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Technical and economic evaluation of solar energy in the heat supply system of buildings in Primorsky krai

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Abstract. The heat supply area is of the utmost interest as the priority spheres of solar plants appliance, because nowadays it is the most capacious consumer of traditional energy resources. For the main indicators of solar radiation - the inflow of direct and diffuse radiation, Primorye is not inferior to admitted "solar" regions of the Russian Federation. Currently available information on the cost-effectiveness of non-traditional heat sources based on solar plants is poor and contradictory, but as a rule, nonobjective. Department employees previously carried out the work to assess the cost-effectiveness of solar systems for heating of various buildings and unambiguously established the inadvisability of their application in the area of the stable heating. The results of the cost effective analysis of solar plants, in decentralized heating of buildings for various purposes, demonstrate the futility of investments in the energy saving measures under the current cost of energy resources and equipment and also the absence of real support of consumers, carried out real implementation of alternative energy sources.

1 Introduction

The use of solar radiation for heat supply of buildings of different assignment in Primorsky krai is one of the directions of the pursued policy of rational energy use through energy-saving measures. The attractiveness of the active solar energy usage in the heating systems of buildings primarily is determined by the substantial savings of energy resources for heating, hot water and electricity of consumers in thermal and electrical energy.

Formulation of the problem. To determine the cost-effectiveness of investments in energy-saving activities involved the use of solar radiation for heating supply of various facilities in Primorsky krai. Production of mainly foreign manufacturers of different solar collectors is available for use in heating systems of various buildings in the Primorsky krai. For the main indicators of solar radiation - the inflow of direct and diffuse radiation, Primorye is not inferior to such admitted "solar" regions of the Russian Federation, as Krasnodar, Stavropol and Astrakhan region. In addition, the location of Primorsky krai is southward of 48 ° N and is fully consistent with domestic and foreign recommendations on the feasibility of implementing solar plants in the areas southward of 50 ° N [1-4].

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It is natural that when investing money in the purchase and installation of solar plants buyer expects that it will be economically feasible in the first place, in the eye of "consumer". It was taken most favorable conditions for the solar plants use in the heat supply systems when solving the task:

- a consumer is out of range of effective district heating;
- a consumer is connected to the system of centralized power, but has a limit of required attached electrical load;
- main source of power supply of consumers is an autonomous electric boiler or heat generator with diesel fuel;
- payment for the consumed energy for electric power supply is carried out from the single price;
- economic evaluation is carried out with the "consumer" products.

The calculations were performed for three variants of individual objects with their characteristic heat flows and the relationship of municipal heating loads for buildings of housing-social purpose.

2 Consumers characteristics

Consumer №1. Residential building heated area Ah is 124 m2. Number of people is 4 people. Central floor heating with parameters of heat-exchanger fluid is 45-35 ºC. Sources of heat: the heating system - single-loop electric boiler capacity is 12 kWh; in the hot water system - water heater volume of 150 liter, capacity is 2,5 kWh. The maximum permissible attached electrical load is 20 kWh. As an alternative heat source is diesel generators with heater storage.

Consumer No 2. Office building heated area A_h is 514 m^2. The heated volume of the building V_h is 1413 m^2 Maximum number of hot water consumers (including visitors) is 180 people. Central floor heating with parameters of heat-exchanger fluid is 45-35 ºC. Sources of heat: the heating system - single-loop electric boiler capacity is 36 kWh. In the hot water system - 2 capacitive water heater of 100 liters and 2,5 kWh each. The maximum permissible attached electrical load is 60 kWh. As an alternative heat source is diesel generators with heater storage.

Consumer №3. Medical and health institution building all year-round. Heated area A_h of the building is 610 m^2. The heated volume of the building V_h is 1980 m^3. Central floor heating with parameters of heat-exchanger fluid is 45-35 ºC. Sources of heat: the heating system - single-loop electric boiler capacity 36 kWh; cooking water is carried out with the heater storage of capacity 7,5 kWh. As an alternative heat source is diesel generators with heater storage (Table 1).

Table 1. Levels of operating energy capacity and the calculated heat inflow.

No	Indicators	Symbol	UMeas.	Consumer		
				No 1	**No 2**	**No 3**
1	Calculated hourly heat inflow for heating	Q_h	kWh	7,1	25,2	30,8
	Calculated daily heat inflow for hot water	Q_{ht}	kWh	16,3 (11,6)	41,8 (20,9)	(116,0)
2	Heat inflow for the year of operation: total	Q^Y	kWh	22042	71593	119872
	including:					
	- for heating	Q_h^Y	kWh	18140	64389	81350
	- for hot water	Q_{ht}^Y	kWh	3902	7204	38522

Note. Calculated daily heat inflow for hot water supply facilities identified if they are decentralized heating and average daily consumption of hot water during the year and periods of the year.

2.1 Submitted application conditions of alternative energy sources

Calculations of solar plants in the heat supply system of the concerned buildings are held for two conditions of their operation:
• for heating system and year-round hot water supply of the building;
• year-round hot water supply.

Necessary structural calculations were performed on the example of systems with flat solar collectors.

3 Quantitative characteristics of the solar radiation inflow on the territory of Primorsky krai

The calculation of the required solar collectors surface is based on the quantitative characteristics of the incoming inflow of direct and scattered (diffuse) solar radiation on a horizontal surface [1] shown in Table 3.

Values of solar radiation inflow on a horizontal surface are made according to actinometric observations of Sad-Gorod meteorological station. Values represent the most characteristic features of the solar radiation condition on the territory of the southern districts of Primorsky krai.

According to the solar radiation inflow on a horizontal surface, in correspondence with existing methods [3, 4], it is calculated the solar radiation inflow (direct and diffuse) on the inclined to the horizontal plane of the solar collector.

Analysis of the calculated data of the solar radiation inflow on the inclined surface shows that the most preferred of the declivity angle value of the solar absorbing surface of the plants intended for year-round heating and hot water supply facilities in the Primorsky krai is 49º - 50º.

In these examples, the plant of solar absorbing surface on the horizon is taken at an angle of 49º, both for plants intended for year-round heating, hot water supply of buildings and for plants of the only year-round hot water supply.

3.1 Solar access on the inclined surface

Solar access on the inclined surface I_{PR}, W/m²

$$I_{PR} = I_{HR} \cdot \beta \tag{1}$$

where I_{HR} - Solar access on the horizontal surface, W/m²; β - coefficient depending on the latitude and the declivity angle of the collector to the horizontal, Table 2 [3].

Table 2. Coefficient β at < 49°.

Month											
1	2	3	4	5	6	7	8	9	10	11	12
2,93	2,01	1,48	1,15	0,97	0,89	0,92	1,06	1,32	1,74	2,51	3,36

The density of diffused radiation on the inclined surface I_{PF}, W/m² is determined from the formula:

$$I_{PF} = I_{HF} \cdot (1 + \cos\beta)/2 \quad (2)$$

where I_{HF} - Solar access on the horizontal surface, W/m².

Values of the solar radiation inflow on the inclined surface are shown in Table 3.

Table 3. The solar radiation inflow on a horizontal surface and inclined at an angle of 49 ° to the horizon.

Month	Duration of the solar radiation, hours	24 hours interval, hours	Daily Σ radiation on a horizontal surface, W/m² [1]		Daily Σradiation on an inclined surface, W/m² (Calculated)		
			Direct I_{HR}	Diffuse I_{HF}	I_{PR}	I_{PF}	$I_{PR}+I_{PF}$
Jan.	7	9 a.m - 4 p.m	1263	825	3700	683	4383
Feb.	7	9 a.m - 4 p.m	1786	1136	3589	940	4529
Mar.	8	9 a.m - 5 p.m	2455	1714	3633	1419	5052
Apr.	9	8 a.m - 5 p.m	2414	2025	2776	1676	4452
May	10	8 a.m - 6 p.m	2761	2200	2678	1822	4500
Jun.	10	8 a.m - 6 p.m	2170	2314	1931	1916	3847
Jul.	10	8 a.m - 6 p.m	1964	2197	1807	1496	3303
Aug.	10	8 a.m - 6 p.m	1986	1980	2105	1639	3744
Sept.	10	8 a.m - 6 p.m	2450	1514	3234	1253	4487
Oct.	9	8 a.m - 5 p.m	2003	1147	3485	950	4435
Nov.	8	9 a.m - 5 p.m	1350	786	3388	650	4038
Dec.	7	9 a.m - 4 p.m	1006	747	3380	618	3998

3.2 The reduced intensity of the absorbed solar radiation

To determine the amount of heat received by the absorbed solar surface (aperture) of the plant, the reduced intensity of the absorbed solar radiation is calculated (Table 4).

The reduced intensity of the absorbed solar radiation, W/m²:

$$I_S = (I_{PR} \cdot \theta_R + I_{PF} \cdot \theta_F) \quad (3)$$

where θ_R and θ_F is reduced optical characteristics of the solar collector, respectively, for the direct and scattered solar radiation. For single-glassed cover θ_R =0,74, θ_F =0,63 [2,3].

Table 4. The reduced intensity of the absorbed solar radiation, I_S

1	2	3	4	5	6	7	8	9	10	11	12
3168	3248	3582	3110	3130	2635	2279	2590	3182	3177	2917	2890

4 Heat consumption by the buildings for heating and hot water supply

4.1 Heat consumption for heating of building

Heat consumption for heating of building are appropriate to normative values of ambient air temperatures by months of heating period, kW:

$$Q_{hi} = Q_h \cdot \frac{t_{\text{int}} - t_{hti}}{t_{\text{int}} - t_{ext}} \cdot 24 \cdot n_i \cdot 10^{-3} \quad (4)$$

where Q_h - the calculated heat consumption for heating of building under the project (Tab. 1)
t_{int} - the average temperature inside the heated space in the building;
t_{ext} - assumed temperature for the design of heating t_{ext} = -24 ° C;
t_{hti} - the estimated average outside temperature for the months between the heating and the heating periods of the year (Table 5).

4.2 Heat consumption for hot water supply

The required amount of thermal energy for hot water supply to the consumer on the months of the year, kW:

$$Q_{ht} = 1{,}16 \cdot G \cdot (t_{w2} - t_{w1}) \cdot n_i \cdot 10^{-3} \quad (5)$$

where G - daily consumption of hot water in kg/day (in a residential building the average daily consumption G is 50·4=200 kg/day; in the office building the average daily consumption G is 180·2=360 kg/day);
t_{w2}- required temperature of hot water, t_{w2} = 55ºC;
t_{w1} - cold water temperature by month of the planning period (Table 5);
n_i - the number of days in the month of the planning period, days.

Table 5. Heat consumption by objects at heating and hot water supply.

Month	t_{hti} ^{0}C	n_i,day	Consumer No.1		Consumer No.2		Consumer No.3	
			Q_{hi}, kW	Q_{ht}, kW	Q_{hi}, kW	Q_{ht}, kW	Q_{hi}, kW	Q_{ht}, kW
Jan.	-13,1	31	3971	360	13883	470	16965	3556
Feb.	-9,8	28	3229	325	11210	594	13700	3211
Mar.	-2,4	31	2687	360	9114	657	11137	3556
Apr.	4,8	30	1764	348	5702	657	6970	3438
May	9,9	31(8)	511	313	2252	562	2752	3092
Jun.	13,8	30		323		592	-	3195
Jul.	18,5	31		287		525	-	2835
Aug.	21,0	31		287		578	-	2835
Sept.	16,8	30		278		630	-	2746
Oct.	9,7	31(7)	452	313	2180	592	2664	3092
Nov.	-0,3	30	2357	348	7906	657	9661	3438
Dec.	-9,2	31	3503	360	12142	690	14837	3528
Total			18140	3902	64389	7204	81350	38522

5 Recommendations for determination of the surface area for solar collectors

5.1 Hot water plants

For the first time, the priority should be given to the calculation of the surface area of absorbed solar surface (aperture) of the year-round hot water plants. The calculation is performed in accordance with existing methods [2,3], which recommend the calculated surface of all types of plants with redundant sources to determine according to the month with the highest reduced intensity of absorption solar radiation.

Calculation data of the solar collectors surface, held by month of the planning period, is evidenced by the fact that the required minimum aperture area of the plants of year-round hot water supply in the Primorsky krai comply with the conditions of September.

Heat capacity supply of the hot water solar plant by month of the planning period at the recommended aperture area is shown in Table 6.

Table 6. Calculated aperture area (F_A) by month of the planning period and heat capacity (Q_A) of the plant at the recommendation of its area.

Month	t_{hti} ^{0}C	Efficiency factor, η	Consumer No.1		Consumer No.2		Consumer No.3	
			F_A, m^2	Q_A, kW	F_A, m^2	F_A, m^2	Q_A, kW	F_A, m^2
Jan.	-13,1	0,244	14,4	131	20,0	287	144	1310
Feb.	-9,8	0,292	11,8	146	22,0	318	118	1460
Mar.	-2,4	0,405	7,7	247	14,6	538	77	2470
Apr.	4,8	0,433	8,3	222	16,2	484	83	2220
May	9,9	0,463	6,9	247	13,6	538	69	2470
Jun.	13,8	0,455	8,4	198	14,0	431	84	1980
Jul.	18,5	0,427	9,2	166	19,0	362	92	1660
Aug.	21,0	0,514	9,3	227	15,7	495	93	2270
Sept.	16,8	0,515	5,5	278	12,0*	606	55	2740
Oct.	9,7	0,466	6,8	252	12,5	549	68	2520
Nov.	-0,3	0,35	10,8	168	21,7	353	108	1680
Dec.	-9,2	0,24	16,0	118	32,0	257	160	1180
Total		0,400	**6,0***	2400	**12,0***	5218	**54***	23960

Note: The values * - recommended area of the aperture of hot water supply system, which corresponds to its heat capacity.

The replacement rate of the solar plant of calculated heat capacity for hot water supply:

$$\eta_{repl} = Q_A / Q_{ht}^{Y} \cdot 100\% \quad (6)$$

The replacement rate of the solar plant of calculated heat capacity for hot water supply for consumers No. 1 and No. 3 is: η_{repl1}=61,5%; η_{repl3}=62%.

Technically and economically feasibility, these values are insignificantly higher than the recommended level of the cover in heat capacity of hot water supply – 60%.

The replacement rate of the solar plant of calculated heat capacity for hot water supply for consumer No. 2 is: η_{repl2}=72,4%.

Equally significant excess of economically viable level of the heat capacity coating of hot water supply is explained by the specifics of administrative buildings operation, which consists in substantial reduction of actual hot water consumption in comparison with the estimated consumption due to holidays and weekends. For such objects, it is advisable to decrease the installed collector area to economically reasonable level of the heat capacity coating of hot water supply, no more than 60%. In this case, reduction of the aperture area collectors form 12 m^2 to 10 m^2 is justified, i.e. 1 section of the common size collector (aperture area is 1,82 - 2,05 m^2).

5.2 Hot water supply plants

When choosing a technically and economically viable aperture area of the solar heating plant it should take into accounts the following objective factors:

- solar heating system even more than solar hot water system is not able to replace the traditional heat generator and compensating thermal power;
- in each plant, assigned for year-round heating and hot water supply in summer period, "heating" power is exploited insufficiently if the system is not connected only with "summer" consumers;
- without accumulation of excess heating the inter-heating period, introduction of the solar heating systems is not economically unviable.

The basis for determining the aperture area of the solar heating plant is the ratio of the thermal capacity on the heating and hot water supply, building purpose and the level of thermal protection:

- for single-family houses, the area of absorbed solar surface of the plant on the heating system is accepted at the rate of 1 m^2 of aperture area to 8 m^2 - 10 m^2 of the heated area of the building;
- for administrative buildings, buildings of social and household appointment, the area of absorbed solar surface on the heating is taken from the rate of 1 m^2 of aperture area to 10 m^2 - 12 m^2 heated area of the building;
- for consumers who heat consumption for hot water supply is comparable or is significantly higher than the consumption of heat for heating the area of absorbed solar area on the heating is taken from the rate of 1 m^2 of aperture area to 14 m^2 - 16 m^2 heated area of the building.

For these consumers aperture area of solar plants is taken with maximum values of corresponding ranges (Table 7).

Table 7. Aperture area of the solar systems for heating and hot water supply of consumers.

Aperture area appointment	Aperture area, m^2		
	Consumer No.1	Consumer No.2	Consumer No.3
For hot water supply	6	10	54
For heating system	12	42	38
Total for heating system and hot water supply	18	58	92

Table 8. Heat capacity of the plant for heating and hot water supply.

Month	Consumer No.1			Consumer No.2			Consumer No.3		
	Q^Y_i, kW	Q_A, kW	η_{repl}, %	Q^Y_i, kW	Q_A, kW	η_{repl}, %	Q^Y_i, kW	Q_A, kW	η_{repl}, %
Jan.	4331	431	10	14353	1390	9,7	20521	2204	10,7
Feb.	3554	478	13,5	11804	1540	13,0	16911	2443	14,4
Mar.	3047	809	26,6	9771	2608	26,7	14693	4137	28,2
Apr.	2112	727	34,4	6359	2343	36,8	10408	3717	35,7
May	824	808	98,0	2814	2605	92,5	5844	4133	70,7
Jun.	323	647	>100	592	2086	>100	3195	3312	>100
Jul.	287	543	>100	525	1750	>100	2835	2775	98,0
Aug.	288	743	>100	578	2393	>100	2835	3796	>100
Sept.	278	883	>100	630	2851	>100	2746	4523	>100
Oct.	765	826	>100	2772	2661	96,0	5756	4222	73,3

Nov.	2705	551	20,4	8563	1776	20,7	13099	2819	21,5
Dec.	3863	387	10,0	12832	1247	9,7	18365	1978	10,8
Total	22042	6132	27,8	71593	18495	25,8	119872	37204	31,0

where Q^Y_i – calculated average monthly heating consumption for heating and hot water supply, kWh;
Q_A - (useful) heat capacity for heating and hot water supply, kW;
η_{repl} - replacement ratio of solar plant of heat load for hot water and heating supply.

The calculation results indicate about a low efficiency of the solar plants intended for heating and hot water supply of buildings for different purposes (Table 8).

When the heat supply of single-family houses and administrative buildings and also buildings of social and household appointment, the replacement rate of solar plant required for thermal load is not more than 26-27%.

In addition, for these consumers, with preferred heat consumption for heating supply, in summer (up to 5 months) the excess of the required heat energy can range from 100% to 300% or more.

Plants of central heating and hot water supply in buildings with primary heat consumption for heat water supply have best indicators. The replacement rate of the solar plant required for thermal load can be up to 31%.

The excess of the required heat energy also takes place in the summer, up to 3 months, but it is much smaller in size (up to 200%) than consumers No.1 and No.2.

The results of rational design are taken as a basis for technical and economic comparison of decentralized heat supply systems based on conventional energy sources and solutions, providing the use of solar plants.

6 Cost effective analysis of the solar energy in heat supply systems of buildings

6.1 Investments

By comparing the options at the stage of feasibility study it was taken into account only the variable components of investment required (one-time costs) in the heating system in relation to the basic variant, required less costs. To conditionally fixed costs in comparable cases it is attributed costs for domestic heating and hot water supply, which, based on the comparability of conditions, shall be identical on the options.

For each of the considered buildings, it is taken the following options for decentralized heating:

- Option 1 (basic). Heat supply is done by electric heating boilers and capacitive electric water heater;
- Option 2 (basic) Heat supply from heat generator of liquid (diesel) fuel tank with the plant - battery reserve of hot water, the fuel tank of the chimney;
- Option 3 is similar to option 1 + solar plant;
- Option 4 is similar to option 2 + solar plant.

One-time costs are defined for the two operating conditions of the solar plants: for the year-round hot water supply; for heating and hot water year-round building supply. (Tables 9, 10)

In view of the variety of proposals on the solar plant market, a wide range of structures, reservoirs and other equipment, one-time costs determined at the middle and close to the maximum value of the basic equipment of solar systems, existing on the market at the moment. Thus the focus is not on the type and structure of taken collectors, flat or tubular (vacuum), as in this case, this theme was not a subject for discussion.

The cost of a standard set, compared to the value specified in many promotional offers, including the cost of piping manifold, thermal insulation, supporting structures, construction and installation works, start-up costs and the adjustment, the design work.

Table 9. Investments for using solar hot water systems (rub.).

Consumer	Option No.1	Option No.2	Option No.3		Option No. 4	
			Average prices	High prices	Average prices	High prices
No.1 Residential building	31000	60000	221000	371000	250000	400000
No.2 Administrative building	58000	82000	373000	593000	397000	617000
No.3 Medical building	85000	114000	1345000	2230000	1374000	2259000

Note: The aperture area of the solar hot water plants of consumer No.1 is 6 m^2, consumer No.2 - 10 m^2 consumer No.3 is 54 m^2.

Table 10. Investments for using solar heating plants and hot water systems (rub.).

Consumer	Option No.1	Option No.2	Option No.3		Option No. 4	
			Average prices	High prices	Average prices	High prices
No.1 Residential building	31000	60000	506000	846000	535000	875000
No.2 Administrative building	58000	82000	1348000	2218000	1372000	2242000
No.3 Medical building	85000	114000	2115000	3529000	2145000	3559000

Note: The aperture area of the solar plants of heating and hot water supply of consumers No.1 is 18 m^2, consumer No. - 58 m^2, consumer No.3 - 92 m^2.

6.2 Operating costs

In addition to the annual energy consumption costs also it is necessary to take into account the substantial annual costs of maintenance and repairs of additional equipment in power saving option, additional amortization expenses.

Only such principled approach to the calculation of all the articles of the annual operating costs can testify about the objectivity of the cost-effectiveness analysis of the received energy saving measures [5, 6].

However, the economic analysis carried out taking into account only the cost of energy consumption in comparable options. Operating costs are defined in the cost of diesel fuel - 36,5 rub/Liter, and the electric energy tariffs - 3,5 rub/kWh (Tables 11-14).

Table 11. Calculated heat consumption by subscribers using solar hot water plants (kWh).

Consumer	Option No.1	Option No.2	Option No.3		Option No. 4	
			By means of solar plant	Economy	By means of solar plant	Economy
No.1 Residential building	22040	22040	19642	2398	19642	2398
No.2 Administrative building	71593	71593	66375	5218	66375	5218
No.3 Medical building	119892	119892	95912	23960	95912	23960

Table 12. Calculated heat consumption of subscribers using solar heating plants and hot water supply (kWh).

Consumer	Option No.1	Option No.2	Option No.3		Option No. 4	
			By means of solar plant	Economy	By means of solar plant	Economy
No.1 Residential building	22040	22040	15910	6130	15910	6130
No.2 Administrative building	71593	71593	53098	18495	55683	18495
No.3 Medical building	119892	119892	82668	37204	82668	37204

Table 13. Operating costs by using solar hot water systems (rub.).

Consumer	Option No.1	Option No.2	Option No.3		Option No. 4	
			By means of solar plant	Economy	By means of solar plant	Economy
No.1 Residential building	77140	89442	68747	8393	79710	9732
No.2 Administrative building	250575	290537	232312	18263	269361	21176
No.3 Medical building	419622	486542	335692	83930	389228	97314

Table 14. Operating costs by using solar heating plants and hot water systems (rub.).

Consumer	Option No.1	Option No.2	Option No.3		Option No. 4	
			By means of solar plant	Economy	By means of solar plant	Economy
No.1 Residential building	77140	89442	55685	21455	64524	24918
No.2 Administrative building	250575	290537	185843	64732	215971	74566
No.3 Medical building	419622	486542	289338	130284	335481	151061

7 Estimated economic efficiency

With the implementation of investment projects at the own expense of individual recipients, as well as "costly" projects that are not designed for profit, economically feasible option of the investment project must comply with the minimum costs and minimum payback time.

At the same time the calculated operating costs in comparable options of accounting period by year are increased due to the growth in tariffs, in order to maintain the required return in terms of inflation.

The given total operating expenses for the period in terms of compounding under compared alternatives C_{CC}, RUB:

$$C_{CC1} = K_1 + C_1 \cdot \left[(1+r)^T - 1\right] / r \tag{7}$$

$$C_{CC2} = K_2 + C_2 \cdot \left[(1+r)^T - 1\right] / r \tag{8}$$

where $T=T_P$ - duration of calculation period, in the particular case the duration of the life of the project, accepted in the calculation T = 15 years; r - required rate of return (interest rate, the increase in tariffs), admitted in the calculation of $r = 0{,}06$.

Simple payback of investments in energy saving projects:

$$T_0 = \frac{K_2 - K_1}{C_2 - C_1} \tag{9}$$

where K_1 and K_2 - the estimated investment in the first (basic) and second (low-power) options, rub.; C_1 and C_2 - the calculated annual operating costs (operating costs) compared to options, rub./year.

Payback period, under condition of accrual (capitalization) of incoming revenues T_C year determined by the formula:

$$T_C = \frac{\ln(1 + r \cdot T_0)}{\ln(1 + r)} \tag{10}$$

A comparison is made between option №1 and №3, options №2 and №4.
Calculation data of economic indicators is shown in tables 15, 16.

Table 15. Economic indicators using solar hot water systems.

Consumer	Options	Calculated operating cost, C_{cc1}, thous.rub.	Simple payback period, T_0 years	Payback period during capitalization, T_C, years
No.1 Residential building	№1	1826		
	№2	2142		
	№3: Average prices High prices	 1821 1970	 22,6 40,5	 14,6 21,1
	№4: Average prices High prices	 2107 2255	 19,5 35,0	 13,0 19,4
No.2 Administrative building	№1	5890		
	№2	6843		
	№3: Average prices High prices	 5779 5999	 17,2 29,3	 12,1 17,3
	№4: Average prices High prices	 6665 6885	 14,9 25,3	 11,0 15,8
No.3 Medical building	№1	9850		
	№2	11436		
	№3: Average prices High prices	 9156 10042	 15,0 25,6	 11,0 15,8
	№4: Average prices High prices	 10431 11316	 12,9 22,0	 9,8 14,4

Table 16. Economic performance using solar plants of heating and hot water supply.

Consumer	Options	Calculated operating cost, C_{cc1}, thous.rub.	Simple payback period, T_0 years	Payback period during capitalization, T_C, years
No.1 Residential building	№1	1826		
	№2	2142		
	№3: Average prices High prices	 1801 2142	 22,1 38,0	 14,4 20,3

	№4: Average prices High prices	 2036 2377	 19,1 32,7	 13,5 18,8
No.2 Administrative building	№1	5890		
	№2	6843		
	№3: Average prices High prices	 5673 6543	 20,0 33,4	 13,5 18,8
	№4: Average prices High prices	 6631 7500	 17,3 29,0	 12,2 17,2
No.3 Medical building	№1	9850		
	№2	11436		
	№3: Average prices High prices	 8850 10263	 15,6 26,4	 11,3 16,2
	№4: Average prices High prices	 9952 11365	 13,4 22,8	 10,0 14,5

8 Conclusion

Heat capacity of plants of the year-round hot water supply is up to 60% or more of the required heat consumption in the communal household needs. Solar plants, used in conjunction with traditional heating and for hot water all year round, are able to cover up to 25 - 32% of the required heat load for the year of operation. During this long period, from 3 to 5 months, the installation of solar heat generation is significantly exceeding "useful" heat consumption.

The duration of a simple payback period T_0 received as a pre-assessment test, indicating about high degree of riskiness of the proposed energy saving measures in buildings for various purposes.

When the useful lifetime of energy-efficient installations 15 - 20 years in the calculation of the T_S = 15 years, economically attractive payback period is considered to be a period of 0,5-0,6 length of "life cycle" of the project. Calculated values of simple payback period to the implementation of energy conservation measures, for example of provided consumers are close or significantly exceed technically justifiable terms of service in the real conditions.

Since most energy saving projects are "costly" and are not intended for the extraction of business profits, it evaluated the cost-effectiveness with "consumer" positions, compounding scenario conditions, taking into account the increase of revenue due to the growth in tariffs for heat sources and energy.

The payback period from the point of compounding T_C, under condition of annual increase of energy costs at the rate of 6% during the lifetime can be reduced to limited maximum terms of economic expediency, but, in general, do not remove the question of the high risks of these energy-saving measures.

Calculation of economic efficiency of investments in energy efficiency measures, on the basis of solar installations, carried out for the most favorable conditions for their compatibility with conventional engineering solutions. It was taken into account only the cost of consumed energy in the calculation of performance indicators.

The admitted growth rate of energy costs is in the amount of 6% over the estimated useful lifetime and to ensure an economically acceptable payback period under accrual

T_C=7-8 years, the electricity tariff at the time of the calculation must be at least 6 rub/ kWh, while the price of diesel fuel is from 63,5-67,0 rub/kg.

In this case, when the economically attractive payback period T_C (with accrued income), 7-8 years, electricity tariff should not be less than 10-10,5 rub/kWh, while the cost of diesel fuel – is from 97 to 102 rub/kg.

Taking into account the annual cost of maintenance and repairs of additional heat source, especially for fairly large consumers of thermal energy, and in some cases, financing conditions (with or without the involvement of borrowed funds), the use of solar plants is not economically feasible under any conditions of the rising rates energy.

Large-scale use of solar plants with current market prices for equipment and energy costs, in the absence of actual current incentive program consumers, practically implementing the introduction of energy-saving projects, economically inefficient.

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