Katarina Đonović, PhD Vanja. Šušteršič*, PhD Dušan Gordić, PhD Dubravka Živković
Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, 34 000 Kragujevac

ANALYSIS OF POSSIBILITIES FOR HEATING AND COOLING OF FACULTY OF ENGINEERING UNIVERSITY OF KRAGUJEVAC WITH HEAT PUMP

ABSTRACT
Humankind needs enormous amounts of energy, from which a large portion is consumed for heating and cooling homes and buildings. A huge amount of consumed energy causes high bills, especially when it comes to the old, big and energy-inefficient buildings. For that reason, in this paper is shown a study of replacement of existing heating methods in building B, Faculty of Engineering University of Kragujevac. A new method of heating involves the use of geothermal heat pump, which is reliable, comfortable and environmentally friendly way to use renewable energy sources. The calculation of heat losses is done, on the basis of which appropriate heat pump was chosen. Then, according to the investment costs and savings in consumed energy, payback period of the system is calculate in three different versions, depending on the number of operating hours of the heat pump and different electricity tariffs during the day.
Keywords: heat pump, geothermal energy, renewable energy sources

Analiza mogućnosti grejanja i hlađenja Fakulteta inženjerskih nauka Univerziteta u Kragujevcu pomoću toplotne pumpe

SAŽETAK
Čovečanstvu je potrebna neizmerna količina energije, od koje se veliki deo troši za grejanje i hlađenje domaćinstava i objekata. Velika količina utrošene energije prouzrokuje i visoke račune, pogotovo kada su u pitanju stari, energetski neefikasni objekti. Upravo iz tog razloga, u ovom radu urađena je studija zamene postojećeg načina grejanja objekta B Fakulteta inženjerskih nauka Univerziteta u Kragujevcu. Nov način grejanja podrazumevao bi korišćenje geotermalne energije tj. toplotne pumpe zemlja-voda, koja predstavljaju pouzdan, komforan i ekološki način korišćenja obnovljivih izvora energije. U radu je prezentovan proračun toplotnih gubitaka na osnovu koga je usvojena odgovarajuća toplotna pumpa. Zatim je, prema investicionim troškovima i uštedi u potrošenoj električnoj energiji, izačunat period otplate sistema za tri različite varijante, u zavisnosti od broja radnih sati rada toplotne pumpe i tarifa po kojima se naplaćuje utrošena električna energije.
Ključne reči: toplotna pumpa, geotermalna energija, obnovljivi izvori energije

1. INTRODUCTION

Faculty of Engineering University of Kragujevac consists of three separate facilities: A and C, B and D. All objects of Faculty are supplied by district heating, which provides Energetika doo. Due to the large volume of Faculty, energy-inefficient building, as well as the old doors and windows, heating bills are very high. The most effective solution would be to re-build and use high quality materials, thicker isolation, energy efficient windows and doors. However, it is a very large investment that also requires the interruption of work time for a certain period of time. It is therefore necessary to find another solution that will require less investment, less construction works and yet contribute to the reduction of heating costs.

Within the study, calculation of heat losses for the current state of the sector B (Figure 1) was made with the intention of replacing the existing method of heating and cooling by using ground-source heat pump with two vertical probes. Building B has an area of 1500 m^2, consists of ground level with three floors and it is connected to facility D by a bridge.

Baseline data were taken from the architectural project, as follows:

- Composition of the walls is:

1. facade sandwich panels from double flat elox aluminum

*Corresponding author: vanjas@kg.ac.rs

Figure 1. *Building B of the Faculty of Engineering*

sheet and 10 cm of polyurethane isolation thickness;
2. flat elox aluminum sheet with a support structure, tervol 5 cm with a vapor barrier, bricks 12 cm, white cement mortar 3 cm;
3. fasadex, extended mortar 3 cm, 5 cm sandwich insulation panel in wood and polystyrene, AB construction (painted inside).

- Composition of the roof constructions is:

1. trapezoidal aluminum sheet, tervol 10 cm with a vapor barrier, aluminum trapezoidal sheet;
2. waterproofing protection, sandwich insulation panel in wood and polystyrene 3 cm, hard tervol 5 cm with a vapor barrier, concrete 3-10 cm, AB constructions;
3. waterproofing protection, sandwich insulation panel in wood and polystyrene 3 cm, hard tervol 5 cm with a vapor barrier, AB construction.

2. CALCULATION OF HEAT LOSS

The values of thermal conductivity and thermal resistance required for the materials were taken from the reference [1] and then the heat transfer coefficient for each external wall were calculated in program URSA building physics 2 [2]. Heat transfer coefficient U [W/m^2·K] is calculated using the formula:

$$U = \frac{1}{R_{si} + \sum\frac{d}{\lambda} + R_{se}} \quad (1)$$

where is: R_{si}, R_{se} – resistance to heat transfer [m^2·K/W],
d – film thickness [m],
λ – thermal conductivity [W/m·K].

All the windows of object B are of double glazing (4-12-4), with an aluminum frame with thermal break. Difference is in the dimensions and the number of windows. The main entrance and the door to the bridge that connects the buildings B and D are made of a single glass, also with an aluminum frame with thermal break. The door on the north side is a metal door. All of these data were obtained by manual measuring on the site.

Heat transfer coefficients of transparent objects (external windows, doors, skylights...) were calculated according to the formula:

$$U_w = \frac{A_g \cdot U_g + A_f \cdot U_f + l \cdot \Psi}{A_g + A_f} \quad (2)$$

where is:
A_g – glass surface [m^2],
U_g – heat transfer coefficient of glass [W/m^2·K],
A_f– frame surface [m^2],
U_f– heat transfer coefficient of frame [W/ m^2·K],
l – contact length glass/frame [m],
Ψ – temperature correction factor of contact glass/frame [W/m·K].

The values of U_g, U_f and Ψ are taken from the reference [1].

Also it is necessary to specify what the total heat loss is to determine the amount of energy to be supplied by the heat pump. Heat losses [W] obtained as the sum of transmission and ventilation losses:

$$Q = Q_T + Q_v \quad (3)$$

Transmission losses are calculated according to the formula:

$$Q_t = A \cdot \Delta T \cdot U \quad (4)$$

where is:
A – area of the wall [m^2],
ΔT – temperature difference [K],
U – heat transfer coefficient [W/m^2·K].

Ventilation losses are calculated according to the formula:

$$Q_v = \rho \cdot c_p \cdot V \cdot n \quad (5)$$

where is:
ρ – air density [kg/m3],
c_p – specific heat at constant pressure [kJ/kg·K],
V – volume of heated space [m^3],
n – the number of air changes [h-1].

Calculation of heat losses was made in the program URSA. The transmission losses are calculated in part Thermal envelope of the building, where it was necessary to enter the data for the existing structure, the surface of the walls and cardinal directions where these walls are. In the transmission losses are also included heat losses due to thermal bridges. Ventilation losses are calculated as part of the Ventilation losses, where it is necessary to withdraw the information on the volume of the object and enter how many air changes per hour there are. Since there is a natural ventilation, number of changes is 0.5. From the program obtained that the total losses are:

$$Q = Q_T + Q_v = 2\,553{,}5 + 2\,095{,}5 = 4\,649\ \frac{W}{K} \quad (7)$$

In addition to the loss of heat in the sector B there are gains: external from solar radiation and internal from people and electronic devices in the premises. Because of these gains, it is necessary to reduce the total heat loss for 10%, so than they will be:

$$Q = 4\,649\ \cdot 0{,}9\ = 4\,184{,}1\ \frac{W}{K} \quad (8)$$

This value shall be multiplied by the temperature difference between the interior temperature of the object and the exterior design temperature. The interior temperature of the object is 20^{0}C, while the exterior design temperature for Kragujevac is -15^{0}C, so than the total heat losses are:

$$Q = 4\,184{,}1 \cdot 35\ = 146\,443{,}5\ W \quad (9)$$

After the obtained values of heat loss it is necessary to adopt the heat pump. The heat pump that will be used is geothermal heat pump with two vertical probes. This type of heat pump was selected primarily due to little available space around the faculty, because horizontal mounting probes require larger area. The good side of a vertical probe is that the soil temperature is about 15°C and it is stable throughout the year at depths over 2 m [3].

In order to obtain pump power it is necessary to increase the value of the resulting heat loss by 20%. In this way it is ensured that the heat pump covers the heat loss value at all times, so for the sector B required heat pump power is 176 kW.

Selected heat pump is TERRA SW 220 Max HGL from German company Energie Systeme IDM (Figure 2). It will be used for heating in winter time and cooling in the summer time.

HGL technology is a new approach that is applied exactly in these types of heat pumps. Practically the energy is divided in two parts: 85% of the energy is used for heating and the remaining 15% is used for domestic hot water. In this case, with the heat pump include two separate reservoirs (buffers), one for the storage of heating water and another for hot water [4]. Since in the sector B domestic hot water is only used in toilets the second tank will not be required. If in the future the need for a larger amount of hot water arises second tank can be easily added.

As regards the control system this heat pump is equipped with NAVIGATOR 1.7 system. In addition to managing heating, cooling and acquisition of domestic hot water, this system controls many other functions such as control of heat sources and charging pump depending on the number of compressors operating, providing a fully automatic monitoring of up to 6 separate heating and cooling circuits. Of course, all this is connected with the control computer and also can monitor the operation of the heat pump over the Internet via any computer with appropriate software [5].

Heat mode in which the heat pump in the winter works is 55/45^{0}C, because the temperature is sufficient for the operation of fan coils that will be set up as heaters.

Dimensions of heat pump are: height 2.020 mm, width 2.632 mm and depth of 774 mm (Figure 3). It must not be stored outdoors or in damp areas or in rooms full of dust. It is very quiet during operation but it is certainly recommended that the door of the room is soundproof.

Inside the building vertical fan coil units would be placed as heaters. They operate at lower temperatures range than radiators that are already installed at the faculty, so that the heat pump can provide the necessary temperatures. Fan-coil units would be used for heating in winter and cooling in summer time. They are easy to install, not noisy at work and are fully automated, so it is very easy to follow and set the desired temperature in the room or turned it off completely if

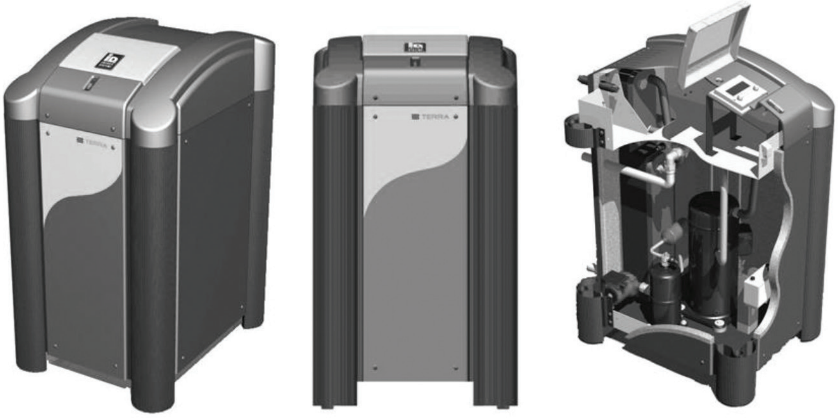

Figure 2. *IDM Energie Systeme heat pump*

		Unit	55	70	85	110	140	170	220	280
			TERRA SW 55-280 Max (HGL)							
Energy efficiency class package label brine circuit (heat pump + temperature control)			A++	A++	1)	1)	1)	1)	1)	1)
B0°C/W35°C	Heating Capacity 2	kW	57.87	73.19	84.82	113.42	137.79	169.63	226.84	275.59
	Power consumption 2	kW	12.50	15.91	18.32	24.55	29,89	36.64	49.10	59.78
	COP 2		4.63	4.60	4.63	4.62	4.61	4.63	4.62	4.61
Energy efficiency class package label ground water (heat pump + temperature control)			A+++	1)	1)	1)	1)	1)	1)	1)
W10°C/W35°C	Heating Capacity 2	kW	76.86	97.20	112.76	149.14	181.06	225.51	298.27	362.13
	Power consumption 2	kW	12.66	16.56	19.08	26.03	31.27	38.16	52.05	62.54
	COP 2		6.07	5.87	5.90	5.73	5.79	5.91	5.73	5.79
Cooling			Active and passive as well as iDM system cooling							
W7°C/W35°C	Cooling Capacity	kW	64.20	80.64	93.68	123.11	149.79	187.35	246.22	299.58
Maximum flow temperature		°C	62							
Compact dimensions (H/W/D)		mm	2020/1066/774			2020/1316/774		2020/2632/774		
Power supply		V	3P/400			3P/400		3P/400		
Operational safety			Two hermetically separate cooling circuits					Four hermetically separate cooling circuits		
Integrated heat pump management			NAVIGATOR 1.7							

1) No energy efficiency class is stated, as heat pumps with rated power output > 70 kW (high temperature application and average climate) are not within the scope of the EU-Regulation No. 811/2013 for energy labelling of space heaters and combination heaters. No energy label will be provided for these heat pumps. 2) according to EN14511 with 5K splay between flow and return.

Figure 3 *Technical data of heat pump [5]*

necessary. As for the pipe system fan coil units use two-pipe system, one for water supply and one return pipe and these are copper pipes. In addition there is the third PVC pipe and it is used for draining of condensate. For installation fan coil units tag 42N American company Carrier, represented by the firm Grappa in Belgrade, were selected (Figure 4).

Figure 4. *Carrier fan coil unit*

The filter is located in the bottom and can be easily removed for cleaning. The temperature range is from 10-30ºC. The fan speed is automatically adjusted: when the room temperature is lower than the fan speed is higher. As the room temperature approaches the set value, the fan speed decreases until the minimum speed is reached. It also includes the ability to automatically switch from the cooling mode to heating mode to maintain ideal room temperature and protect from frost, so that room temperature does not fall below the minimum value [6].

3. INVESTMENT COSTS

Required investments in this project consist of two parts. The first part is a heat pump with additional equipment, as well as the part related to probes and their installation. The second part refers to the interior of the building where it is necessary to set the fan coil devices, perform piping along with all equipment.

Copper pipes are a product of Tehnomont Ltd Company, Aranđelovac. The price of these pipes is 1.196 dinars for a length of 5 m, while the price of PVC pipe, from the Valdom Company in Šid, is 76 dinars per meter. Fan coil units will be deployed in any room in which it resides. If it happens that in some laboratories is not necessary to continuously heat the space fan coils can be easily turned off.

Total investment for the heat pump and its setting is 262.320 €. The cost for construction work must be added. This includes removing radiators in all rooms of sector B and instead placing fan coil units. It is also necessary to remove

IDM TERRA MAX 220 heat pump, B0ºC/W55ºC	66.500 €
Additional equipment with heat pump - set brine circuit, set for system cooling, pressure switches, sensors, flexible connecting hoses, frequency circulation pump for buffers, flow switch for cooling, three-spoke valves, piping, pipe insulation, security hardware and other equipment in the substation...	33.000 €
20 pcs. PE-Xa geoprobes, length of 125 m/pcs., with thermal cement fill, the necessary equipment for connection, shafts with dividers, ethylene glycol and other parts of equipment	44.000 €
Well drilling and routing probes - 2500 m	57.500 €
Connecting the probe collector pipes, installation of equipment in a technical block...	12.000 €
TOTAL	**213.000 €**

Table 1. *Primary circuit and energy block of geothermal heat pump*

Fan coil units (120 peaces)	46.800 €
Pipes (copper 28x1,5mm and PVC Ø32)	2.100 €
+ 20% - Curves, branches, valves...	420 €
TOTAL	**49.320 €**

Table 2. *Secondary circuit inside the building*

all the air conditioning, because the fan coil units will be used for cooling also.

It should be noted that there are more fan coil units because of three large rooms that are located on the ground floor in sector B. These rooms serve as a laboratory for the testing of vehicles. Ceilings in laboratories are very high (5 m in one and 4 m in the other two), and their surfaces are large (total area of all three rooms is 672 m^2). Determining the number of fan coil units was done as recommended by the manufacturer: for every 15 m^2 goes one fan coil unit. Because of this recommendation and large areas of these rooms number of fan coil unit is much higher and therefore initial investment is higher.

Payback period

Since the setting of the heat pump sector B will no longer be heated through Energetika d.o.o. a portion of the money will be saved. According to accounts from 2014 it is the sum of 13.962 €.

Also, electricity for cooling will not be consumed via air conditioning in the summer. The sector B is set with 19 air conditioners. Air conditioners are the strength of 12.000 BTU and the average electricity consumption for cooling and heating modes is 1,2 kW. For calculation is taken that the air conditioning working for 2 months during the summer period (and they work even more), which is 45 working days.

Heat pump consumes a certain amount of electricity. This is happening in summer and in winter, because it is used for heating and cooling. The annual cost must be included. Number of working days during the heating season is about 130, more precisely from October 15th to April 15th. In the winter period 49,1 kWh of electricity for heating is consumed, while in the summer 73,5 kWh for cooling.

Price of 1 MWh of electricity for faculty is 45,74 € - higher tariffs, and 29,42 € - lower tariff (data obtained from the Company for Electricity Distribution Centre Ltd. Kragujevac). Three variants of the viability period of the system are done:

1. The number of air conditioners working hours per day during the summer and heat pumps in winter and summer time is 8 hours (classically working time of faculty) with higher price of electricity (because the lower tariffs are still in the evening).

Consumption of electricity for operate the air conditioners is 8.208 kWh. This would mean that annually saving is 375.5 €.

Regarding the work of the entire system related to the heat pump during the heating season electricity consumption is 51.064 kWh. In the summer period electricity will be spent for cooling, precisely 26.460 kWh. It follows that the heat pump consumes 77.524 kWh for heating and cooling. As stated above the price of 1 MWh of electricity for college is 45,74 € (higher tariff) which means that the cost per annum is 3.546 €.

Payback period of investment is obtained when the initial investment is divided by the savings achieved due to changes in ways of heating and cooling:

$$\frac{262360}{13962+375,-3546} = \textit{24 years and 4 months} \qquad (10)$$

2. The number of air conditioners working hours per day during the summer and heat pumps in winter and summer time is 10 hours (longer working time of faculty) with higher price of electricity (because the lower tariffs are still in the evening).

Consumption of electricity for operated the air conditioners is 10.260 kWh. This would mean that annually saving is 470 €.

Regarding the work of the entire system related to the heat pump during the heating season electricity consumption is 63830 kWh. In the summer period 33.075 kWh of electricity will be spent for cooling. It follows that the heat pump consumes 96.905 kWh for heating and cooling. The cost per year is 4.433 €. Payback period is then:

$$\frac{262360}{13962+470-4433} = \textit{26 years and 4 months} \qquad (11)$$

3. The number of air conditioners working hours per day during the summer and heat pumps in winter and summer time is 10 hours (longer working time of faculty) with 80% higher price of electricity and 20% lower price (due to the large number of working hours per year).

Consumption of electricity for operate the air conditioners is 10.260 kWh. This would mean that annually saving is 436 €.

Regarding the work of the entire system related to the heat pump during the heating season electricity consumption is 63.830 kWh. In the summer period 33.075 kWh of electricity will be spent for cooling. It follows that the heat pump consumes 96.905 kWh for heating and cooling. The cost per year is 4.032 €. In this case payback period is:

$$\frac{262360}{13962+436-4032} = \textit{25 years and 4 months} \qquad (12)$$

4. ACKNOWLEDGEMENTS

This paper is a result of the research project III42013 funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

5. CONCLUSION

One of the reasons for starting the initiative for heating using heat pump, and therefore writing this study, are certainly extremely high heating bills that arrive to the address of the Faculty. Heating of Faculty using geothermal energy is something that will significantly reduce these costs, make a step forward in using new technologies and be sure to reduce consumption of the energy obtained from fossil fuels. Using ground-source heat pump all the geothermal potential that our country has to offer can be used. It also means that the dependence on imports will be reduced and also pollution of water and air.

In this paper, an analysis of the cost-effectiveness of heating sector B of Faculty of Engineering University of Kragujevac by using geothermal heat pump with two vertical probes is done. Losses through the exterior walls are calculated in the program URSA, in order to obtain installed capacity and therefore adopted a geothermal heat pump. Selected heat pump is TERRA SW HGL 220 Max IDM, German company Energie Systeme, which will be used for space heating in winter and cooling in summer time. The system is a fully featured, automated, with the possibility of production domestic hot water if necessary. With the use of heat pumps replacement of heaters need to be done, as well as the air conditioners that are used for cooling. In this case, instead of central heating radiators and air conditioning, will be used fan coil units tags 42N American company Carrier.

The investment is of course significant, because this equipment is still very expensive in the market. The total investment for the whole system is 262.320 €. The saving will definitely be heating bills, the electricity bills due to the not use of air conditioning, but it is necessary to add the consumption of electricity of newly installed system. The resulting payback period is between 24 and 26 years, depending on the number of working hours of system and the tariffs by which electricity is charged.

Three rooms on the ground floor of the sector B, which represent a laboratory for testing vehicle, have the greatest impact on the number of required fan coil unit, and thus the total investment value. Due to the high volume of premises a fan coil unit may not be the best choice. It takes a lot of them and due to the constant opening the door to all three areas the question is how they managed to warm up the rooms. Perhaps a better solution would be installation of floor or wall heating that require even lower temperature regimes than for fan coil units.

The payback period of these systems is not small and large investments are needed. However, these systems represent the future of technology and encourage the use of renewable energy sources instead of traditional sources whose reserves are slowly disappearing. A positive impact on the environment by reducing pollution and CO2 emissions is also present. State incentives and subsidies can surely help that as many of these and similar systems can be found in our region.

REFERENCES

[1] Regulations on energy efficiency of buildings, The Official Gazette of RS 061/2011 (in Serbian)

[2] URSA http://www.ursa.rs/sr-latn-cs/arhitekti/stranice/program-gf.aspx (accessed 5.03.2016.)

[3] V. Šušteršič, M. Babić., Geothermal energy, Faculty of Mechanical Engineering, Kragujevac, 2009 (in Serbian)

[4] http://www.idm-energie.at/en/warmwasser-mit-hgl-technik.html (accessed 25.05.2016.)

[5] Technical documentation for TERRA SW 50-280 Max HGL heat pumps

[6] Technical documentation for Carrier Idrofan fan coil type 42N