Natália JASMINSKÁ
Technical University of Kosice, Slovakia

DESIGN OF HEATING AND HOT WATER SUPPLY SYSTEM LIKE A POWER OF LOW-TEMPERATURE HEATING UTILIZATION IN COMBINATION WITH SOLAR COLLECTORS

The low-potential sources in combination with solar devices used in supply heating systems present a perspective alternative to fossil energy in both economic and environmental point of view. The issue of low-temperature heating and renewable energy sources at present, when humanity stands on the threshold of fuel-energy sources selection, is extraordinarily important. Currently the solar energy, geothermal water energy and environmental energy used in supply of heating systems with low-energy potential present a perspective alternative in comparison to limited fossil energy. The energy utilization appropriateness depends on geographic area and climate zone. The article presents and solves the design issue of low-temperature heat pump system in combination with solar panel devices.

Keywords: heating systems, hot water supply systems, renewable energy sources

INTRODUCTION

Energy is an important condition of satisfying basic human needs. Everyone of us realizes energy need whether in the form of heat, light, fuel or other forms. Actual way of fossil fuels utilization (coal, crude oil, gas and uranium) is time-limited. Presently, when mankind is about to choose the fuel-energetic sources the problems of low-temperature heating and renewable sources of energy are extremely important [1]. Just heat supplying systems with low-energetic potential using sun energy, geothermal energy represent perspective alternative in comparison with limited fossil sources of energy. Suitability of their utilization depends on geographical area and climatic conditions in which we live.

In spite of real possibilities, the utilization of low-temperature sources of energy in Slovakia is negligible in comparison with states of the European Union. Virtue of technologies which use low-potential sources of energy in comparison with traditional sources of energy is not only in energy saving in the heat supplying systems, but also relates to ecological cleanness of environment.

1. APPLICATION OF LOW-TEMPERATURE AND RENEWABLE SOURCES OF ENERGY

Low-temperature heating in conjunction with renewable sources of energy can be used for heat supply to all spaces where hot water heating of radiant-type heating systems are used.

Requirements for heated object:

- Object with low-temperature heating system must meet the requirements:
  - thermal loss of heated objects must be the lowest ($15 \div 20\ \mathrm{W \cdot m^{-3}}$),
  - heated space must have such thermal loss that can cover heating surface with its output without overpassing hygienically acceptable surface temperature of heating surface (floor, wall, ceiling),
  - when the thermal loss is higher than reachable output of heating surface then thermal resistance of perimeter constructions needs to be increased by additional insulation or cover the shortage output by radiant heating surface in other plane or by heating element [2, 3].

1.1. Object characteristic, its surface and actual way of heat supply

House with housing area of 117.49 $\mathrm{m^2}$ and floorage of 317.223 $\mathrm{m^3}$ is situated in Borša village (Trebišov district), in row houses at estate of 900 $\mathrm{m^2}$ area. The estate contains a garden of 450 $\mathrm{m^2}$ and unbuilt area of 70 $\mathrm{m^2}$.

At present the way of heat supply and hot water heating is realized in electrical reservoir of 80 l size and heating is secured by gas condensing boiler of Cerapur ZSBR 7-28 A 23 type from Junkers company with continuous equithermal control of heating output from 7 to 28 kW and connecting with solar system option.

For the design of the house heating and HW supply it is necessary to know its thermal loss and day HW consumption for a particular 4-member family.

1.2. Calculation of object total thermal loss

Total thermal loss of the object (in this case) is a sum of particular room thermal losses and it is determined according to the equation:

$$Q_{t,h} = \sum_{i=1}^{n} Q_{t_i} \quad [\mathrm{W}] \tag{1}$$

where: $Q_{t,h}$ - total thermal loss of the house [W],
Q_{t_i} - total thermal loss of particular rooms [W].

Calculation leads to the total thermal loss of the house that is 13.806 kW.

1.3. Calculation of heat and HW heating year consumption

In calculation of year heat consumption for heating it comes out from thermal loss of the object $Q_{t,h}$ for uninterrupted heating according to the standard EN 12 831. Total heat and HW heating year consumption:

$$Q_{total,y} = Q_{heat,y} + Q_{tw,y} \quad [\mathrm{kWh \cdot y^{-1}}] \tag{2}$$

$$Q_{total,y} = 99.372 + 13.29 = 112.662\ \mathrm{kWh \cdot y^{-1}}$$

1.4. Calculation of heat and HW heating year consumption

The goal while designing the heat supply for heating and HW heating of the house was to create a system which would effectively utilize excessive solar energy for heat pump support and as backup facility heat source – gas-condensing boiler.

Mentioned interconnection of old and new way of heat supply has advantage in the gas boiler being able to ensure the total heat need for space heating and HW heating in case of problems with heat pumps or solar collectors.

There was designed bivalent operation mode in combination with solar collectors where heat pump will work separately until so-called point of bivalence at which peak source starts to heat i.e. gas-condensing boiler.

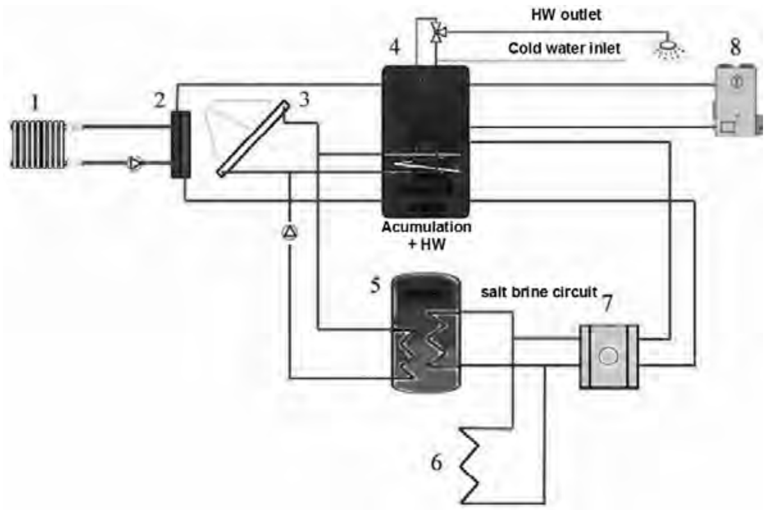

Fig. 1. Principal scheme of heat supplying system: 1 - radiator circuit, 2 - board heat exchanger, 3 - solar collectors, 4 - storage reservoir with nested HW reservoir, 5 - storage reservoir, 6 - heat pump ground probes, 7 - heat pump earth-water, 8 – gas-condensing boiler

1.5. Required number of solar collectors determination

All elements of solar system were chosen the same as storage reservoir from the product offer of Regulus company.

For choosing the solar collectors it is necessary to know their operation conditions. Collectors will be situated at flat roof of additional building oriented on south. As it is considered all-year-round service, so the angle of inclination will be 45°. Specifically, they will be vacuum tube solar collectors with more effective reflective KTU R2 metal sheet KTU 9R2 type of 2.15 m^2 aperture area.

Required number of collectors calculation is realized according to the equation from [4-6]:

$$n_k = \frac{A_{ef}}{A_k} \quad [-] \tag{3}$$

where: n_k - required number of solar collectors [-],
A_{ef} - calculating absorption area of solar [m^2],
A_k - effective area of absorber [m^2], $A_k = 2.15\ m^2$.

Whereas the equation for calculating absorption area of solar collectors is:

$$A_{ef} = \frac{P_u}{P_s \cdot \eta} \quad [m^2] \tag{4}$$

where: P_u - heat need for HW heating [$kWh{\cdot}day^{-1}$],
P_s - average useable solar energy (see table 1),
$P_s = 4.7\ kWh{\cdot}m^{-2}.day^{-1}$ - summer half-year (April - September),
$P_s = 2.2\ kWh{\cdot}m^{-2}.day^{-1}$ - temperate season (autumn, spring),
η - average efficiency of solar system [-].

Table 1. **Average amount of solar energy per south-oriented area**

	Amount of incident solar energy per area unit in Trebišov (kWh.m^{-2})												
Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Daily	1,36	2,33	3,58	4,36	5,03	4,85	5,21	4,78	3,98	3,22	1,59	1,09	3,45

Heat need P_u is based on equation:

$$P_u = m \cdot c \cdot (t_{hw} - t_p) \quad [kWh{\cdot}day^{-1}] \tag{5}$$

where: m - day hot water consumption, ($l{\cdot}day^{-1}$)
m = number of people 50 $l{\cdot}day^{-1}$ = 4.50 = 200 $l{\cdot}day^{-1}$
c - specific heat capacity of water, $c = 1.16{\cdot}10^{-3}\ kWh{\cdot}kg^{-1}{\cdot}K^{-1}$,
t_{tw} - temperature of taken water, $t_{tw} = 45°C$,
t_{sw} - temperature of supplied water, $t_{sw} = 10°C$.

$$P_u = m \cdot c \cdot (t_{tw} - t_{sw}) = 200 \cdot 1.16 \cdot 10^{-3} (45 - 10) = 8.12\ kWh{\cdot}day^{-1}$$

a) system sizing for summer season:

$$A_{ef} = \frac{P_u}{P_s \cdot \eta} = \frac{8.12}{4.7 \cdot 0.5} = 3.46\ m^2$$

$$n_k = \frac{A_{ef}}{A_k} = \frac{3.46}{2.15} = 1.61 \approx 2 \text{ collectors}$$

b) system sizing for temperate season:

$$A_{ef} = \frac{P_u}{P_s \cdot \eta} = \frac{8.12}{2.2 \cdot 0.5} = 7.38 \text{ m}^2$$

$$n_k = \frac{A_{ef}}{A_k} = \frac{7.38}{2.15} = 3.43 \approx 3 \text{ collectors}$$

There were designed three solar collectors of KTU 9R2 type based on the calculations and with knowing the solar energy accumulation demand.

What concerns reservoir heater whereas there are 4 persons with daily HW consumption of 50 litres, it is enough to choose storage reservoir with reservoir of DUOV 750/200 type with total value of 750 litres and heat water reservoir of 200 litres. Inner surface of the reservoir is enamelled and it is equipped with magnesium anode.

Storage reservoir for storing solar energy excess will be PS2F 300 type of 300 litres volume and 2 tube exchangers the size of which will be customized according to the chosen application and needed performance.

1.6. Option of suitable heat pump type

As indicated by principal scheme in Figure 1, heat supply for heating and HW (through period of need) will be ensured by heat pump earth-water, because mentioned heat pump type can be easily and effectively interconnected through salt brine circuit with storage reservoir of solar system.

As central heating of the house is solved by using hot-water heating system 90/70°C. It was necessary to choose a heat pump type which is able to operate at these conditions in order to heating elements not to have to be changed.

Compressor heat pump earth-water with electric drive from Viessmann company marked as VITOCAL 350 with outlet temperature 65°C meets those conditions. That was specially developed for modernization with radiator circuit left.

Particular type VITOCAL 350 HP depends on required heat need.

Because thermal losses of object are calculated at lowest outer temperature of surroundings, which in reality introduces little number of hours needed, HP output will be designed to ensure 75÷95% of heat need for heating and HW and addition will be ensured by additional source.

What concerns HW at present demand for comfort day energy need for preparing HW is about 17 kWh or average energy input for water heating about 0.7 kW per 4 persons [7, 8].

Next, it is necessary to consider everyday HP lay off for certain number of hours in order to ensure its trouble-free operation. What is related to temperature regeneration inside the earth. This means that daily the heat pump will be blocked for 4 hours in two two-hour intervals and heat will be removed from DUOV storage reservoir, what is taken into account by increasing the total required HP output by 1.2 times. In consequence total required HP output will be: (13.738 kW + 0.7 kW). 1.2 = 17.326 kW.

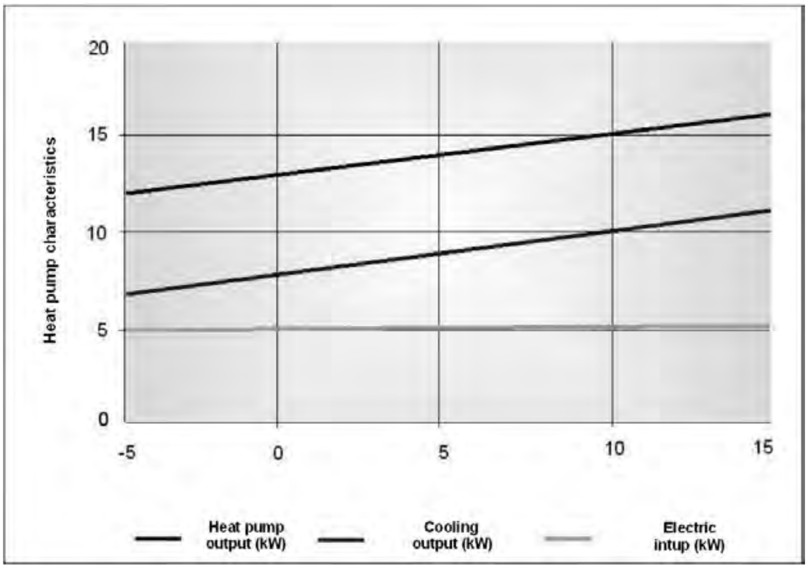

Fig. 2. HP VITOCAL 350 characteristics

After taking the required output into account heat pump type was selected VITOCAL 350 type. Heat pump characteristics taken from technical materials from Viessmann company are shown in Figures 2 and 3.

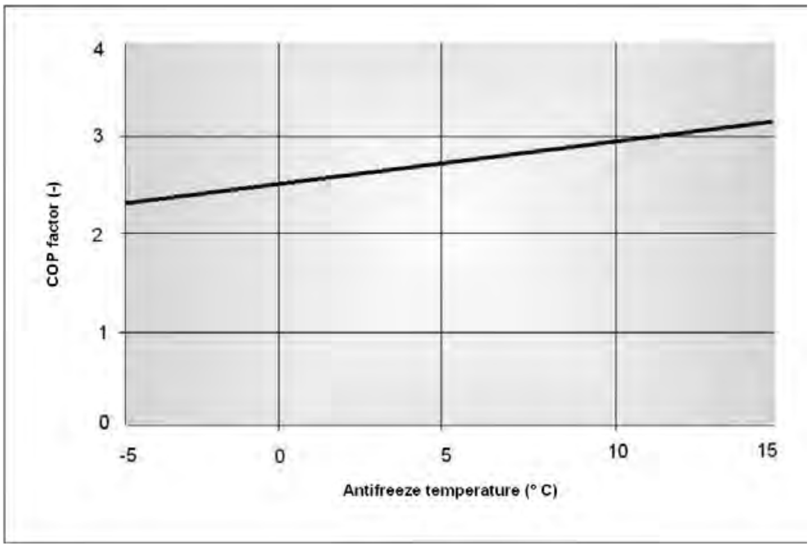

Fig. 3. Heating factor of HP VITOCAL 350 BWH 110 process

1.7. Point of bivalence determination

Point of bivalence was defined according to [3] (see Fig. 4) for salt brine temperature of 2°C what corresponds to 13.2 kW heating output of heat pump. If temperature of salt brine is under 2°C, gas-condensing boiler will work as help out.

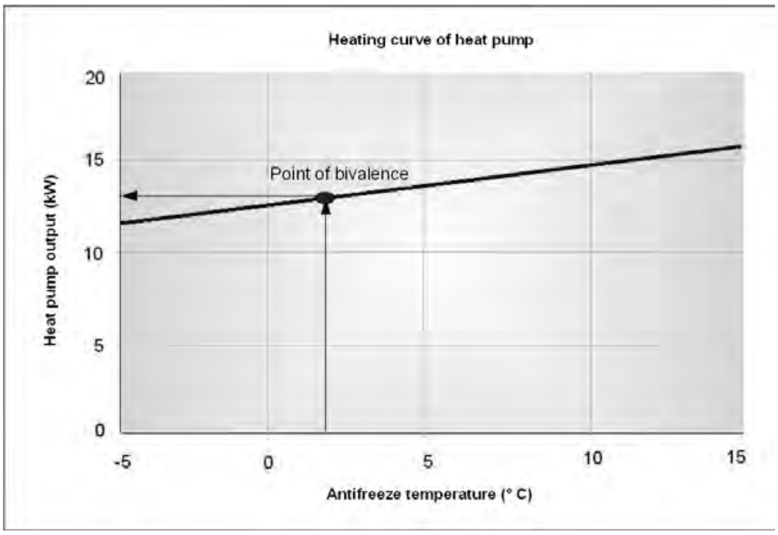

Fig. 4. Point of bivalence determination diagram

1.8. Point of bivalence determination

Drill holes depth for HP ground probes is affected by the type of foot wall, amount of underground water and other factors.

Table 2 was important for determination of vertical collectors depths for selected HP. This contains informative values of needed collectors length in dependence on required output and foot wall composition.

Table 2. **Informative ground collectors depth in dependence on HP output**

Type of foot wall	Heating output [W] per 1 m of collector length	Depth [m] per 1 kW of heating output
Dry soil	30	33
Continual solid soil	55	18
Rockwith big thermal conductivity, clay	80	13
Rock with underground water	100	10

Since unbuilt area of 70 m^2 is made by clay rock with big thermal conductivity. Two drill holes of 88 m depth and 5 m spacing (because of little interaction and ensuring regeneration in summer) were designed based on heating output of 13.2 kW.

Despite of the earth temperature in our climatic conditions in the depth of 10 m the temperature is already steady around 10÷12°C. As shown in Figure 5, it is obvious that at constant taking off from drill hole the temperature will progressively decrease in its environment certain temperature cone. The level will be balanced again after stopping heat taking off. Thermal flows will become constant even if the temperature can slowly decrease.

This problem is analysed in detail in source [9]. According to that it is valid that if output of 75 W/m is not overpassed system works without problems.

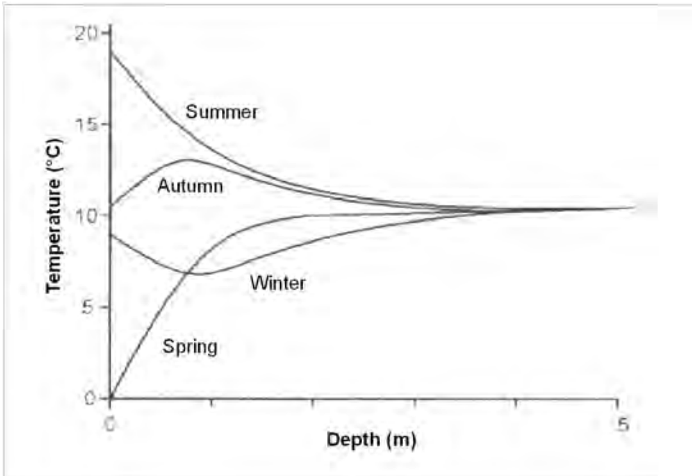

Fig. 5. Earth temperature process in dependence on year season

2. DESIGN OF SALT BRINE FLOW THROUGH SOLAR SYSTEM STORAGE RESERVOIR

Utilization of solar system summer excess stored in storage reservoir will take place in the period when HP will not be able to ensure necessary heat as result of salt brine temperature fall from ground collector under the point of bivalence. In that case the salt brine circuit would be closed and this would flow through storage reservoir of solar system and take off its accumulated heat from summer.

Temperature of water in storage reservoir would be kept at 60°C in the time of charging from solar system and heat would be taken from it until the temperature of 2°C. This circuit would be closed after decreasing of water temperature on 2°C and salt brine would flow back to the ground. It would ensure required heat in bivalent mode with gas condensing boiler on the basis of automatic regulation by equithermal system.

Salt brine is demanded to warm up about 3°C while flowing through reservoir because during ground probe flowing it is warmed up about this temperature difference. Determination of salt brine temperature increase during ground probe flowing:

It is necessary to know output of low-potential heat source for making calculation which is defined as:

$$Q_0 = Q_V \cdot (\varepsilon - 1) / \varepsilon \ \text{[kW]} \tag{6}$$

where: Q_v - heating output of heat pump [kW],
Q_0 - energy from low-temperature source of heat [kW],
ε - work supplied to the heat pump [kW].

$$Q_0 = 13.2 \cdot (2.59 - 1) / 2.59 = \underline{\underline{8.1}} \text{ kW}$$

Then on basis of this output with knowing salt brine flow salt brine warming up is determined as:

$$Q_0 = m_{s,1} \cdot c_s \cdot dt \ \ \text{[kW]} \tag{7}$$

where: Q_0 - energy from low-temperature heat source [kW],
$m_{s,1}$ - minimal flow of salt brine through vertical collector,
$m_{s,1} = 2.7 \text{ m}^3 \cdot \text{h}^{-1}$,
c_s - specific heat capacity of salt brine, $c_s = 1.1875 \text{ kW} \cdot \text{t}^{-1} \cdot \text{K}^{-1}$,
dt - warming up of salt brine [°C].

$$m_{s,2} = \frac{16.3701}{1.1875 \cdot 3} = 4.595 \text{ m}^3 \cdot \text{h}^{-1} \approx \underline{\underline{4.6}} \text{ m}^3 \cdot \text{h}^{-1}$$

Diameter of tube heat exchanger for salt brine flowing will be designed on basis of this minimal flow and circulating pump will be selected.

CONCLUSION

Possibility of effective solar energy utilization for low-temperature heating systems depends on solar equipment efficiency as from technical as economical aspect so with the highest possible efficiency at the lowest investment costs.

There are real possibilities of improving technical-economical parameters for solar collectors in the systems of heat pumps from point of view of significant investment demandingness decrease by removing the clear casing of collector and thermal insulating layers. As a result of low temperature of working medium in the collector -what increases collector efficiency. At low temperature in the collector the diffusion radiation can be used in early morning and late evening hours.

The collector in the system of heat pump should be designed not only for solar radiation utilization but also for heat gaining from environment (air, rain, wind). One of serious problems of solar energy utilization for heat pumps systems is unpredictable periods without solar shine which can be in the winter season in our geographical area even more than 7 days. Therefore for solar energy utilization in winter season for heat pump systems it is necessary to install alternative source of thermal output or use relatively big and capital-intensive heat reservoirs [1, 9, 10].

REFERENCES

[1] Vranayová Z., Vranay F., Očipová D., Renewable energy for smart buildings in conditions of the Slovak Republic, Journal of International Scientific Publication 2009, 3, 1, 486-493.

[2] Lichner M., Nagy R., Renovation of apartment buildings with respect to energy savings and greater efficiency = Renowacja budynków mieszkalnych ze względu na oszczędności energii i większą efektywność, [In:] Energodom 2008, Materiały konferencyjne, ASTERIAS, Kraków 2008, 271-278.

[3] Petráš D. et al., Nízkoteplotné vykurovanie a obnoviteľné zdroje energie, Jaga group, Bratislava 2001.

[4] Klenovčanová A., Brestovič T., Možnosti využitia fotovoltických článkov na výrobu elektrickej energie v oblasti Košíc, Acta Mechanica Slovaca 2007, 11, 4-D, 511-516.

[5] Tauš P., Taušová M., Využitie solárnych energetických fasád na vykurovanie a vetranie administratívnych budov, AT & P Journal 2005, 12, 3, 35-37.

[6] Tkáč J., Hvizdoš M., Meranie intenzity slnečného žiarenia, Elektroenergetika 2011, 4, 4, 20-24.

[7] Hvizdoš M., Tkáč J., Experimentálne tepelné čerpadlo, Elektroenergetika 2011, 4, 1, 20-22.

[8] Viessmann: Vitocal 300/350. List technických údaju, Chrášťany 2011.

[9] Vranayová Z. et al., Risk analysis for RWH system and its verification by mathematical methods, Visnik Nacionaľnovo universiteta Ľvivskaja Politechnika 2013, 756, 74-76

[10] Žeravník A., Stavíme tepelné čerpadlo, Přerov: EURO-PRINT spol. s. r. o., 2003.

PROJEKTOWANIE OGRZEWANIA I SYSTEMU CIEPŁEJ WODY UŻYTKOWEJ JAKO ŹRÓDEŁ NISKOTEMPERATUROWYCH W POŁĄCZENIU Z KOLEKTORAMI SŁONECZNYMI

Niskotemperaturowe źródła w połączeniu z urządzeniami słonecznymi w systemach ogrzewania stanowią perspektywicznie alternatywę dla paliw kopalnych z punktu widzenia ekonomicznego i środowiskowego. Kwestia niskotemperaturowego ogrzewania i odnawialnych źródeł energii jest w chwili obecnej, kiedy ludzkość stoi na progu paliwowo-energetycznego doboru źródeł, niezwykłe ważna. Obecnie energia słoneczna, geotermalna i inne źródła niekonwencjonalne wykorzystywane w systemach ciepłowniczych są alternatywą w porównaniu do ograniczonych zasobów energii z paliw kopalnych. Wykorzystanie energii jest uzależnione od obszaru geograficznego i strefy klimatycznej. Artykuł przedstawia rozwiązanie niskotemperaturowego systemu pompy ciepła w połączeniu z panelami słonecznymi.

Słowa kluczowe: **system centralnego ogrzewania, system przygotowania ciepłej wody użytkowej, odnawialne źródła energii**