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Energy Parameters' Calculation of a Hybrid Heat Supply System for a Private House in the Conditions of Western Part of Ukraine

Yurii Pantsyr, Ihor Garasymchuk, Taras Hutsol and Ivan Gordiychuk

Abstract In the article the power supply scheme of a private house was developed for the Western Ukraine region conditions with Sun energy usage and soil thermal energy. It was evaluated the annual heat-flux density of the scheme. The solar collectors are justified and selected The parameters have been calculated and the heat pump was chosed The proposed hybrid system of heat supply for a private house with the solar energy usage and soil heat can save more than 5 thousand cubic meters of natural gas per year, which will bring the corresponding economic effect. The payback period of the necessary additional capital investments is just over 6 years.

Keywords Hybrid system · Heat pump · Solar collecting panel

1 Introduction

Completeness of natural gas reserves, as well as other fossil energy carriers, as well as their constant and significant increase in price, necessitate the search for alternative energy sources. In the western region of Ukraine there are many sunny days, so it is advisable to use the thermal energy of the sun for heating, as well as heating the water in a private house. And since in some periods the heat is received from solar collectors may not be enough, and also for more guaranteed provision with thermal energy, it is advisable to use in parallel a heat pump that uses low-potential energy of the soil [1].

Considering this, the goal of the work is the hybrid system development of power supply for a private home due to the energy of the sun and the soil heat.

Y. Pantsyr · I. Garasymchuk (✉) · T. Hutsol · I. Gordiychuk
State Agrarian and Engineering University in Podilya, Khmelnytskyi, Ukraine
e-mail: igorgarasymchuk@gmail.com

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To achieve this goal, it is necessary to solve the following tasks

- To determine the heat load of the heating system;
- To calculate the heat load of the hot water supply system;
- To Estimate the total heat load;
- To select the parameters of the solar power plant;
- To Conduct an analysis of monthly energy balances;
- To calculate the heat pump parameters.

1.1 The Input Parameters of Private House Energy Supply

To calculate the hybrid heat supply system of a private house, let us set the following input parameters (average for a typical private house of a given geographical location)

- The volume of the building by its external dimensions $V = 840$ m^3;
- Specific heat dissipation of the house $q_0 = 0.50\,\frac{\mathrm{W}}{\mathrm{m^2\,gon}}$;
- Minimum temperature of the coldest five-day period $t_{\mathrm{cp}}^{min} = -17\,°\mathrm{C}$;
- The maximum number of people who live or work in this house $N = 10$ pers.;
- Rate of hot water consumption per person $a = 30\,\frac{l}{\mathrm{pers.}}$;
- Specific heat of soil $q = 20\,\frac{\mathrm{W}}{\mathrm{m^2}}$;
- Other parameters for easy calculation are included in Table 1.

Solar energy is converted into heat in a flat solar collector (SC) and transferred by a liquid coolant to a boiler-heat accumulator, from where it is used, if necessary, in hot water. The solar parameters of installation are calculated for 80% of the degree coverage of the house's need for hot water during the eight-month season: from March 1 till October 30.

The main heat load of the house heating system is provided by a heat pump which takes low-potential heat from the soil. The maximum thermal power of the pump is selected according to the requirements of the full coverage of the building's thermal load in the cold five-day period of the year. In heating systems, the heat pump mainly works at night, when the temperature on the street is low, and the cost of electricity is the least.

Table 1 Average monthly ambient temperatures t_{ns} of tap water t_{cp} and soil temperature t_s

Parameter	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
t_{cp}	−5.4	−5.0	−0.4	8.8	16.4	20.1	24.2	23.1	19.6	10.2	2.0	−2.0
t_{min}	5	5	5	5	6	12	18	18	14	12	8	6
t_s	10	10	10	10	11	12	12	12	12	11	10	10

Therefore, a heat accumulator (HA) is also proposed in the heating circuit (possibly combined with a solar system) to accumulate excess heat. During the day, the HA is discharged directly to the heating devices, and if its temperature drops below the allowable temperature, the heat pump starts.

The solar and heat pumps of the heat supply system are more effective than lower temperature at their outlet. Therefore, in the calculations are guided by low-temperature parameters of the coolant, which are inherent in the panel (floor) or air heating circuit. The latter allows the heat pump system usage and in summer—in the air conditioning mode and hot water production as by-side thermal release of the heat pump system.

1.2 Determination of the Heating Load of the Heating System

Calculations used in the work were carried out according to the methods and algorithms were given in [2–5].

The heating system compensates for heat loss at house, the power of which is estimated by the formula

$$P_{\mathrm{heat\,loss}} = q_0 V_{\mathrm{house}}(18 - t_{\mathrm{cp}}), \mathrm{W} \tag{1}$$

where

q_0	Specific power of heat, W/m^3 gon;
V_{house}	Heating volume of the building, calculated by its external dimensions, m^3;
18 °C	normalized internal temperature
T_{et}	environment temperature.

We'll give an example of calculating the heat loss at the house and in January

$$P_{\mathrm{heat\,loss}} = 0.50 \cdot 840(18 - 5.1) = 9702\,\mathrm{W}$$

The results of calculating the heat loss of a private house in other months are shown in Table 2.

The maximum capacity of the heating system is designed to provide comfortable conditions in a cold five-day period for a given area t_{cp}^{min},

$$\begin{aligned} P_{heat\,loss}^{max} &= q_0 V_{house}(18 - t_{cp}^{min}), \mathrm{W} \\ P_{heat\,loss}^{max} &= 0.50 \cdot 840(18 + 17) = 14{,}700\,\mathrm{W}. \end{aligned} \tag{2}$$

Average daily heat load of the heating system is calculated monthly, for the average monthly temperature of the environment t_{cp}:

Table 2 Results of thermal loads calculation Q in MJ, P in kW

Parameter	Months												The yearly tale
	1	2	3	4	5	6	7	8	9	10	11	12	
$Q^{d}_{heat\ loss}$	838.3	834.6	667.7	333.8	–	–	–	–	–	283.0	580.6	725.8	–
$Q^{\min}_{heat\ loss}$	25,986	23,369	20,699	10,014	–	–	–	–	–	8773	17,418	22,500	128,765
Q^{d}_{hw}	114.6	114.6	114.6	114.6	110.2	99.0	82.0	79.3	87.8	96.3	104.8	110.2	–
$Q^{\min}_{hw}$	3552.6	3208.8	3552.6	3438	3416	2970	2460	2458	2634	2995	3144	3416	37,244
$Q^{\mathrm{M}}_{\mathrm{TL}}$	29,538.6	26,578	24,251	13,452	3416	2970	2460	2458	2634	11,774	20,562	25,916	166,009
P^{M}_{hw}	1.32	1.32	1.32	1.32	1.27	1.14	0.94	0.91	1.01	1.07	1.21	1.27	–
P^{M}_{NL}	11.03	10.25	9.36	3.49	1.31	1.14	0.95	0.95	1.01	4.53	7.91	9.97	–
$P_{\text{тв}}$	9.7	9.7	7.7	3.9	0.7	–	–	–	–	3.3	6.7	8.4	–

$$Q^{d}_{heat\,loss} = 86.4\, q_0 V_{\text{house}}(18 - t_{cp}), \text{kJ} \tag{3}$$

1.3 The Heat Load Determination of Hot Water Supply System

The daily heat load of hot water supply system of a private house is calculated by the formula

$$Q^{i}_{hw} = 1.2\, a\, c_p \rho (t_{hw} - t_{\min}) \cdot N, \text{kJ} \tag{4}$$

where:

- Q^{i}_{hw} Daily heat load, kJ;
- a Rate of hot water consumption per person in l/day;
- c_p 4.19 kJ/kg gon—Specific heat of water;
- ρ 1.0 kg/l—density of water;
- N Number of persons;
- T_{hw} 45 °C—Normalized temperature of hot water;
- $t_{\min}$ cold tap water temperature at the inlet to the heating device.

The same formula calculates the monthly average daily load of a hot water supply system Q^{d}_{hw} using the average monthly cold water temperature t_{min}. For example, the value of the average daily load for January:

$$Q^{d}_{hw} = 1.2 \cdot 30 \cdot 4.19 \cdot 1.0(45 - 5) \cdot 10 = 114{,}638.4\, \text{kW}.$$

Similarly, calculations for other months are carried out, and its results are listed in Table 2.

Average monthly values of the daily capacity of the hot water supply system in kilowatts are calculated by the formula

$$P^{M}_{hw} = 1.15 \times 10^{-5} Q^{d}_{hw}, \text{kW} \tag{5}$$

For January, it is

$$P^{\mathcal{M}}_{hw} = 1.15 \times 10^{-5} \cdot 114{,}638.4 = 1\, \text{kW}.$$

In the solar system of hot water supply we assume a backup electric heater. Its power is selected provided that the specified volume of low-temperature water is fully heated during the night energy tariff (8 h):

$$P_{res}^{M} = \frac{Q_{hw}^{d}}{6} \cdot 0.000278 = 114{,}638.4 \cdot 4.6 \times 10^{-5} = 5.3\,\text{kW}.$$

In particular, reserve capacity is required for January

$$P_{res} = 5.3 \cdot 1.32 = 7.0\,\text{kW}.$$

The monthly load of the hot water supply system is calculated by the daily average for the number of days in a month

$$Q_{hw}^{M} = 114.6 \cdot 31 = 3552.6\,\text{kJ}.$$

The annual load of the HW system is calculated as the monthly sum

$$Q_{hw}^{\text{p}} = \sum_{i=1}^{12} Q_{hw}^{\text{M}} = 14{,}991\,\text{kJ} \tag{6}$$

The calculation results are listed in MJ and are listed in Table 2 Conversion kJ into kW h is performed according to the relation

$$1\,\text{kJ} = 0.000278\,\text{kW h}.$$

1.4 Calculation of the Total Heat Load

The monthly heat load of the heat supply system is calculated as the sum

$$Q_{\text{TH}}^{\text{M}} = Q_{\text{ОП}}^{\text{M}} + Q_{\Gamma\text{B}}^{\text{M}}, \text{kJ} \tag{7}$$

In January the calculation result will be as follows:

$$Q_{TL}^{M} = 25{,}986 + 3552.6 = 29{,}538.6, \text{kJ}.$$

The annual thermal load of the system is equal to the sum of the monthly ones:

$$Q_{TL}^{p} = \sum^{12} Q_{TL}^{\mathcal{M}} = 81{,}495\,\text{kJ}.$$

The monthly average load capacity of the heat supply system in kilowatts is calculated by dividing the monthly heat load in kJ by the number of seconds in a month:

$$P_{TL}^{\mathcal{M}} = \frac{Q_{TL}^{\mathcal{M}}}{24 \cdot n \cdot 3600}, \text{kW} \tag{8}$$

In January, the average capacity of the heat supply system is

$$P_{TL}^{\mathcal{M}} = \frac{29{,}538.6}{24 \cdot 31 \cdot 3600} = 11.03\,^{\circ}\text{C}.$$

In addition, the maximum heat loss capacity in a cold five-day period

$$P_{TL}^{max} = P_{heat\,loss}^{max} + P_{hw}^{1} \tag{9}$$

where $P_{hw}^{1} = 1.15 \times 10^{-5}\, Q_{hw}^{1} = 1.15 \times 10^{-5} 114{,}638.4 = 1.3\,\text{kW}$;

$$P_{TL}^{max} = 14.7 + 1.3 = 16\,\text{kW}.$$

The results are listed in Table. 2.

1.5 The Solar Energy Amount Determination of Entering the Solar Collector

For the calculations were used the values of the average daily solar radiation fluxes to the horizontal surface, which were taken from meteorological data.

$H_{th}^{d}, \text{J/m}^2$	Average daily intake of total solar radiation per month on a horizontal surface;
$H_{dh}^{d}, \text{J/m}^2$	Average daily intake of scattered solar radiation per month on a horizontal surface;
β	angle of inclination of the heliocollector surface to the horizon, degrees;
m	the ordinal number of the day in a year;
δ	solar declination for the current day of the year, gon;
φ	geographical breadth of region, gon, P Sh;
A_h, A_β	the azimuthal angles of the sunset direction for the horizontal plane and inclined at an angle β to the horizon, gon;
r	is the reflection coefficient of the sun's rays by the soil surface.

The ordinal number of the day in the year is calculated as of the 15th day of each month: January 15 m = 15; February 15, m = 31 + 15 = 46, etc.

The solar declination δ is calculated by the formula:

$$\delta = 23.5\, \sin\frac{284 + m}{365} \cdot 360\,\text{gon}. \tag{10}$$

In summer, δ > 0, in winter δ < 0, and on the day of the spring and autumn equinox (March 21 and September 21) δ = 0. In January, for example, the solar declination is

$$\delta = 23.5\ \sin\frac{284 + 15}{365} \cdot 360 = -21.3\,\text{gon}.$$

The inclination optimal angle of the solar collector to the horizon is calculated from the formula

$$\beta = \varphi - \delta_{cp}, \text{gon} \tag{11}$$

where δ_{cp}—Means value of solar declination for the billing period:

$$\delta_{cp} \cong \frac{1}{12}(\delta_1 + \delta_2 + \delta_3 + \delta_4 + \delta_5 + \delta_5 + \delta_7 + \delta_8 + \delta_9 + \delta_{10} + \delta_{11} + \delta_{12}), \text{gon}. \tag{12}$$

The value of the solar declination at the middle of each month from January 1 to December 31 is taken from meteorological data. The average seasonal declination δ_{cp} calculated from these data and the optimal inclination angle β level:

$$\delta_{cp} = \frac{1}{12}(-21.3 - 13.3 - 2.8 + 9.4 + 18.8 + 23.4 + 21.2 + 13.8 + 2.2 - 9.6 - 19.2 - 23.4) = 0.2^\circ;$$

$$\beta = 50 - 0.2 = 49.8^\circ.$$

The sunrise azimuth angle for the horizontal plane is calculated by the formula

$$A_h = \arccos[-tg\varphi \cdot tg\delta], ^\circ. \tag{13}$$

In January, for example, the azimuth angle of sunrise is

$$A_h = \arccos[-tg50 \cdot tg\delta(-21.3)] = 62.3^\circ.$$

The azimuth angle of the sunrise for the case of the surface of the SC inclined at an angle β to the horizon is calculated from

$$A_\beta = \arccos[-tg(\varphi - \beta) \cdot tg\delta], ^\circ.$$
$$A_\beta = \arccos[-tg(50 - 49.8) \cdot tg(-21.3)] = 90.03^\circ. \tag{14}$$

In January, the sunrise angle for the inclined plane exceeds that for a horizontal surface is impossible. Therefore, by fulfilling the additional condition $A_\beta \leq A_h$, the azimuthal sunrise for the older collector is assumed to be the same as for the horizontal surface: $A_\beta = A_h = 62.3^\circ$.

The recalculation of the arrival of only direct radiation from the reference value for the horizontal surface to the value for the surface inclined at an angle β to the horizon and oriented in the south direction is carried out through the auxiliary coefficient R_β:

$$R_\beta = \frac{\cos(\varphi - \beta) \cdot \cos\delta \cdot \sin A_\beta + \frac{\pi}{180} A_\beta \sin(\varphi - \beta) \cdot \sin\delta}{\cos\varphi \cdot \cos\delta \cdot \sin A_h + \frac{\pi}{180} A_h \sin\varphi \cdot \sin\delta} \quad (15)$$

In particular, in January the auxiliary coefficient is

$$R_\beta = \frac{\cos(50 - 49.8) \cdot \cos(-21.3) \cdot \sin 62.3 + \frac{\pi}{180} 62.3 \sin(50 - 49.8) \cdot \sin(-21.3)}{\cos 50 \cdot \cos(-21.3) \cdot \sin 62.3 + \frac{\pi}{180} 62.3 \sin 50 \cdot \sin(-21.3)} = 3.8.$$

The conversion factor R of the total solar radiation input from the value for the horizontal surface which was given in the directory to the value for the inclined surface was calculated by the formula

$$R = \left(1 - \frac{H_{dh}}{H_{th}}\right) R_\beta + \frac{H_{dh}}{H_{th}} \cdot \frac{1 + \cos\beta}{2} + r \frac{1 - \cos\beta}{2} \quad (16)$$

The value of albedo r in summer is taken equal to 0.2, and in winter—0.7.

For example, this factor for January will be

$$R = \left(1 - \frac{2.592}{3.678}\right) 3.8 + \frac{2.592}{3.678} \cdot \frac{1 + \cos 49.8}{2} + 0.7 \frac{1 - \cos 49.8}{2} = 1.8.$$

The average daily (per month) intake of total solar radiation per 1 m^2 of the inclined surface of the SC is calculated by multiplying:

$$H_\beta^{д} = RH_{th}, \ MJ/m^2 \quad (17)$$

In January, the average daily supply of solar energy to the inclined surface of the SC will be:

$$H_\beta^{д} = 1.8 \cdot 3.093 = 5.78 \ MJ/m^2.$$

Monthly and annual intake of total solar radiation per 1 m^2 of the inclined surface of the SC is calculated by multiplying by the number of days n in a month and the subsequent summation of monthly correspondences:

$$H_{\beta}^{\text{м}} = nH_{\beta}^{\text{д}}, MJ/m^2; \quad (18)$$

$$H_{\beta}^{p} = \sum_{i=1}^{12} RH_{\beta}^{i}, \text{MJ/m}^2. \quad (19)$$

The calculation of the corresponding values for January and the year as a whole are given below:

$$H_{\beta}^{1} = 31 \cdot 5.78 = 179.33\,\text{MJ/m}^2;$$
$$H_{\beta}^{c} = \sum_{i=1}^{12} RH_{\beta}^{i} = 4465.6\,\text{MJ/m}^2.$$

The calculations' results for the remaining months of the year are summarized in Table 3.

2 Analysis of Monthly Energy Balances

The solar heat supply system peculiarity is the uneven generation of heat energy during the year with the practically stable heat load of the hot water supply system. Seasonal unevenness of the thermal energy can be partially smoothened by changing the angle of inclination of the solar collector to the horizon β. But at the same time, the volume of heat production decreases [6, Fig. 1.8].

The increase in the number of solar collectors will increase the reliability of the heat supply system and expand the season of using solar energy, but due to the increase in the cost of the installation. Conversely, if the total area of the SC is reduced, the effective life of solar installations is limited only by the warm period of the year. Therefore, the final recommendations on the operating parameters of the proposed solar plant will be developed based on the analysis of monthly energy balances. It also concludes that:

- correspondence of monthly solar energy input from the calculated amount of SC to the needs of the hot water supply system in house;
- the electricity amount or heat necessary to compensate for the insufficient capacity of solar collectors in covering the needs of hot water supply during periods of solar radiation low level;
- the solar energy share in covering the total heat loss in house during the winter (four-month) period with the selected area of the SC;
- the excess energy amount in summer;
- The need to correct the number of solar collectors (Fig. 1).

Table 3 Results of calculation of solar energy parameters

Mom	$H_{th}, \frac{\text{MJ}}{\text{m}^2}$	$H_{dh}, \frac{\text{MJ}}{\text{m}^2}$	$H_0 \frac{\text{MJ}}{\text{m}^2}$	m	δ, gon	A_h, gon	A_β, gon	r	R_β	R	$\dot{H}_\beta^{д}, R' \frac{MJ}{m^2}$	$H_\beta^{М}, \frac{MJ}{m^2}$
1	3.093	2.383	9.0	15	−21.3	62.3	−92.5	0.7	3.8	1.79	5.78	179.3
2	5.35	3.846	14.5	46	−13.3	73.6	−91.5	0.7	2.6	1.63	9.07	254.1
3	9.78	5.434	22.3	74	−2.8	86.6	−90.3	0.7	1.67	1.32	13.04	404.5
4	13.96	7.399	31.2	105	9.4	101.4	−88.9	0.2	1.13	0.98	13.92	417.7
5	18.78	9.447	38.1	135	18.8	113.9	−87.8	0.2	0.84	0.85	16.81	521.3
6	21.82	10.24	41.2	166	23.4	121.0	−87.2	0.2	0.73	0.79	17.52	525.9
7	20.48	9.865	38.6	196	21.2	117.5	−87.5	0.2	0.78	0.82	17.96	556.8
8	17.18	8.151	33.8	227	13.8	107.0	−88.5	0.2	0.99	0.94	16.93	525.1
9	12.62	5.894	25.4	258	2.2	92.6	−89.7	0.2	1.47	1.21	15.88	476.6
10	7.315	3.782	16.7	288	−9.6	78.4	−91.1	0.2	2.23	1.49	10.67	330.9
11	2.968	1.797	10.3	319	−19.2	65.5	−92.2	0.7	3.25	1.63	4.65	139.8
12	2.132	1.714	7.6	349	−23.4	59.0	−92.8	0.7	4.3	1.91	4.31	133.7

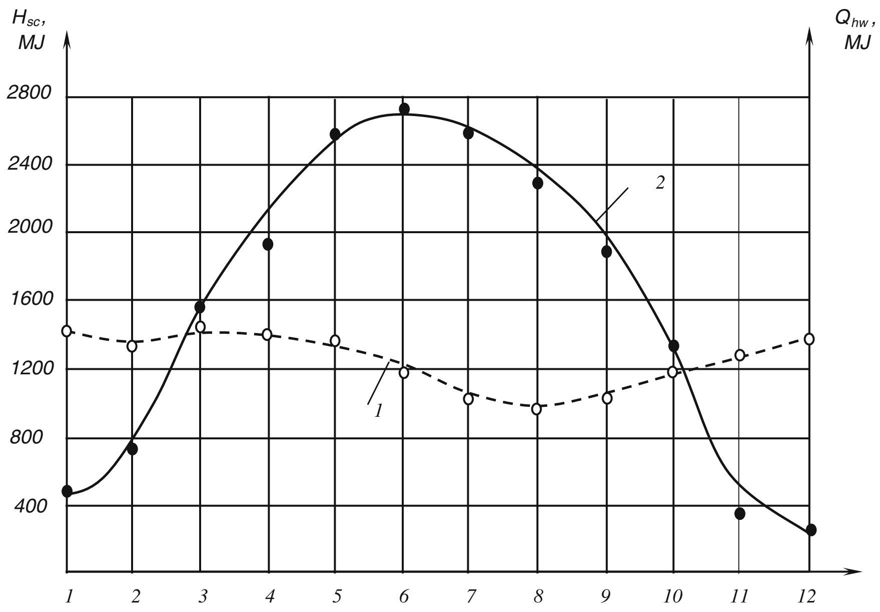

Fig. 1 Monthly energy balance of the solar hot water supply system

2.1 The Parameters' Calculation of the Heat Pump System

The heat pump work is possible in two modes—monovalent and most suitable for our case bivalent (Fig. 2). In the first mode, as a rule in winter, the heat pump completely covers the heat load at home, and in the second - it works together with the solar system. In addition, it is possible to break the power supply three times a day at 2:00, which occurs in rural electricity networks.

Necessary for the calculation of the pumps' operating characteristics in the linear dependences form of the thermal power of the P_{HP}, the electric power P_{el} and the conversion factor ε on the temperature of the primary heat source, in this case—the soil temperatures t_{soil} are taken from [7]. The heating medium output temperature is chosen equal to 35 °C, which completely satisfies the requirements of the floor heating system.

The heat pump brand is chosen according to its rated capacity P_{HP}^{0}, sufficient to compensate for the maximum heat load of the building in a cold five-day period = $P_{TL}^{max} = 16\,\text{kW}$. This takes into account the limited period of its operation due to possible power outages three times two hours during the day. Then the rated power must correspond to the value

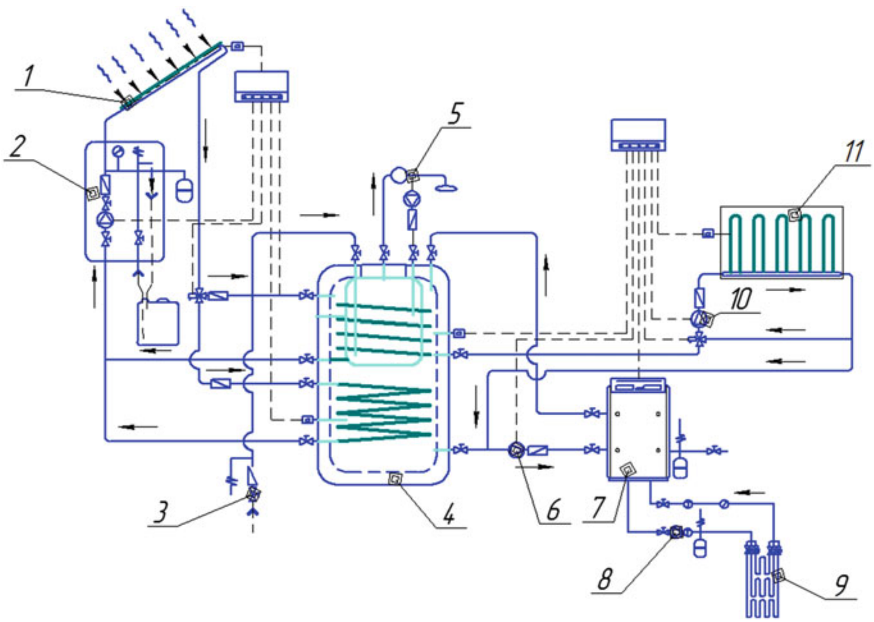

Fig. 2 Hybrid scheme of heat supply in the solar installation and heat pump: 1—solar collectors; 2—pump group and control unit; 3—tap water inlet; 4—universal heat exchanger-heat accumulator; 5—the mixer; 6, 8, 10—circulation pumps of circuits 7—heat pump; 9—screw heat exchanger; 11—panel (floor) heating device

$$P_{HP}^{0} \geq \frac{24 \cdot P_{TL}^{max}}{18+2} = 1.2P_{HP}^{max}$$
$$P_{HP}^{0} = 1.2 \cdot 16 = 19.2\,\text{kW}. \tag{20}$$

Two in the denominator are introduced as an amendment to the thermal inertia of the house.

The received value of thermal power corresponds to the pump BW110 with the corresponding energy and performance characteristics. The current average monthly operating modes of the selected heat pump—thermal $P_{HP}^{\mathcal{M}}$ and electrical P_{HP}^{M} power and conversion factor ε^{M}—are set from the operating characteristics in accordance with the monthly average soil temperature.

The average daily τ^{d} and monthly τ^{M} the heat pump operation duration is calculated by dividing the average monthly heat load Q_{TL}^{M} (in kW hours) which are given in Table 2, the current capacity of the heat pump, is determined from its performance [8, 9, Fig. 3.11, p. 64], taking into account the number of days n in the month:

$$\tau^d = \frac{24 P_{TL}^M}{P_{HP}^M}; \quad \tau^M = n\tau^d, \mathrm{h}. \tag{21}$$

For example, in January, these values are

$$\tau^d = \frac{24 \cdot 11.03}{20} = 13.2;$$
$$\tau^{\mathcal{M}} = 31 \cdot 13.2 = 409.2\,\mathrm{h}.$$

The daily and monthly values duration of the pump were determined.

Monthly and annual electricity consumption for driving the heat pump is calculated by formulas

$$\begin{aligned} W_{\mathrm{el}}^{\mathrm{M}} &= \tau^{\mathcal{M}} P_{el}^{\mathcal{M}}; \\ W_{\mathrm{el}}^{\mathrm{M}} &= 409.2 \cdot 5.9 = 2414.3\,\mathrm{kW} \end{aligned} \tag{22}$$

$$\begin{aligned} W_{\mathrm{el}}^{\mathrm{p}} &= \sum_{\mathcal{M}=3}^{10} W_{\mathrm{el}}^{\mathrm{M}}; \mathrm{kW\,h} \\ W_{\mathrm{el}}^{\mathrm{p}} &= 2414.3 + 2029.6 + 2054.4 + 741.0 + 279.0 + 235.0 + 189.1 + 189.1 \\ &\quad + 201.3 + 936.0 + 1467.9 + 2194.8 = 12931.0\ \mathrm{kW\,h} \end{aligned} \tag{23}$$

The temperature regime of the floor is regulated by changing the flow rate of the heat transfer medium G_{HP} with the temperature difference Δt (input t_{hw} = 35 °C and output, inverse t_{reverse} = 30 °C):

$$\Delta t = t_{hw} - 30\,^{\circ}\mathrm{C} = 45 - 30 = 15\,\mathrm{gon}.$$

The circulation pump selection for the water heating circuit is made at the flow rate of the heat carrier at the heat pump maximum power:

$$G_{HP} = \frac{P_{HP}^{max}}{c_p \cdot \Delta t} = \frac{22.0}{4.19 \cdot 15} = 0.35\,\mathrm{kg/s}. \tag{24}$$

To estimate the necessary heat removal capacity of the soil, the maximum value of the thermal power of the heat pump is divided by its corresponding value

$$P_{\mathrm{soil}} > P_{HP}^{max} - P_{el} = P_{HP}^{max} - \frac{P_{HP}^{max}}{\varepsilon_{max}^{\mathcal{M}}} = 22.0 - \frac{22.0}{3.6} = 17.9\,\mathrm{kW}. \tag{25}$$

The area of the land plot for the soil heat selection is determined by dividing the required heat removal capacity of the soil P_{rp} (determined in *W*) by the specific heat output of the soil q_{soil}, in W/m^2:

$$S_{\text{гр}} > \frac{P_{гр}}{q_{гр}} = \frac{17900}{20} = 895\ m^2. \tag{26}$$

The polyethylene pipe length with a diameter of 25 mm, which will ensure an effective selection of soil heat, is calculated through the specific length of heat removal, permissible for 1 m^2 of the area L_0=1.7 m/m^2:

$$\begin{aligned} L &\geq S_{\text{soil}} \cdot L_0 \\ L &= 895 \cdot 1.7 = 1521\,\text{m}. \end{aligned} \tag{27}$$

In the case of laying the pipeline in zigzag, the distance between two parallel branches can not be less than 0.6 m. To ensure an acceptable level of hydraulic resistance, the one branch length of the pipeline is chosen not to exceed 100 m.

3 Summary

In the article the power supply scheme of the private house is developed for the Western Ukrainian region conditions with the energy usage of sun and thermal energy of soil.

The annual thermal load of the system is estimated at 128,765 MJ.

The heat load of the hot water supply system has been determined, and an electric heater with a capacity of 5.3 kW is provided as a backup source of hot water.

The average monthly capacity of the heat supply system and the maximum heat loss capacity in the cold five-day period of the year, which is 16 kW, are calculated.

The calculations allowed to substantiate the necessary of solar collectors' total area, which is 8.34 m^2. Five thermal solar collectors are selected for the given conditions.

The parameters were calculated and the heat pump with the nominal power of 19.2 kW was selected.

To drive the heat pump, the annual electricity consumption will be 12,931 kW per hour.

The proposed hybrid system of heat supply for a private house with the solar energy usage and soil heat can save more than 5 thousand cubic meters of natural gas per year, which will bring the corresponding economic effect. The payback period of the necessary additional capital investments is just over 6 years.

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