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An integrated approach to energy saving of buildings with wear

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Abstract. The specific costs of thermal energy approved by the Decree of the Government of the Russian Federation No. 306 in buildings with wear and tear do not cover the actual costs. Building owners resist the installation of meters, preferring to pay according to the standard. In the North, the state is forced to reimburse the actual costs of heat supply organizations for fuel. The regulator requires automated systems for rationing the consumption of thermal energy for each heat consumer object in accordance with the thermal characteristics of this object in this area. The relevance of the work is associated with significant subsidies from the regional budget for heating and the need for a regulator to monitor each heated object. The article substantiates a new increased standard of thermal energy consumption for use in buildings with high wear. As well as automation of regulation of heating costs for each individual object.

Keywords: problems of energy saving, wear of buildings, climatic parameters, regulation, standards.

1 Introduction

Yakutia is the coldest region of the Arctic zone of the Russian Federation, occupying almost 1/5 of the territory of Russia and where only 1 million people live. The population is dispersed across 411 local government (hereinafter referred to as LG), uniting 642 settlements (hereinafter referred to as SL) in 36 municipal districts (hereinafter referred to as MD) and urban districts (hereinafter referred to as UD). The organization of life in these localities is associated with inaccessibility. The state subsidizes part of the costs of heating social infrastructure and housing. According to the statistics of 2021 in the region, 30% of the housing stock has a deterioration of 31-65%, 9% has a deterioration of 66-70%, 10% more than 70% [1, p. 9]. It is important to stimulate energy saving in 40-50% of the housing stock. But energy saving in these buildings is not carried out due to the low regulatory framework for calculating heat savings by energy-saving measures. Laid down in the Decree of the

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Government of the Russian Federation No. 306 [2, Table. 4] the specific costs of thermal energy for buildings built in 1999 and earlier do not cover the actual costs of heat supply organizations for buildings with high wear. For rationing based on higher standards, it is necessary to process about 60 indicators, starting from the name of the MP, ending with the amount of thermal energy for the heating period for each specific heating object, or operating more than 4 million indicators. It is necessary to automate the rationing of heating costs for more than 70 thousand housing stock objects, social infrastructure facilities and the national economy on the basis of higher standards in buildings with high wear. The purpose of this article is to stimulate energy saving in buildings with high wear by justifying higher standards and overcoming the problems of automation of rationing of heat energy consumption.

2 Research methods

The research method is based on creating a database of heat energy supplies by heat supply organizations and consumption by heating facilities and processing this database with heat engineering calculations according to the methods of the regional government [7] and in accordance with the methodology of the Decree of the Government of the Russian Federation No. 306 [2].

The study was conducted in two stages. At the first stage, climatic parameters were formed for thermal engineering calculations based on observations of the hydrometeorological stations of “Yakut Department for Hydrometeorology and Environmental Monitoring” (hereinafter referred to as YDHEM) for the last five heating periods.

At present, the YUGMS is deploying 110 hydrometeorological stations throughout the region, where as in 1962 there were only 51 [5], in 1972 63 stations [6], in 1999 and 2018 only 50 [7].

Due to the increase in the objects of observation, the authors had to make a new binding of settlements in the region to the closest 75 hydrometeorological stations. According to the sources [2; 4], at the first stage of the research, the average temperatures of the winter months from October to April and the average daily temperatures of the off-season months from May to September for 2015-2020 were obtained from the YDHEM. According to them, the main climatic parameters for thermal engineering calculations were calculated: a) the start and end dates of the heating period, b) the duration of the heating period, c) the average outdoor temperature for the heating period. And the calculated outdoor air temperature equal to the temperature of the coldest five-day period with a provision of 0.92 was set in accordance with the Code of Rules [7], since all buildings and structures in the country are designed in accordance with this Code. On their basis, the average degree-day of the heating period (hereinafter referred to as DDHP) for the last five heating periods were calculated and they are compared with indicators according to regional and federal standards.

Calculations of average climatic parameters were made. If in some regions of central and southern Yakutia the months of May and September were the off-season, then in other Arctic regions July and August, such as Tiksi. The duration of the heating period and its average temperature were also calculated and, as their product – DDHP.

As the data in Table 1 show, the weighted average temperature of the heating period $t_{w.a.t.h.p.}$ for all hydrometeorological stations except Aldan show an increase in the average temperature of the heating period from 5.5°C in Deputatsky to 1.7°C in Chulman. An increase in the temperature of the heating period is characteristic, especially in the Arctic districts, for example, in Olenka by 5.3°C, in Chersky by 4.2°C. In turn, an increase in the average temperature of the heating period causes a decrease in the degree-days of the heating period calculated according to the methodology of Resolution 306 [2] against those calculated according to the Resolution of the Government Yakutia No. 186 [8].

The duration in days of the heating period according to the results of the calculation for the last 5 heating periods as a whole decreased against the duration according to the Resolution No. 186 for all hydrometeorological stations except for 6 stations in which there is an increase in the duration of the heating period: in Chersky for 6 days, Olekminsk for 5 days, Nera for 4 days, Tommot for 2 days, Amga and Churapcha for 1 day. The greatest decrease in the duration of the heating period is observed in Tiksi village for 26 days.

The DDHP calculated according to the methodology of the joint venture "Construction Climatology" are in an intermediate position between them. The decrease in the degree-day in the village of Deputatsky is from 12439 to 10832 or by 13%, in the village of Tiksi from 12556 to 11103 days, or by 11.6%, while in the village of Chulman by only 5.2%.

Table 1, in general, shows the possibilities of reducing heating costs when using the calculation method according to the method of Resolution 306 against the Resolution of the Government Yakutia No. 186.

At the first stage, work was carried out in parallel to determine the resistance to heat transfer of enclosing structures.

3 Normative and methodological support for the calculation of specific heat consumption

For measuring the actual heat transfer resistance of enclosing structures and subsequent calculation of the specific heat consumption per 1 sq. m. m of the total living area required instrumental surveys.

When carrying out thermal imaging survey work, regulatory documents and methods approved by the State Energy Supervision for widespread use in object surveys are used.

To determine the normalized parameters of the survey objects, the contractor used sources [7; 11-14].

To carry out measurements of visual and instrumental surveys, the contractor used sources [15-21].

Instrumental monitoring of temperature and humidity conditions of survey objects is carried out selectively in accordance with the requirements of GOST [12]. For the analysis of the obtained data, CR 60.13330.2016 was used [17].

3.1 General provisions for determining the thermal conductivity coefficient of enclosing structures

The measurement of the density of heat flows is carried out, as a rule, from the inside of the enclosing structures of buildings and structures. The control of the heat exchange conditions is carried out using a U-probe and means for measuring the heat flux density.

The surface areas are selected specific or characteristic for the entire enclosure structure being tested, depending on the need to measure the local or average heat flux density.

The areas of the surface of the enclosing structures on which the heat flow converter is installed are cleaned until the visible and palpable roughness is eliminated.

The U-probe is tightly pressed along its entire surface to the enclosing structure and fixed in this position, ensuring constant contact of the heat flux converter with the surface of the studied areas during all subsequent measurements.

When using devices for measuring thermal conductivity that have restrictions on ambient temperature, they are placed in a room with an air temperature acceptable for the operation of these devices, and heat flow converters are connected to them using extension wires.

Table 1. A fragment of comparative climatic parameters according to the Decree of the Government of the Russian Federation No. 306 [2], according to the Code of Rules 131.13330.2018 "Construction Climatology" [7] and according to the Resolution of the Government Yakutia No. 186 [8].

No	Hydro meteo stations	Heating period 2015-2020 for Resolion of Government RF № 306				Code of Rules 131.13330.2018 «Construction Climatology»			Resolution Government Yakutia № 186 "Rationing of heat and fuel consumption for heating and hot water supply of buildings in the Yakutia"			
		$day_{h.p.y}$	$t°C_{w.a.t.h.p..}$	DDHP in $t°_{int}=21°C$**	Temperature zones	$day_{h.p.y}$	$t°C_{w.a.t.h.p..}$	DDHP in $t°_{int}=21°C$**	$day_{h.p.y}$	$t°C_{w.a.t.h.p..}$	DDHP in $t°_{int}=20°C$**	DDHP in $t°_{int}=21°C$**
1	Aldan	263	-14,3	9285	**1**	263	-13,6	9100	266	-13,1	8805	9071
2	Tommot	262	-14,3	9249	**1**	260	-17,4	9984	260	-17,4	9724	9984
3	Buyaga	262	-15,6	9594	**2**	262	-15,6	9594	262	-15,6	9332	9594
4	Uchur	260	-12,5	8713	**1**	260	-12,5	8713	260	-12,5	8453	8713
5	Lensk	257	-11,6	8366	**1**	257	-14,3	9072	258	-14,6	8927	9185
6	Vitim	255	-10,8	8108	**1**	255	-13,7	8849	256	-14,6	8858	9114
7	Dorozhny	261	-11,7	8529	**1**	261	-11,7	8529	261	-11,7	8268	8529
8	Chulman	266	-15,3	9662	**2**	266	-15,3	9656	268	-17	9916	10184
9	Olyokminsk	257	-12,7	8669	**1**	254	-15,5	9271	252	-16,1	9097	9349
10	Kiliyer	261	-12,9	8839	**1**	261	-12,9	8839	261	-12,9	8578	8839
11	Tyanya	258	-13,5	8909	**1**	261	-16,0	9657	261	-16,0	9396	9657
12	Dikimdya	257	-12,8	8681	**1**	256	-16,6	9626	256	-16,6	9370	9626
13	Macha	253	-12,0	8341	**1**	253	-12,0	8341	253	-12,0	8088	8341
14	Vilyuysk	256	-15,8	9414	**1**	259	-18,7	10282	260	-18,8	10088	10348
15	Verkhnevilyuysk	259	-15,7	9509	**2**	264	-18,7	10481	264	-18,7	10217	10481
16	Nyurba	258	-15,3	9371	**2**	261	-18,0	10179	260	-17,9	9854	10114
17	Suntar	256	-13,6	8857	**1**	257	-16,7	9689	259	-16,1	9350	9609
18	Kresttyakh	259	-14,3	9148	**1**	259	-14,3	9148	259	-14,3	8889	9148
19	Mirniy	265	-12,9	8974	**1**	267	-15,2	9665	267	-15,2	9398	9665
20	Chernyshevsky	266	-12,6	8950	**1**	266	-12,6	8950	266	-12,6	8684	8950
21	Berdigestyakh	262	-16,7	9885	**2**	263	-19,6	10678	265	-20,2	10653	10918
22	Sangary	259	-17,6	10007	**2**	259	-20,0	10619	260	-19,9	10374	10634
23	Khatyryk-Khomo	261	-17,2	9959	**2**	261	-17,2	9959	261	-17,2	9698	9959
24	Batamay	262	-18,7	10393	**3**	262	-21,5	11135	262	-21,5	10873	11135
25	Amga	257	-18,4	10131	**3**	254	-21,8	10871	256	-21,8	10701	10957
26	Tegyulte	256	-16,5	9601	**2**	256	-16,5	9601	256	-16,5	9345	9601
27	Ust-Maya	251	-18,1	9816	**2**	251	-20,6	10442	254	-20,5	10287	10541
28	Ust-Yudoma	251	-16,5	9419	**1**	251	-16,5	9419	251	-16,5	9168	9419
29	Ust-Mil	254	-16,4	9509	**2**	254	-19,5	10287	254	-19,5	10033	10287
30	Yugorenok	262	-17,3	10041	**2**	262	-17,3	10041	262	-17,3	9779	10041
31	Yakutsk	252	-17,2	9628	**2**	252	-20,6	10483	254	-21,2	10465	10719
32	Namtsy	252	-18,9	10061	**2**	254	-21,2	10719	254	-21,2	10465	10719
33	Pokrovsk	257	-17,7	9938	**2**	258	-20,2	10630	258	-20,2	10372	10630
34	Isit	256	-14,6	9126	**1**	256	-17,6	9882	256	-17,6	9626	9882
35	Ytyk-Kyuyol	257	-20,1	10550	**3**	257	-22,9	11282	257	-22,9	11025	11282
36	Krest-Khaldzhay	253	-20,1	10409	**3**	253	-22,8	11081	253	-22,6	10778	11031
37	Okhotsky-Perevoz	256	-19,6	10392	**3**	256	-22,2	11059	256	-22,2	10803	11059
38	Tyoply Klyuch	258	-17,7	9979	**2**	258	-17,7	9979	258	-17,7	9721	9979
39	Tompo	267	-21,1	11240	**4**	269	-23,3	11917	269	-23,3	11648	11917

All equipment is prepared for operation in accordance with the operating instructions of the corresponding device, including taking into account the required exposure time of the device to establish a new temperature regime in it.

3.2 Preparation for thermal imaging measurements

Thermal imaging measurements are made when the temperature difference between the outdoor and indoor air exceeds the minimum allowable difference, determined by the for formula:

$$\Delta t_{min} = 2\Delta\theta R_0^n \frac{\alpha r}{1-r} \ , \tag{1}$$

where:
θ – the limit of thermal sensitivity of the thermal imager, ° C;
R_0^n – is the design value of the heat transfer resistance, sq. m·°C/W;
α – is the heat transfer coefficient assumed to be equal to: for the inner surface of the walls – according to the normative and technical documentation; for the outer surface of the walls at wind speeds of 1, 3, 6 m/s - respectively 11, 20, 30 W /(sq.m · ° C);
r – is the relative heat transfer resistance of the defective section of the enclosing structure to be detected, assumed to be equal to the ratio of the value required by the regulatory and technical documentation to the design value of the heat transfer resistance, but not more than 0.85.

Thermal imaging measurements are performed in a heat transfer mode close to stationary. The deviation of the actual heat transfer mode from the stationary one is estimated according to the reference appendix. In many cases, the temperature difference between indoor and outdoor air of at least 10 °C - 15 °C is sufficient to fulfill the condition according to formula (1). The higher the temperature difference, the more accurate and more amenable to analysis and processing the results of thermal imaging surveys.

Thermal imaging measurements are made in the absence of precipitation, fog, and smoke. The examined surfaces should not be in the zone of direct and reflected solar irradiation for 12 hours prior to the measurements.

Measurements should not be made if the value of the integral radiation coefficient of the object surface is less than 0.7.

The installation locations of the thermal imager are chosen so that the surface of the measuring object is in line of sight at an observation angle of at least 60 °.

The distance of the thermal imager installation sites ***L*** in meters from the surface of the object is determined by the formula:

$$L \leq \frac{\Delta H N_c}{10\varphi} , \tag{2}$$

where:
φ – is the instantaneous field of view of the thermal imager, defined as the linear angle of view of one element of the decomposition of the thermogram, radii;
ΔH – is the linear size of the section of the enclosing structure to be identified with impaired thermal protection properties, taken when monitoring the inner surface from 0.01 to 0.2 m; when monitoring the outer surface - from 0.2 to 1 m;
N_c – is the number of scan lines in the thermal imager frame.

The surfaces of enclosing structures during thermal imaging measurements should not be subjected to additional thermal effects from biological objects, lighting sources. The minimum permissible approach of the operator of the thermal imager to the examined surface is 1 m, electric incandescent lamps - 2 m.

Heating devices installed with a distance of more than 10 cm from the examined surface or located on surfaces adjacent to it should be shielded with film materials with a low radiation coefficient.

3.3 Thermal imaging measurements

The internal surfaces of the base area and areas with impaired thermal protection properties are subjected to detailed thermography. Additionally, the areas of the floor and ceiling abutting to the exterior walls of the building in the rooms of the first and upper floors, as well as the corner sections of the external wall interfaces, are thermographed.

In accordance with the instructions of the device, the thermal imager is calibrated before measuring temperature fields.

When measuring temperature fields on the thermal imager screen, thermal images with illuminated isothermal surfaces are obtained and photographed sequentially, starting with the minimum value of the thermal imager output signal and ending with its maximum value. The values of the thermal imager output signals for isothermal surfaces are determined by the formula:

$$L_k = L_{min} + \frac{k-1}{A} \Delta\tau, \quad (3)$$

where:

L_{min} – minimum value of the thermal imager output signal;
k – the ordinal number of the isothermal surface;
A – coefficient of the thermal imager calibration characteristic, °C;
$\Delta\tau$ - the temperature difference between neighboring isotherms, assumed to be from 0.3 to 1 ° C.

Indoor and outdoor air temperatures are measured with an aspiration psychrometer. The measurement results are recorded in the log of thermal imaging measurements.

The resistance to heat transfer of the base section of the enclosing structure is determined by the results of field measurements in accordance with STST 26254-84. If it is impossible to determine it, the value of the heat transfer resistance is calculated according to the normative and technical documentation according to the project of the enclosing structure.

The following elements of the building are subject to thermal imaging:

Window designs;
Joints with overlappings;
Corner joints of wall structures;
Heating devices.
Surfaces of wall structures.

4 Intermediate research result

At the second stage, a “Database of suppliers and consumers of thermal energy of the Republic of Sakha (Yakutia)” was formed. The most complete database of suppliers and consumers of thermal energy turned out to be at the State Committee on Pricing Policy of the Republic of Sakha (Yakutia). The regulator collects reports from suppliers of thermal energy in thirteen forms (tx) in order to have a complete picture of the cost of thermal energy for each LG, the technical condition of thermal energy sources and heating networks. In Form 3 (tx) there are all contractual objects of heat energy recipients with their suppliers, which reflect: the name of the supplier, the recipient's address indicating the house and building, the ownership of the object. The names of the MD or UD, LG, localities, the name of the source of thermal energy, the total area and the construction volume of the recipient's building or structure are also indicated. There is also an estimated full load from the heating object on the source, including the current costs of thermal energy for the object with a division into heating, ventilation, satellites, hot water, losses, heat exchangers, the number of residents in residential buildings, number of floors, the degree of improvement, the air temperature of heated rooms, the duration of the heating period and its average the temperature is the same for the forecast period.

To process the database, software was written in the language “Visual Basic for Applications” to calculate the standards of thermal energy consumption for each of the 71 thousand heating facilities. The calculation of standards was planned to be carried out according to the two methods mentioned above, but during the instrumental determinations of the specific heat capacity of residential buildings, it was decided to divide the gradations of the specific heat capacity of buildings not into two subgroups, as indicated in Resolution No. 306, but into three. This decision was made due to significant losses of resistance to heat transfer of enclosing structures of buildings built before 1985.

5 Results

When developing the DBSCTE of the region, the developers faced a number of problems. Firstly, there are technical problems: the original reporting form in Excel was not sorted and grouped. The initial problems of automation served as an obstacle to this: empty cells and lines, spaces, grammatical errors in the name of MD, LG, and localities, the presence of sheet protection and cell blocking, the lack of uniformity in the designation of the property category of the recipient of thermal energy, attempts to partially use macros, etc. Secondly, purely organizational problems: there was no requirement for which version of Excel to fill in tables, there was no requirement for initial sorting and grouping of data from heat energy suppliers and the principles of sorting and grouping.

The DBSCTE macros that were written made it possible to distribute 11-digit codes of localities in the region according to the Russian classifier of territories of municipalities (hereinafter referred to as RCTM) [9] across all 642 localities of regions, to summarize interim results for MD, LG and separately for each boiler house on the first sheet and for heat supply organizations, LG and boiler houses on the second sheet of UD.

The survey showed that the specific expenditure of thermal energy for heating residential buildings in Yakutia in 1986 and later years is almost identical with the indicators of the Decree of the Government of the Russian Federation No. 306 [2]. And for buildings built in 1985 and earlier, due to long-term operation and dilapidation of buildings, the specific consumption has increased significantly.

All indicators of the database were calculated according to the formula (4) of the Decree of the Government of the Russian Federation No. 306 [1] and the Resolution of the Government Yakutia’s No. 186 [7]:

$$Q_h = q_{max} \text{x} \frac{t_{int} - t_{adothp}}{t_{int} - t_{eotdhs}} \text{x} 24 \text{x} n_0 \text{x} 10^{-6}, \tag{4}$$

where:

q_{max} – hourly heat load for heating of an apartment building or residential building (kcal/hour);

t_{int} – the internal air temperature of the heated residential premises of an apartment building or a residential building (°C);

t_{adothp} – average daily outdoor temperature for the heating period (°C);

t_{eotdhs} – estimated outdoor air temperature for the design of heating systems (°C) (the coldest five-day period);

n_0 – the duration of the heating period (days per year), characterized by an average daily outdoor temperature of 8 °C and below;

24 – number of hours per day;

10^{-6} – conversion coefficient from kcal to Gcal.

Table 2. Indicators of the specific consumption of thermal energy for heating residential buildings in Yakutia, calculated on the basis of instrumental measurements of the heat transfer resistance of enclosing structures, kcal / (h · m^2).

Number of floors in the building	Estimated outdoor air temperature, °C				
	-40	-45	-50	-55	-60
Apartment buildings and residential buildings built up to and including 1985					
1-2	237	242	255	271	287
3-4	150	160	169	179	189

5 & more	102	109	115	122	129
Apartment buildings and residential buildings from 1986 to 1999 built inclusive					
1	156	162	168	174	180
2	125	130	135	141	146
3-4	110	115	120	125	130
5-9	89	104	109	115	120
10	76	94	99	105	110
11	75	80	85	89	94
12	74	79	83	88	92
Apartment buildings and residential buildings built in 2000					
1	68	74	81	86	92
2	58	63	68	73	78
3	57	62	67	72	77
4-5	49	54	58	62	66
6-7	46	50	54	58	62
8	44	48	52	55	60
9	44	48	52	55	60
10	41	45	49	52	56
11	41	45	49	52	56
12 & more	40	43	47	50	53

The quantitative values of t_{int}, t_{adothp}, t_{eotdhs} and the cases of their application are determined "on the basis of information provided by the hydrometeorological service for the previous 5 consecutive heating periods as the arithmetic mean of the average daily outdoor temperatures for the heating period. In the absence of such information, the average outdoor air temperature during the heating period is determined based on the climatic parameters used in the design of buildings and structures, heating systems" [2, p. 44]:

t_{int} – STST 30494-2011 "Indoor microclimate parameters. Residential and public buildings" [12];

t_{adothp} and t_{eotdhs} – Code rules 131.13330.2018 “CS&R 23-01-99 Construction climatology” [7].

In the absence of design or audit documentation, the hourly thermal load (kcal per hour) is determined by the following formula:

$$q_{max} = q_{sh} * S, \tag{5}$$

where:

q_{sh} – the normalized specific consumption of thermal energy for heating an apartment building or a residential building (kcal per hour per 1 sq. m), provided from sources [2, Table 4; 7, Table 3.1 and Table 2 of this Article];

S – the total area of residential and non-residential premises of an apartment building, as well as premises that are part of the common property in an apartment building, or the area of a residential building (sq. m).

6 Conclusion

The specific heat energy costs per 1 sq. m established by the authors. m of the total area of buildings built in 1985 and earlier years allow heat supply organizations to submit regulatory costs for the production of thermal energy to the regulator. And organizations that carry out energy-saving measures should have a regulatory framework for determining the basic costs of heating facilities to calculate cost savings after energy-saving measures. The increased savings from the application of these unit costs will be able to cover large costs when carrying out energy-saving measures on buildings with high wear.

An integrated approach to energy saving in the aggregate of buildings in the region, based on the climatic parameters of the last five heating periods and calculations of specific heat consumption separately by type of buildings will be able to establish a basis for calculating heat savings. The heat savings calculated in this way buy energy-saving measures for buildings with high wear.

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