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Optimization for the Equipment in Combined Heating Systems

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Abstract

The article discusses the prospects for using various types of renewable energy sources for continental climate conditions (on the example of the Zabaikalye Territory). It is determined that the most efficient is the use of solar energy for the heating needs. The method for optimizing the composition of the equipment in combined heating systems, which allows quick determination of the optimal amount of solar collectors without reusability of complex astronomical calculations needed to determine the exact position of the Sun in the required time. Application of the developed methodology in conducting energy audit of heating supply objects can reasonably represent the technical and economic advice on the implementation of renewable energy sources.

Keywords: non-traditional power source, solar installations, power supply, solar energy

1. Introduction

1.1 Continental Climate Characteristic of the Russian Federation

Climate of the biggest territory of Russia can be characterized as continental. The substantial part is located in the areas of extreme continental climate (e.g. the Zabaikalye Territory). The average temperature of the coldest month is -26.6℃, the minimal temperature can reach -55℃. The average temperature of the hottest month is +18.8℃, the maximum temperature can reach +55℃. The quantitative indicator of the climatic features of regions can serve as an integral characteristic of the heating season. It is estimated by the sum of average monthly temperature differences of indoor and outdoor air during the heating period (Batuhtin, A. G., 2014; Batuhtin, A. G., 2013; Semenov, B. A., 2002). The average value of this indicator in Russia is 5000℃ · day, which is almost 2 times higher than in Denmark and the United States. This value is higher than the value for most northern European country - Sweden (4017℃·day.) (Department of Energy of Denmark, 1993). In this case, integral characteristic of the regions of Siberia with extreme continental climate are much higher and reach 12045℃·day for Oimjakon (Semenov, B. A., 2002).

1.2 The Problem of Low Efficiency of Heat Supply Systems of the Russian Federation

Harsh climatic conditions predetermine widespread central heating systems in Russia. The efficiency of using the fuel burned in central heating systems of the Russian Federation is extremely low. According to (SNiP 23-01-99 - RF), the average unit cost of primary energy carrier (fuel) for heating buildings in the heating system during the heating season in Russia as a whole is 55 kg t.c./m^2 (1.528 MJ/m^2), and for areas with extreme continental climate (eastern Siberia, Yakutia and the Zabaikalye Territory) - 110 kg t.c./m^2 or more (Matrosov Yu. A., 1994). For comparison, the corresponding figures of energy consumption of buildings in Germany are estimated to be 34 kg t.c./m^2 (944 MJ/m^2), in Sweden and Finland - the value of 18 kg t.c./m^2 (500 MJ/m^2) (Semenov, B. A., 2002). Multiple excess of unit costs determines the urgency of the problems in energy conservation and the need to reduce fuel consumption in existing heating systems and during their development (Goryachikh, N. V. et al., 2010). Currently, some installations of traditional and renewable energy are close in terms of their cost, while the renewable energy has significant advantages in energy and environmental efficiency (Bass, M. S., & Batuhtin, A. G., 2011). Without them, it is impossible to perform the introduction of targets to improve energy efficiency inherent in long-term programs and the relevant laws of the Russian Federation (Government of the Russian Federation, 2010, the President of the Russian Federation, 2008, the President of the Russian Federation, 2009). Assessment of prospects for using alternative energy sources in the continental climate of Russia (on the example of the Zabaikalye Territory) is provided in this article.

1.3 Overall Assessment of the Potential of NTRE Sources (Non-Traditional and Renewable Energy) in the Zabaikalye Territory.

Renewable energy sources are the sources based on existing or constantly recurring processes in nature, as well as the life cycle of the plant and animal world and the life of human society (Ministry of Regional Development, 2007)

The main types of renewable energy include the following:

1. Geothermal energy.
2. Tidal energy.
3. Biomass energy.
4. Water energy (mini-HPP).
5. Wind energy.
6. Solar energy.

Geothermal energy.

Geothermal springs in the Zabaikalye Territory are located in the Kalar district, their energy potential is underexplored. The area is sparsely populated. The prospects for being a source of heat and electricity supply from the geothermal energy require a detailed feasibility study.

Tidal energy.

The absence of sea or ocean coast in the Zabaikalye Territory makes it impossible to use this type of energy.

Biomass energy.

Biomass energy is a promising direction of development in the field of alternative energy industry in the Zabaikalye Territory, especially the gasification of wood wastes. The main problem is the high moisture content of raw material, which requires additional energy for drying and preparing the primary substance. Technical and economic benefits shall be determined based on this factor. In addition, the greatest effect from this method can be achieved on large wood-processing industries. The evaluation of all possible factors requires a pilot project. Using its example will give the chance for evaluation in practice of the pros and cons of the technology.

As for the production of biogas technology, China is one of the world leaders and cooperation of the Zabaikalye Territory, as the border area, with China in this area is very promising. The main factor for obtaining significant technical and economic effect is the presence of large agro-industrial complexes with significant quantities of organic waste.

Water energy (mini-HPP).

The main limiting factors of widespread implementation of these energy sources in the Zabaikalye Territory are the duration of the winter period and preservation of this equipment. Because nearly half of the year, the rivers in the region are covered with ice, the number of hours of equipment use is low. In addition, during the period of maximum power consumption, this equipment will not work, resulting in a long payback period. Furthermore, an additional power source for equipment downtime will be required.

The most rational is using this type of energy for the seasonal works, e.g. gold mining cooperatives.

Wind energy.

When choosing a wind turbine type, it is necessary to consider the weather conditions and terrain. The Zabaikalye Territory, due to the rugged terrain and the presence of Lake Baikal, is characterised by the well-developed local winds. It means that both in the mountains and on the coast of Lake Baikal are distinct for phoenes, which cause thaws and snow cover loss in winter, and temperature increase and humidity decrease in summer. The warm periods are characterised by the developed local mountain-valley winds. The area, adjacent to Lake Baikal, is characterized by local winds in summer and spring from the lake to the land, and in winter, the winds blow in the opposite direction.

Traditional wind turbines start operation at wind speeds above 3 m/s, leaving the nominal performance at speeds of 10-16 m/s (Li, H., & Zhe, C., 2008). The average wind speed in the Zabaikalye Territory in recent years is 1.7 m/s with an average maximum of 5.3 m/s, which does not allow these wind turbines to work throughout the year with normal values.

A significant disadvantage of autonomous wind power is the presence of storage batteries in the circuit, as the life cycle of these batteries is 3-5 years. Their cost comprises from 30 to 50% of the cost of wind power installation, which leads to a significant rise in price for this type of a renewable energy source.

Solar energy

The main ways of using solar energy is to convert it into electricity and heat (Sébastien, A., & Michael, R., 2012).

Today, the most effective way to use solar energy is solar heating of water using solar collectors of various types (E. Mohseni-Languri, et al., 2009, A. Saxena, et al., 2013, Ebru Kavak Akpinar and Fatih Kocyigit, 2012). The lack of widespread use of this technology in Russia is due to the misconception that the possibility of collecting solar energy is directly related to the ambient temperature. In fact, the power of solar collectors depends on the intensity of solar radiation, air transparency and the day length (Batuhtin, A. G., & Batuhtin, S. G., 2009). This provision gives the prerequisites for the use of solar collectors in the Zabaikalye Territory, which has considerable number of cloudless days and the maximum value of solar activity in Russia.

Solar activity in the Zabaikalye Territory (ZT) in the maximum month is not much higher than, for example, in Krasnodar, and the value of total solar radiation is significantly higher (Bass, M. S. et al., 2012). This is because the quantity of solar activity in ZT is significantly higher than in other regions during the winter months. This fact, along with the highest total solar activity value for the year gives considerable promise for using solar heating in heating systems.

Table 1 presents a comparative analysis of solar radiation intensity on a number of regions (Bass, M. S. et al., 2012). Table 1 shows that the solar activity in the Zabaikalye Territory (ZT) in the maximum month is not much higher than, for example, in Krasnodar, and the value of total solar radiation is significantly higher. This is because the quantity of solar activity in ZT is significantly higher than in other regions during the winter months. This fact, along with the highest total solar activity value for the year gives considerable promise for using solar heating in heating systems.

Table 1. Intensity of solar radiation

No. No.	City	The value of the average radiation per day in the most intense month kW·h/m^2 per day	Month of maximum radiation	The total solar radiation per year, kW·h/m^2
1	Volgograd	5.95	June	1170
2	Irkutsk	5.2	May	1128
3	Kiev	6.0	May	1198
4	Krasnodar	6.2	June	1344
5	Moscow	5.15	May	962
6	Chita	6.3	June	1531

The magnitude of rainfall in the ZT is significantly below average within Russia. This is typical for the winter months. Low snowy winters (and a very low value of annual rainfall) allow minimizing the operational costs in the operation of solar heating systems in the winter months and significantly improving their performance compared with other solar regions of Russia.

The use of solar collectors for heating and hot water in the Zabaikalye Territory is connected with certain difficulties. The main one is the very low temperature of the ambient air in winter (design outdoor air temperature for heating and ventilation systems -38^0C and average heating temperature is -11 ^0C).

There are currently a number of different schemes for using solar energy in the hot water supply and water heating. Warm air heating of premises based on different types of heat sources makes it possible in many cases to reduce significantly capital and operating costs. In the harsh continental climate, the most justified is the use of solar energy to heat the air. Solar heating using various types of solar collectors for air heating systems will significantly increase the effectiveness of such systems, as well as increase the degree of substitution for the traditional sources of heat. Such systems heat air or water depending on the temperature, or joint heating of the water is made for heating hot water supply and air for heating. Since our ultimate goal is heating the air in the room, it is precisely such complexes can achieve the maximum efficiency by eliminating all intermediate processes and transformations (Batuhtin et al., 2009; Batuhtin, A. G. & Kalugin, A. V., 2011).

Air collectors are mainly used in conditions of Canada similar to the Russian conditions. Currently, the most efficient designs of flat solar collectors are developed by the company of Conserval Engineering Inc in conjunction with a number of Canadian research centres. The average annual efficiency of the best examples is as follows: Efficiency = 35-60% (SolarWall, 2008), at sufficiently low coefficient of heat transfer (Tabish et al., 2014; Smith et al., 2012; Thianpong et al., 2012). The leader in the implementation of solar heating of air in the Asian market is the company of "Himin", using vacuum capillary heat pipes for air heating (national patent 1 NO. 200820123062.7). These schematics are not widely used due to the low efficiency values (passport average heating efficiency is 50%; average annual is less than 30%) at a high cost. Recently, there were developed air-water solar collectors with an average year conversion efficiency of solar energy of more than 65%, due to the benefits of gaseous and liquid heat carriers and as a result, year-round load of radiant heat absorbing surface (RF patent No. 2403511). Universality of the system causes a wide scope of their application: from cottage houses to heating giant industrial buildings and greenhouses. The majority of the advantages of this scheme is only possible when using unfreezing liquids in solar collectors. Air heating can be performed in a heat interchanger from the intermediate liquid heated both in the manifold, and directly in the interchanger. The produced feasibility study on the use of solar heating systems demonstrated that the conditions for the Zabaikalye Territory, the payback period is in the range of 9-11 years. A larger value corresponds to a lower heating load of the building.

Solar photovoltaic installations carry out direct conversion of solar energy into electricity via solar cells.

Their main disadvantage is the low power output from the area of photovoltaic panels. Therefore, huge areas are required to obtain a significant amount of electricity.

2. Methodology

2.1 The Method for Optimizing the Proportion of Replacing Power at the Base Source of Power Supply by Solar Heating Units

As shown above, the most reasonable way to use renewable energy sources in a continental climate is solar heating of water using solar collectors of various types.

Technical and economic characteristics of solar power plants depend mainly on the following factors: climatic conditions of the area under consideration, determining the amount of generated energy (solar radiation, cloudiness, number of sunny days per year, etc.); specific investments in solar installation; availability and cost of the spent fuel and energy. Low density of solar energy distribution in the territory, the volatility of energy supply in time, the dependence on climatic conditions determine the increase in the size of solar power and complexity of their designs, which in turn causes an increase in specific capital investments and consumption of materials in the construction of solar power plants.

An important factor in the cost-effectiveness of renewable energy is the proportion of replacing power base power supply. When choosing the number of solar collectors (hereinafter SC), one shall take into account the two important factors - the maximum heating load of the consumer and reliability of solar heating systems. If solar energy is the only source of heat, it is required to install a large number of both SC and heat storage tanks that are guaranteed to provide the consumer with the maximum load in the absence of solar radiation. In this case, during the biggest part of the heating period, the equipment shall be operated at partial power. Consequently, this approach is inefficient and SC shall be combined with the heat power sources, in particular with electric boilers. The goal of the methodology is the feasibility in determining the optimal number of SC carrying the base load with additional heating of the heat carrier in the boiler. The optimality criterion is the minimum payback period of heating.

Determining the optimal number of collectors shall be made in the following order:

1. Calculation of the heat of the object by month.

2. Determination of the amount of incoming solar energy.

3. Selection of the required number of solar collectors for different values of the proportion of replacement heat consumption with the heat from the solar collectors and the determination of the optimal quantity.

Determination of the heat of the object by month.

Heating consumption is determined based on the calculation of heat loss through the building envelope, for a given heat load depending on the ambient temperature or heat meter readings.

$$Q_{м}^{i} = Q_{p} \cdot \frac{t_{в}^{p} - t_{взд}^{н}}{t_{в}^{p} - t_{взд}^{н.р.}} \cdot \tau_{м}, \quad (1)$$

where Q_p - is the heat load of the building, kW;

$t^{p}_{в}$ - is the design temperature inside the building, °C;

$t^{н.р.}_{взд}$ - is the design outdoor temperature, °C;

$t^{н}_{взд}$ - is the average outdoor temperature, °C;

$\tau_{м}$ - is the number of operation hours of the heating system, h

Determination of the amount of incoming solar energy.

Determination of the amount of incoming solar energy requires specific data calculated by region:

E – is the total solar radiation (direct and indirect) on a horizontal surface under cloudless skies MJ/m^2;

$E_{в}$ – is the total solar radiation (direct and indirect) on a vertical surface under cloudless skies MJ/m^2;

E_0 – is the average daily arrival of solar radiation on a horizontal surface outside the earth's atmosphere, MJ/m^2.

Then, based on the data, it is possible to determine the ratio of average monthly inflows of daily total radiation on inclined and horizontal surfaces

$$R = (1 - \frac{E\partial}{E}) \cdot R_n + \frac{E\partial}{E} \cdot \frac{1+\cos\beta}{2} + \rho \cdot \frac{1-\cos\beta}{2}, \quad (2)$$

where $E\partial$ - is average daily arrival of diffuse radiation (scattered radiation) on a horizontal surface;

R_n - is the ratio of average monthly inflow of direct radiation onto inclined and horizontal surface;

β - is the collector inclination angle to the horizon, deg;

ρ - is the coefficient characterizing soil reflectivity (from 0.2 to 0.7).

The ratio $\frac{E_\partial}{E}$ is a function of the coefficient K_m (Saransk, 2004):

$$\frac{E_\partial}{E} = 1{,}39 - 4{,}03 \cdot K_m + 5{,}53 \cdot K_m^2 - 3{,}11 \cdot K_m^3, \quad (3)$$

where $K_т = E/E_0$.

The average daily inflow of total solar radiation on a horizontal surface equals to $E_к = R \cdot E$.

As the collector cannot be installed not perpendicular to the sun's rays, it is necessary to use the method by (Vissarionov V. I., et al., 2008). The angle of ray incidence on the location of the site arbitrarily inclined to the horizon at an angle β and oriented to the north at an angle γ:

$$i = \arccos((A - B) \cdot \sin(D_{ecl}) + (C \cdot \sin(HA) + (D + E) \cdot \cos(HA)) \cdot \cos(D_{ecl})), \quad (4)$$

where

$A = \sin(lat) \cdot \cos(\beta)$;

$B = \cos(lat) \cdot \sin(\beta) \cdot \cos(\gamma)$;

$C = \sin(\beta) \cdot \sin(\gamma)$;

$D = \cos(lat) \cdot \cos(\beta)$;

$E = \sin(lat) \cdot \sin(\beta) \cdot \cos(\gamma)$;

D_{ecl} - The Sun inclination, in degrees;

HA - Meridian angle;

lat - Latitude in degrees;

Then the power of direct solar radiation on an inclined area is defined as follows:

$$I_S = I_S^{ид} \cdot \cos(i). \quad (5)$$

The ratio $\frac{I_S}{I_S^{ид}}$ indicates the efficacy of the pad orientation by direct radiation and can be calculated both for the given moment (in this case coincides with the value of cos(i)), and for days or months.

A more accurate calculation shall take into account the characteristics of the heat exchanger and the storage tank using the method (Batuhtin A. G., 2010).

When calculating for the storage tank, the input data are as follows: tank parameters, costs for intermediate heat carrier and tap water, the temperature of the intermediate coolant at the tank inlet.

The calculation starts with the definition of tubes flow section:

$$f_{mp} = 0,785 \cdot d_B^2 \cdot z \, , \tag{6}$$

where ***d_B* – is the inner tube diameter, mm; *z* – q-ty of tubes.**

Next we define the cross-section of tubular annulus:

$$f_{м} = 0,785 \cdot (D_B^2 - z \cdot d_H^2) \tag{7}$$

and the equivalent diameter of the tubular annulus:

$$d_{экв} = \frac{D_B^2 - z \cdot d_H^2}{D_B + z \cdot d_H} \, , \tag{8}$$

where ***$d_н$* – is external tubes diameter, mm;**

***$D_в$* – is internal case diameter** of the storage tank, mm.

Then the velocity for heat carrying and heated mediums is defined:

$$\omega_T = \frac{G_T}{3600 \cdot f_{mp}} \, , \tag{9}$$

$$\omega_м = \frac{G_м}{3600 \cdot f_м} \, . \tag{10}$$

where ***G_T* – is the flow for heat carrying medium, m³/h;**

***f_{mp}* – is the tubular space area, m²;**

***G_M* – is flow for heated medium, m³/h;**

***$f_м$* – is the tubular annulus area, m².**

Using the known velocities of the medium and the average temperature of the corresponding heat carriers, heat transfer coefficients for heat carrying and heated mediums are determined:

$$\alpha_1 = (1400 + 18 \cdot T - 0,035 \cdot T^2) \cdot \frac{\omega_T^{0,8}}{d_B^{0,2}} \, , \tag{11}$$

$$\alpha_2 = (1400 + 18 \cdot t - 0,035 \cdot t^2) \cdot \frac{\omega_T^{0,8}}{d_B^{0,2}} \, , \tag{12}$$

where T – is the average temperature of the heating water, K;

t – is the average temperature of the heated water, K.

Known α and tubes characteristics, heat transmission coefficient k can be determined. After that, the transferred heat amount can be determined:

$$Q = \mu \cdot k \cdot \Delta t_{cp} \cdot F, \tag{13}$$

where μ – is the coefficient taking into account the scale and dirt of the heater tubes;

Δt_{cp} - is the mean log temperature difference is determined by the method of successive approximations, °C;

F – is the heat exchange surface area, ***m²***.

Knowing the amount of the transferred heat, one can find the heat carriers temperature at the outlet of the heat exchanger:

$$T_2 = T_1 + \frac{Q}{G_T \cdot c_{p(T)}}, \tag{14}$$

$$t_2 = t_1 + \frac{Q}{G_M \cdot c_{p(M)}}, \tag{15}$$

where T_1 and t_1 are respectively the temperature of heat carrying and heated heat carrier temperature at the inlet to the heat exchanger, ºC.

Since the storage tank has a volume of accumulated fluid, it is necessary to determine the average temperature of tap water at the outlet of the considered time and the average temperature in the tank at the beginning of the next time:

$$t_б = \frac{G_м \cdot \tau \cdot t_2 + V_б \cdot t_б^н}{G_м \cdot \tau + V_б}, \tag{16}$$

Where $V_б$ – is the tank volume, ***m³***;

$t_б^н$ - is the initial temperature in the storage tank, °C.

Determination of the solar collectors' number

The optimal amount of solar collectors will match the ratio of electricity and solar heating with a minimum payback period of additional capital investments.

1) The amount of heat coming from the solar collectors in the past month, kW·h:

$$Q^i_{с.к.} = n_к \cdot F_к \cdot \eta_к \cdot E^i_к, \tag{17}$$

where $n_к$ – is the number of collectors;

$\eta_к$ - The efficiency of the solar collector;

$F_к$ – is the unit surface area of the collector receiving solar energy, m².

2) Determining the cost of electricity spent by the electric boiler:

$$П^i_с = ц_{ээ} \cdot (Q^i_м - Q^i_{с.к.}), \tag{18}$$

where $ц_{ээ}$ – is the electricity cost, RUR/kW.

Since the value of $П_с^i$ in the summer months due to the excess of the value of $Q^i_{с.к.}$ on $Q^i_м$ can be negative, it is necessary to apply the Heaviside function for zeroing negative values.

$$П^i_с = \begin{cases} 0, П^i_с \le 0 \\ П^i_с, П^i_с > 0 \end{cases} \tag{19}$$

3) The optimality criterion is the minimum payback time considering the time factor. In this case, the costs of reconstruction are defined as follows (Batuhtin A. G., 2014, Batuhtin et al., 2014):

$$И=n_к \cdot ц_к+ц_{монт}+ц_{арм}+ц_{ант}+ц_{б.ак}+ц_{авт},$$

where $ц_к$ - is the solar collector cost; $ц_{монт}$ - is the installation costs; $ц_{арм}$ - is the reinforcement cost; $ц_{ант}$ - is the non-freezing heat carrier cost; $ц_{б.ак}$- is the storage tank cost; $ц_{авт}$ - is the automation cost.

The first four components are dependent on the number of solar collectors, the latter two - are not.

The payback period is defined as follows

$$T_{ок}=\frac{И}{Э}, \tag{20}$$

where Э – is cost savings during the installation of solar collectors.

For the conditions of the Zabaikalye Territory, there were developed analytical dependences which allow large simplification of the determining the optimal composition of the equipment in the combined system.

In the Zabaikalye Territory, the complex $\theta=\dfrac{t_в^р-t_{взд}^н}{t_в^р-t_{взд}^{н.р.}}$ during the year is shown in Figure 1.

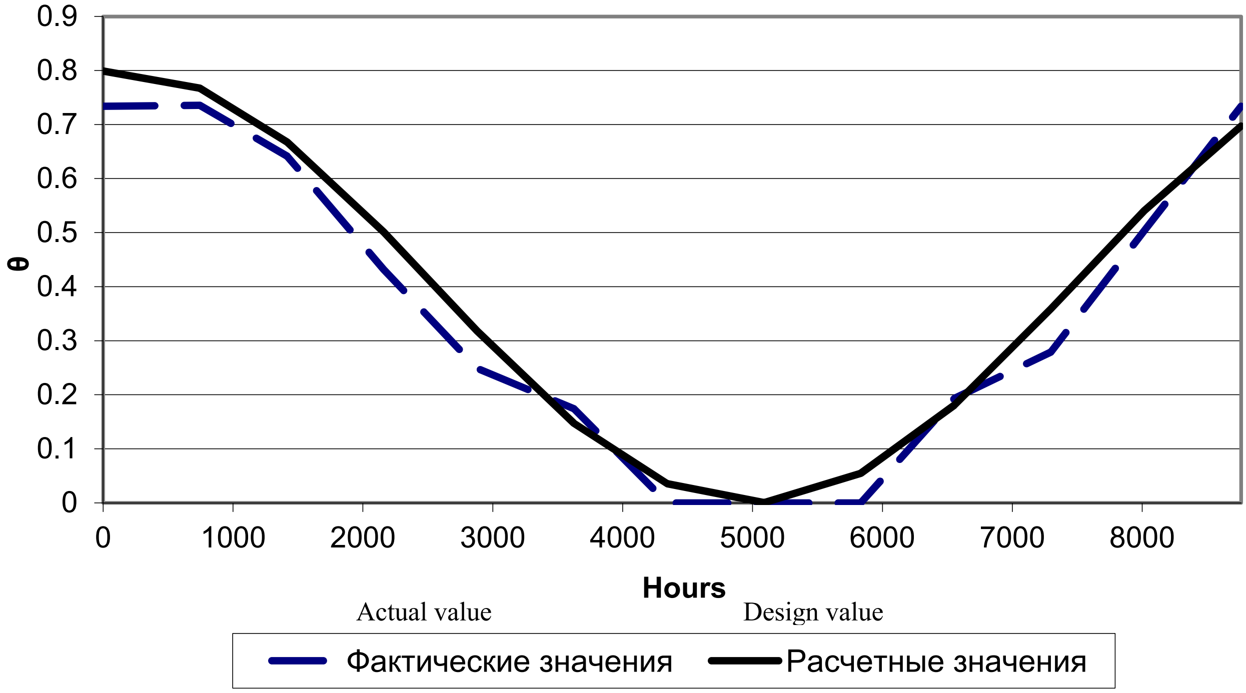

Figure 1. The values of the complex θ during the year to the conditions of the Zabaikalye Territory

Complex θ dependence on time for any object with sufficient precision can be described by the following empirical formula:

$$\theta=a+b\cdot\sin\left(\frac{2\cdot\pi\cdot\tau}{d}+c\right), \tag{21}$$

where τ - is time, h; a, b, c, d - are the empirical coefficients.

For the Zabaikalye Territory: a=0.4; b=0.4; c=1.5; d=9793.

The average daily inflow of total solar radiation on a horizontal surface $E_к$ are quite accurately described by the formula (20), where the coefficients are as follows a=185.5; b=42.6; c=3.9; d=4022.

Thus, the amount of heat required by the consumer for heating the premises based on the equations (1) and (5) shall look as follows:

$$Q^{i}_{м} = Q_{р} \cdot \; (0.4+0.4 \cdot \sin(\frac{2 \cdot \pi \cdot \tau_i}{9793} + 1,5)) \cdot \tau_{м}. \quad (22)$$

The amount of heat coming from the solar collectors in the past month, shall be defined as follows:

$$Q^{i}_{с.к.} = n_{к} \cdot F_{к} \cdot \eta_{к} \cdot (185,5+42,6 \cdot \sin(\frac{2 \cdot \pi \cdot \tau_i}{4022} + 3,9)). \quad (23)$$

In the absence of hot water supply on-site, the question of heat recovery in the summer months is of high importance. Dependence of the time of heat consumption with a considerable degree of accuracy can be determined according to the method by (Bass M. S., et al., 2009) by the formula:

$$\frac{Q_{месяц}}{Q_{год}} = \left[\cos\left(\frac{\tau - \tau_{\max}}{T} 2 \cdot \pi \right) + 1 \right]^{a} \cdot \frac{Q_{\max}}{2 \cdot b \cdot Q_{год}} + q_{гвс} \quad (24)$$

where $\tau_{\max}$ - is the time by which the highest load of boiler $Q_{\max}$ is achieved, T - is the year duration, $q_{гвс}$ - is the proportion of generated heat that goes to the hot water supply, a and b - are the empirical coefficients.

Sufficient accuracy is achieved at a=3/2 и b=1.35. The dimension of time can be any - months, days, hours.

2.2 Example for Optimizing the Proportion of Replacing Power at the Base Source of Power Supply by Solar Heating Units

The example of application for the developed methods, Tables 2-3 present the results of calculations of the optimal number of solar collectors for combined heating systems of the two-way car border crossing point "Olochi". Design characteristics of the object were identified because of the energy audit.

Table 2. Heat consumption of an object

Month	Ambient air temperature, C	Design internal air temperature, C	Design ambient air temperature, C	Designed heat load, kW	Heat load, kW	The number of operation hours of the heating system, h	Heat consumption, Q^{i}_{month} kW*h	Heat consumption, Gkal
January	-24	18	-38	21	15.750	744	11718	10.08
February	-19	18	-38	21	13.875	672	9324	8.02
March	-7.9	18	-38	21	9.713	744	7226	6.21
April	1.8	18	-38	21	6.075	720	4374	3.76
May	5.75	18	-38	21	4.594	384	1764	1.52
September	4.75	18	-38	21	4.969	360	1789	1.54
October	0.2	18	-38	21	6.675	744	4966	4.27
November	-11.7	18	-38	21	11.138	720	8019	6.90
December	-23.9	18	-38	21	15.713	744	11690	10.05
Year		18	-38	21		5832	60870	52.35

Table 3. Characteristics of the incoming solar radiation

Month	E /3/, MJ/m^2	Ev /3/, MJ/m^2 N	NE/NW	E/W	SE/SW	S	n, day	E^*_0, MJ/ (m^2·day)	E_0, MJ/m^2
January	164			143	371	495	31	9	279
February	270			210	424	566	28	14.5	406
March	528		152	365	572	692	31	22.3	691.3
April	678	110	243	459	557	558	30	31.2	936
May	850	176	332	512	573	497	31	38.1	1181.1
June	880	206	370	512	514	427	30	41.2	1236
July	882	212	340	518	511	452	31	39.6	1227.6
August	719	130	268	457	542	520	31	33.8	1047.8
September	540		191	371	530	584	30	25.4	762
October	344		110	263	490	611	31	16.7	517.7
November	194			166	392	543	30	10.3	309
December	126			121	305	475	31	7.6	235.6

* For the conditions of 50 degrees latitude.

The calculations determined the optimal number of solar collectors equal to 10 (when the unit collector area equals to 1.38 m^2) with a minimum payback period of about 8 years (Figure 2).

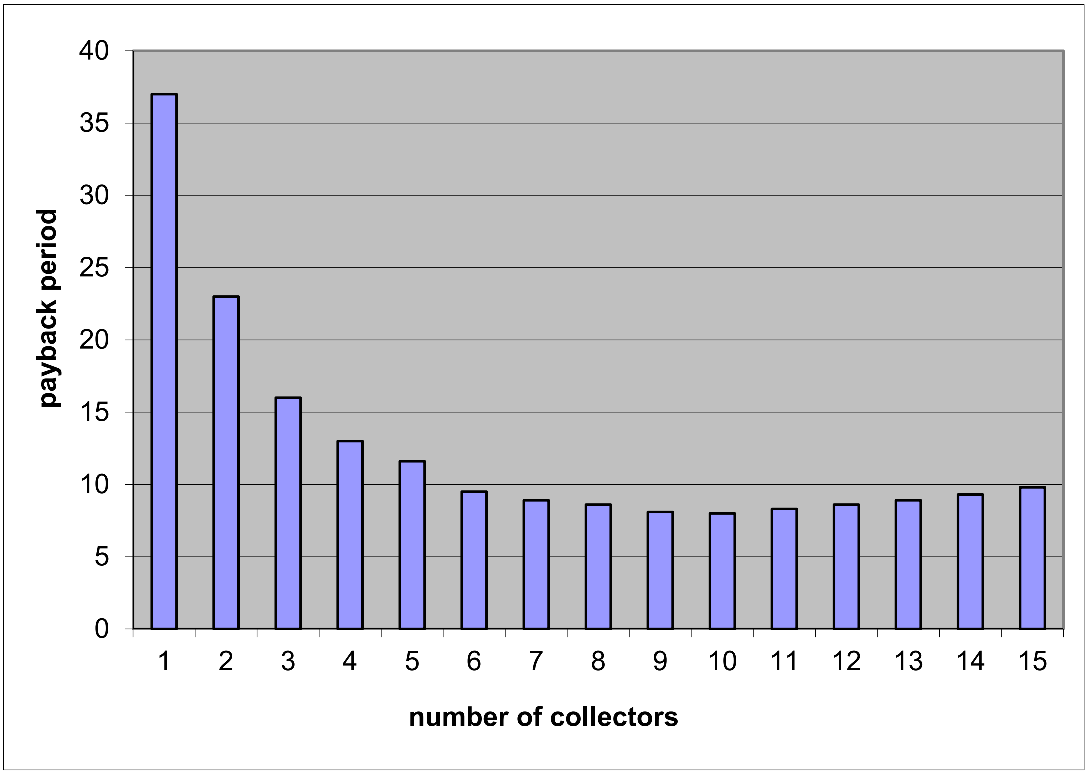

Figure 2. The optimal amount of solar collectors for heating system conditions in TWCBCP "Olochi"

3. Discussion and Conclusions

The article discusses the prospects for using various types of renewable energy sources for continental climate conditions (on the example of the Zabaikalye Territory). The main types of renewable energy sources for the region include the following:

1. Geothermal energy.
2. Biomass energy.
3. Water energy (mini-HPP).

4. Wind energy.
5. Solar energy.

It is determined that the most efficient is the use of solar energy for the heating needs. The estimation of solar activity in the Zabaikalye Territory in comparison with a number of regions of the former USSR is characterized by high solar activity.

The method for optimizing the composition of the equipment in combined heating systems, which allows quick determination of the optimal amount of solar collectors without reusability of complex astronomical calculations needed to determine the exact position of the Sun in the required time. This methodology is based on obtaining the integral characteristics of thermal loads and tributaries of useful operation of solar radiation based on determining the heat consumption of the object by months. High solar activity is characterised with high unevenness during the year, and in the summer months, the excess heat is generated. Mathematical interpretation of this excess needs the application of the Heaviside function for zeroing negative values. The analytical dependence has a high degree of convergence with the real data.

Application of the developed methodology in conducting energy audit of heating supply objects can reasonably represent the technical and economic advice on the implementation of renewable energy sources.

The produced calculation of the optimal amount of solar collectors for heating supply of an operative object (TWCBCP - two-way car border crossing point "Olochi") demonstrated that the payback period of renewable energy installations is largely dependent on the proportion of rational choice of replaced power. The payback period of the installation of solar collectors ranged from 37 to 8 years. Such a large variation of key performance indicators of investment determines the relevance of the present study and the need for careful calculations to optimize the structure of the equipment in combined heating systems for more efficient use of the potential of renewable energy sources.

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