazi u Kragujevcu, Srbija. Istraživanje je sprovedeno softverski, tj. simulacijom pomoću programa EnergyPlus. Rezultati pokazuju da se tokom grejne sezone mogu ostvariti uštede od 56,41%.

Ključne reči: pasivna kuća, rekuperator toplotne, toplotna pumpa, simulacija, EnergyPlus

In order to minimize the consumption of final energy for heating, the passive house is recognized as the direction in which buildings should be developed. However, in Serbia few investigations related to the testing of passive house performance have been conducted. This paper investigates how the operation of a heat recovery exchanger affects the consumption of final energy in a passive house. The investigated passive house has a heating system that includes floor heating panels and a geothermal heat pump. The analyzed building is located in Kragujevac, Serbia. The research has been conducted by simulations in software EnergyPlus. The results show that energy savings of 56.41% can be achieved during the heating season.

Key words: passive house, ERV, GSHP, simulation, EnergyPlus

1. Introduction

The basic idea of a passive house is the heat recovery of a ventilation air. The supply air entering the conditioned area is heated by the exhaust air living the same, in order to minimize the required amount of energy for heating the object.

According to the Passivhaus Institut, it has to meet the following criteria [1]:

– final energy consumption for heating during the heating season does not exceed 15 kWh/m² of net residential space;

* Corresponding author's e-mail: aca.nesovic@gmail.com

- the total energy consumption must not exceed 120 kWh per square meter per year;
- a maximum of 0.6 air changes per hour at 50 Pa pressure, as verified with a blower door test;
- not more than 10% of the hours in a given year over 25°C.

To achieve Passive House criteria, building designers must consider as mandatory the following principles: thermal bridge free design, superior windows, ventilation with heat recovery, quality insulation and airtight construction [2].

A number of standards have been developed worldwide to improve the energy efficiency of new buildings [3]. There is also a large number of passive houses in the world and in Europe whose performance has been tested and certified [4].

However, there are few data related to the testing of performance of a passive houses on the territory of Serbia. Pukhkal and others analyzed the moisture condensation in the outer walls of the passive house in Niš in [5] and gave recommendations for making door insulation. Bajc et al. [6] numerically examined how the Trombe wall influences the energy performance of a passive house.

The aim of this paper is related to that how the waste air heat recovery system affects the final energy consumption of the heat pump compressor.

2. Description of the analyzed building

2.1. Building constructions

According to the rules on classification of objects, the subject of investigation is a house with two apartments with a total area less than 400 m². The classification number of this type of building is 11211 [7].

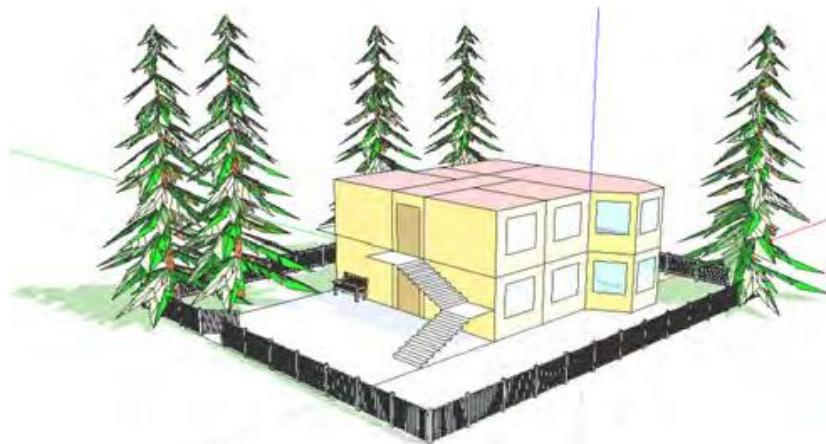


Figure 2.1. Analyzed building

The passive house (Fig. 2.1) has two floors (ground floor and first floor). On each floor there is one apartment with identical arrangement of rooms (Fig. 2.2). The entrance doors are oriented towards the west. Each apartment accommodates a four-member family. Total useful (net) area of the passive house is 198.39 m² (99.195 m² per apartment).

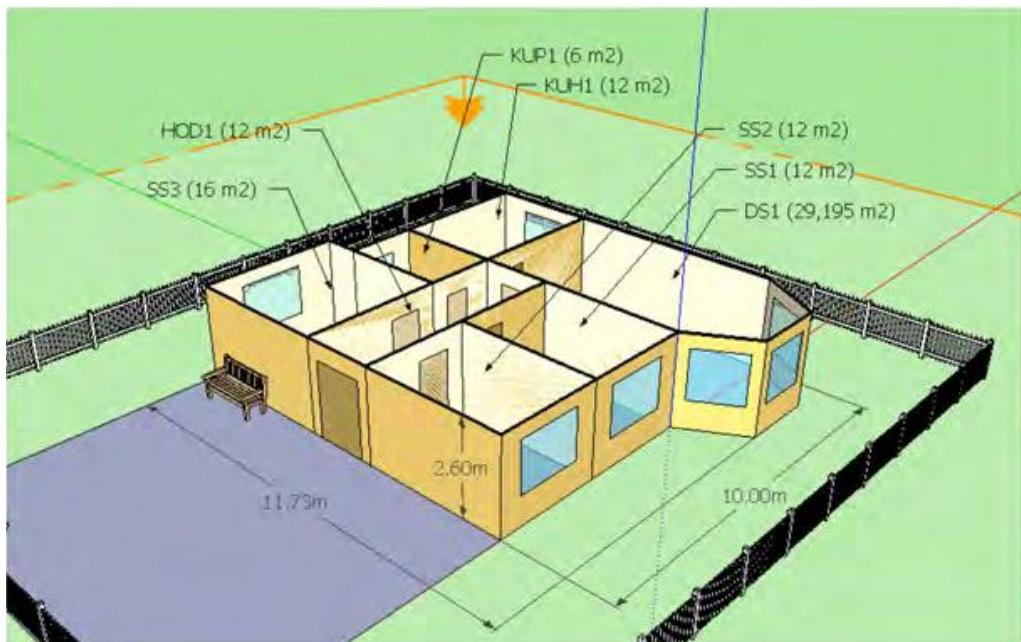


Figure 2.2. Arrangement of the rooms on the ground floor of the passive house

The total surface of the building envelope is 416.79 m^2 . The surface of all transparent elements is 39.12 m^2 , while the surface of non-transparent elements is 377.67 m^2 (for the exterior walls 179.28 m^2 , for the ground floor 99.195 m^2 and for the flat roof above the heated area 99.195 m^2). The total ratio of the transparent surfaces to the exterior walls is 19.83%. The thermal characteristics of the building constructions are shown in Table below (Table 2.1).

Table 2.1. Thermal characteristics of the building constructions

| Construction | Layer | $U [\text{W}/\text{m}^2\text{K}]$ |
|------------------|--|-----------------------------------|
| Ground floor | stone (25 cm), gravel (5 cm), concrete (15 cm), reinforced concrete (4 cm), cement screed (4 cm), expanded polystyrene foam (12 cm), concrete (15 cm), cement screed (4 cm), ceramic tile (1.5 cm) | 0.203 |
| Interior ceiling | lime mortar (2.5 cm), reinforced concrete (4 cm), expanded polystyrene foam (12 cm), cement screed (4 cm), ceramic tile (1.5 cm) | 0.226 |
| Roof | gravel (5 cm), waterproofing (0.2 cm), vapor barrier (0.2 cm), cotton (10 cm), vapor barrier (0.2 cm), concrete (5 cm), cement screed (4 cm), concrete (16 cm), lime mortar (2.5 cm) | 0.312 |
| Exterior wall | brick (12 cm), air (5 cm), expanded polystyrene foam (20 cm), clay block (25 cm), lime mortar (2.5 cm) | 0.172 |
| Exterior door | wood (3.5 cm) | 4 |
| Window | glass (4 cm), krypton (8 cm), glass (4 cm), krypton (8 cm), glass (4 cm) | 1.574 |

2.2. Location of the building

To simulate weather conditions of the city of Kragujevac (latitude of 44.02°N, longitude of 20.92°E, the average height above sea level of 209 m) the EnergyPlus weather file was used [8]. Kragujevac (with the time zone of GMT+1 h) is characterized by moderate continental climate with pronounced seasons. The years are hot and humid, with temperatures reaching +37°C. On the other hand, winters are cold (temperature below -12°C) and with snow. The meteorological data for the city of Kragujevac are shown in Table 2.2.

Table 2.2. Thermal characteristics of the building constructions

| Month | Dry bulb temperature | Wet bulb temperature | Diffuse solar radiation | Direct solar radiation | Relative humidity | Wind Direction | Wind speed |
|-----------|----------------------|----------------------|-------------------------|------------------------|-------------------|----------------|------------|
| | [°C] | [°C] | [W/m ²] | [W/m ²] | [%] | [deg] | [m/s] |
| January | -0.24 | -1.44 | 33.30 | 63.63 | 79.92 | 213.17 | 2.1 |
| February | 0.88 | -0.46 | 49.39 | 86.66 | 79.82 | 210.60 | 2.02 |
| March | 5.57 | 3.29 | 77.08 | 106.12 | 72.06 | 207.98 | 2.35 |
| April | 10.87 | 7.74 | 92.65 | 149.02 | 67.92 | 209.06 | 2.27 |
| May | 16.06 | 12.18 | 113.30 | 176.45 | 66.57 | 210.08 | 1.77 |
| June | 18.85 | 14.99 | 109.50 | 208.94 | 69.42 | 209.51 | 1.69 |
| July | 20.78 | 16.04 | 110.60 | 228.12 | 64.49 | 198.04 | 1.62 |
| August | 20.38 | 15.69 | 96.25 | 215.40 | 64.05 | 211.45 | 1.51 |
| September | 16.68 | 13.30 | 75.54 | 166.92 | 71.21 | 203.79 | 1.68 |
| October | 11.18 | 8.83 | 57.34 | 119.43 | 76.40 | 222.28 | 1.69 |
| November | 6.08 | 4.45 | 39.83 | 64.51 | 79.80 | 210.38 | 2.06 |
| December | 1.13 | 0.09 | 28.66 | 58.86 | 83.51 | 208.33 | 1.87 |

3. Description of the heating system

For the heating of the analyzed house, a geothermal heat pump (ground-water) is selected. It is connected to the floor heating panels. Also, the heating system includes the waste air heat recovery system (energy recovery ventilator (ERV)).

3.1. Energy Recovery Ventilator

In order to control the quality of air in the building, each room is equipped with an ERV. The basic elements of ERV are [9]:

- supply air fan (fan 1, Fig. 3.1);
- exhaust air fan (fan 2, Fig. 3.1);
- air to air plate heat exchanger;
- controller.

During each simulation step, the mass flow rate of air passing through the ERV depends on the defined schedule of its operation and is calculated as follows (eq. 3.1 and 3.2) [9]:

$$\dot{m}_1 = \rho_1 \cdot \dot{V}_1 \quad (3.1)$$

$$\dot{m}_2 = \rho_2 \cdot \dot{V}_2 \quad (3.2)$$

where: \dot{m}_1 , \dot{m}_2 – is the mass flow rate of the supply and exhaust air [kg/s]; ρ_1 , ρ_2 – is the density of the supply and exhaust air [kg/m^3]; \dot{V}_1 , \dot{V}_2 – is the volumetric flow rate of the supply and exhaust air [m^3/s], respectively.

The sensible heat transfer rate to the zone by the ERV is calculated by using the eq. 3.3 and the total heat transfer rate by the eq. 3.4. The latent heat transfer rate is determined as the difference between the total and the sensible heat transfer rate (eq. 3.5) [9]:

$$\dot{Q}_{sens} = \dot{m}_1 \cdot (h_{1b} - h_{2a})_{sens} \quad (3.3)$$

$$\dot{Q}_{tot} = \dot{m}_1 \cdot (h_{1b} - h_{2a}) \quad (3.4)$$

$$\dot{Q}_{lat} = \dot{Q}_{tot} - \dot{Q}_{sens} \quad (3.5)$$

where: \dot{Q}_{sens} , \dot{Q}_{lat} , \dot{Q}_{tot} – is the sensible heat transfer rate, latent and total heat transfer rate [W]; $(h_{1b} - h_{2a})_{sens}$ – is the difference of the enthalpy of the air being supplied to the zone and enthalpy of the air being exhausted from the zone through the ventilator (at a constant humidity ratio) [J/kg]; $(h_{1b} - h_{2a})$ – is the difference of the enthalpy of the air being supplied to the zone and enthalpy of the air being exhausted from the zone through the ventilator (at a given conditions) [J/kg], respectively.

The amount of heat exchanged during the heating season (15th of October to 15th of April), which simultaneously represents the realized heat energy savings, is determined by the eq. 3.6 [9]:

$$\dot{Q}_{systot} = \dot{Q}_{tot} \cdot TimeStepSys \cdot 3600 \quad (3.6)$$

where: \dot{Q}_{systot} – is the total heat transfer during the heating season [J]; $TimeStepSys$ – HVAC system simulation time step.

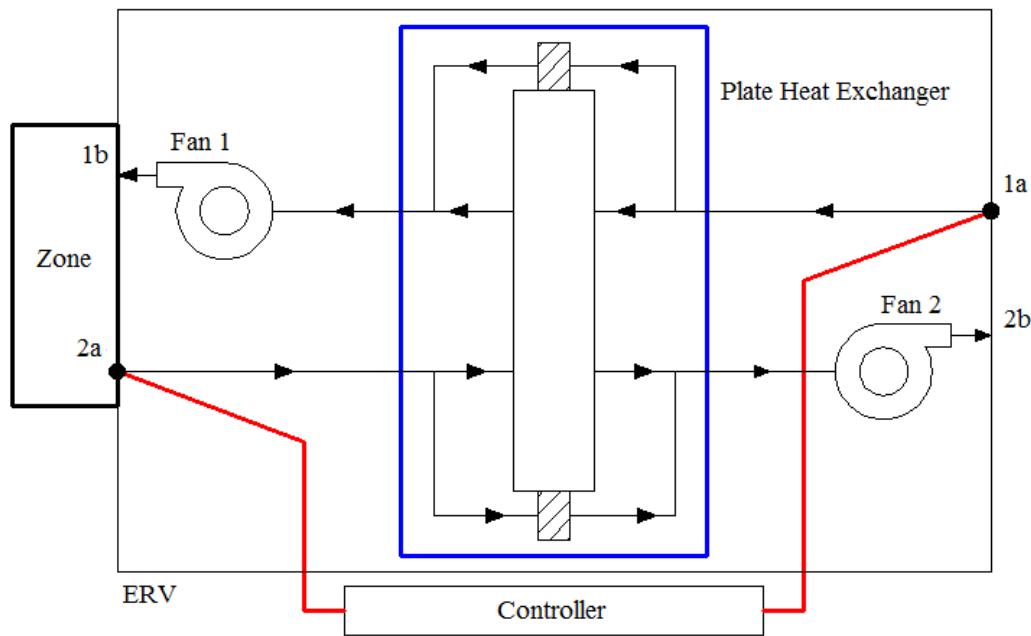


Figure 3.1. Schematic of the ERV [9]

3.2. Geothermal heat pump

The functional scheme of the analyzed heating system is shown in the Fig. 3.2.

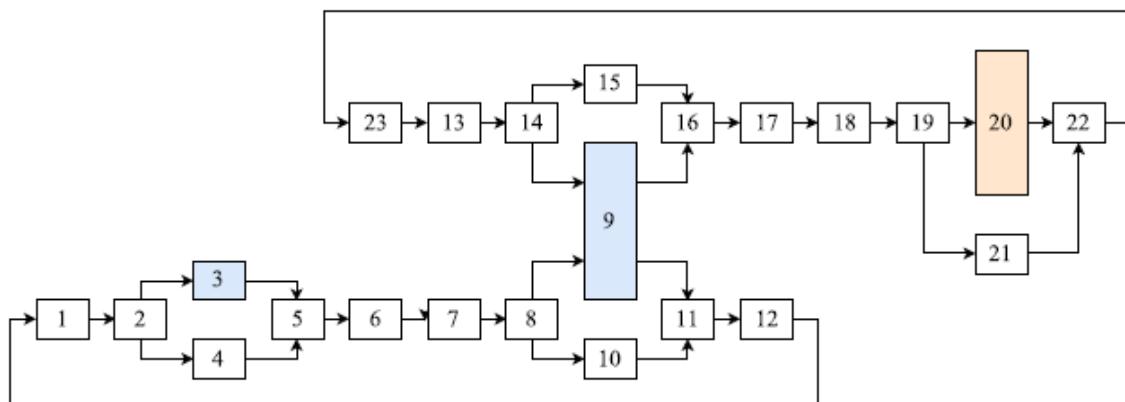


Figure 3.2. Analyzed heating system; 1, 13 – circulation pump;
2, 8, 14, 19 – splitter; 3 – ground heat exchanger; 4, 10, 15, 21 – bypass branch;
5, 11, 16, 22 – mixer; 6, 12, 17, 23 – outlet pipe; 7, 18 – inlet pipe;
9 – heat pump; 20 – conditioned zones

Based on the calculation of the thermal losses of the analyzed building, a heat pump REHAU GEO 7 was adopted [10]. The technical characteristics of this heat pump are given in Table 3.1.

The parameters of the ground heat exchanger used in the EnergyPlus software were taken from [11] (Table 3.2).

Table 3.1 – Technical characteristics of the heat pump (REHAU GEO 7) [10]

| Parameter | Unit | Value |
|-----------------------------------|--------|-------|
| Rated heating capacity | [W] | 7300 |
| COP | [-] | 4.1 |
| Rated heating power consumption | [W] | 1600 |
| Minimum water flow rate (heating) | [l/h] | 1100 |
| Minimum brine flow rate | [kg/h] | 1300 |

Table 3.2 – Parameters of the vertical geothermal probe [10] [11]

| Parameter | Unit | Value |
|-----------------------------|----------------------|---------|
| Number of bore holes | [-] | 2 |
| Bore hole lenght | [m] | 73.2 |
| Bore hole radius | [m] | 0.0889 |
| Pipe out diameter | [m] | 0.04 |
| Pipe thickness | [m] | 0.0037 |
| U-tube distance | [m] | 0.03 |
| Ground thermal conductivity | [W/mK] | 2.08 |
| Grout thermal conductivity | [W/mK] | 1.47 |
| Pipe thermal conductivity | [W/mK] | 0.39 |
| Ground temperature | [°C] | 13.37 |
| Working fluid | water and antifreeze | |
| Maximum flow rate | [m ³ /s] | 0.00036 |
| Fluid heat capacity | [J/kgK] | 4066 |
| Fluid thermal conductivity | [W/mK] | 0.513 |
| Fluid density | [kg/m ³] | 1016 |

4. Results

In the Fig. 4.1, the consumption of final (electric) energy for heating a passive house for the two analyzed cases is shown. In the first case there is no heat recovery of ventilation air. For the second case the ERV operates. The value of air changes per hour is the same in both cases and amounts 0.5 h^{-1} for each room.

The final energy consumption during the heating season amounts: 1987.6 kWh (without heat recovery) and 866.38 kWh (with heat recovery). The achieved energy savings would be 56.41%. The monthly savings are shown in the Fig. 4.2.

The highest savings are achieved in October, November, March and April, because of the higher outdoor temperature in these months. In relation to that, the lowest savings are achieved in December, January and February. The average energy savings for entire heating season amounts 56.41%.

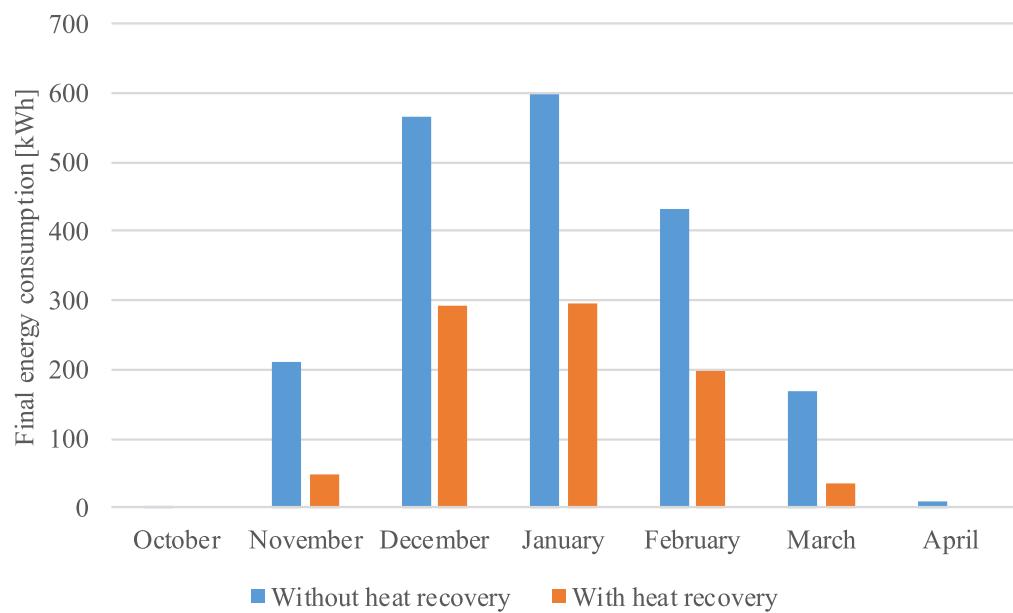


Figure 4.1. Final energy consumption for heating the passive house

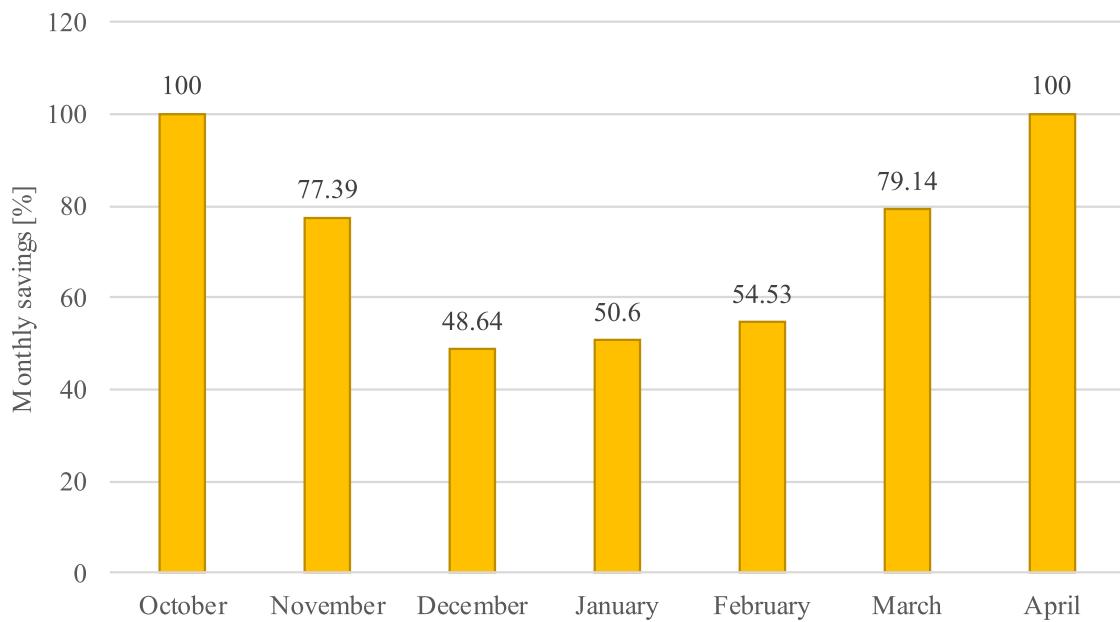


Figure 4.2. Monthly percentage savings for heating the passive house

5. Conclusions

In order to meet passive house criteria, building designers must consider the following: thermal bridge free design, superior windows, ventilation with heat recovery, quality insulation and airtight construction.

The simulation results show that a passive house consumes 1987.6 kWh (10.01 kWh/m² of the heated area) during the heating season if there is no heat recovery. On the other side, when the ERV operates, the final energy consumption during the heating season is 866.38 kWh (4.37 kWh/m² of the heated area).

The lowest energy savings are achieved in December (48.64%). The average energy savings for entire heating season amounts 56.41%.

6. References

- [1] **Feist, W. et.al.** PHPP Handbook, PHI Darmstadt, 2007.
- [2] **Rehab, I., Andre, P., Aparecidia, Silva, C., Massy, G., Hannay, J., Lebrun, J.**, Verification of the energy balance of a passive house by combining measurements and dynamic simulation, Energy Procedia 78 (2015) 2310 – 2315.
- [3] *** Greenhouse Office. International Survey of Building Energy Codes, Commonwealth of Australia, ISBN 1 876536 32 2, 2000.
- [4] *** Passive House Energy Use Measurements
- [5] https://passipedia.org/operation/operation_and_experience/measurement_results/energy_use_measurement_results (Accessed 3rd April 2017).
- [6] **Pukhkal, V., Tanic, M., Vatin, M., Murgul V.**, Studying Humidity Conditions in the Design of Building Envelopes of "Passive House" (in the case of Serbia), Procedia Engineering 117 (2015) 859 – 864.
- [7] **Bajc, T., Todorovic, M. N., Svorcan, J.**, CFD analyses for passive house with Trombe wall and impact to energy demand, Energy and Buildings, Volume 98, 1 July 2015, Pages 39-44.
- [8] *** Pravilnik o kategorizaciji objekata (Sl. glasnik RS, br. 22/2015).
- [9] *** EnergyPlus, Energy Simulation Software (Weather File).
- [10] *** EnergyPlus, Engineering Reference.
- [11] http://plummadiaserver.com/grejanje.com/rehau/teh_informacija_toplotne_pumpe_952002.pdf (Accessed 15th July 2017).
- [12] **Yavuzturk, C., Spitler, J. D.**, A short time step response factor model for vertical ground loop heat exchangers, ASHRAE Trans, 105 (2) (1999) 475–485.

kgh