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PROGNOSTIC METEOROLOGICAL REGULATION IN SOLAR ENERGY ENGINEERING

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Abstract

This paper considers an idea of saving energy resources by using meteorological data. Applying a prognostic meteorological approach to regulate parameters of a heat medium in solar thermal collectors allows decision-makers to regulate the temperatures designed, which might improve the efficiency in heating buildings.

Keywords: solar thermal collector, prognostic meteorological approach, solar radiation, heat supply, heat carrier.

МЕТЕОПРОГНОСТИЧЕСКОЕ РЕГУЛИРОВАНИЕ В ГЕЛИОЭНЕРГЕТИКЕ

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Аннотация

В работе рассматриваются вопросы энергоресурсосбрежения на основе использования метеорологической информации. Метеопрогностическое регулирование параметров теплоносителя позволяет адаптировать подготавливаемые температуры, тем самым повышая эффективность отопления зданий.

Ключевые слова: гелиоколлектор, метеопрогностический подход, солнечное излучение, теплообеспечение, теплоноситель.

Introduction

In this research solar thermal collectors are taken as an alternative partial substitute for conventional heat sources. According to Solar Heat Worldwide 2021 [1], the solar thermal market is growing steadily. The global solar thermal energy yield increased from 51 TWh in 2000 to 407 TWh in 2020, i.e., it grows by 10 % annually.

In Belarus the share of renewable energy resources in the total energy yield is increasing gradually. According to REN21 and the United Nations Economic Commission for Europe [2], the estimated 7 % share of renewable energy in the total final energy consumption in 2025 was already reached in 2018. The target share of 9 % in 2035 is likely to be reached much earlier due to the complete commissioning of Belarusian nuclear power plant. What is more, some research [3] estimates solar power potential in the area as quite sufficient to be used in both solar heating collectors and PV systems.

Highly efficient operation and optimization are of high priority for any heating system. These criteria depend not only on the heat carrier's properties and its economic feasibility but also the effectiveness in regulating parameters of the heating system.

This research is based on a prognostic meteorological approach used to regulate the parameters of the heat carrier in a predictive way [4]. A number of basic criteria necessary to provide algorithms for predictive control have some internal and external factors.

Internal factors directly affect the microclimate of the room. The main internal factor is temperature regime as it constantly changes due to its interaction with outside disturbance agents. Local building codes [5] regulate a standard inside temperature range within 18-24 °C. Often dwellers expect more optimal temperature parameters which are taken into account in prognostic meteorological approach which can contribute to much more comfort during the heating season. There are other unregulated internal factors that influence the microclimate in the room. These are household appliances, people in the room, etc. It is difficult to calculate the heat produced by them as it depends on how long they work generating heat. However, it is possible to calculate the heat lost through the walling and hysteresis of water heating systems.

External factors mean meteorological characteristics making impact on the walling. The most important one is dynamic changes of ambient air.

Methods and Materials

In this research we developed a method for a combined use of solar thermal collectors as a primary heat source and a prognostic meteorological approach in order to determine the most accurate parameters for the heat carrier with the optimal operational efficiency of the heating system.

The paper is based on meteorological observation data registered in 2021-2022 by Belhydromet (Belarus state institution "Republican centre for hydrometeorology, control of radioactive contamination and environmental monitoring") [6]. These data allow us to analyse temperature fluctuations in the area under study. API Яндекс.Погоды [7] is used as a source of prognostic meteorological data.

The authors of the research applied such methods of processing statistical and experimental data as regression analysis, time series analysis, analytical generalization of meteorological data with further calculation, etc. The calculation is automated with the use of SunCalc JavaScript library and MS Excel software.

Results and Discussion

We estimate the performance of flat-plate collectors by identifying hourly peaks in thermal energy generation and total daily sums. The efficiency factor of solar collectors is interpreted with the following formula [8]

$$\eta = \frac{Q_{gk}}{F_{gk} \cdot Q}, \quad (1)$$

where Q_{gk} is thermal energy generated by the solar collector per unit of time, W; F_{gk} is solar collector area, m^2; Q is total solar radiation reaching the solar collector's surface, W/m^2.

Q_{gk} parameter characterizes effective work of the solar collector since in general terms it represents the difference between the solar radiation absorbed by the plate and the one reflected back to the environment. The calculation is performed with the following equation [9]

$$Q_{gk} = q_{\text{o}} \cdot F_{gk} \cdot \left(Q(m \cdot l) - W \cdot \left(T_{vch} - T_{vych}\right)\right), \quad (2)$$

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where q_o is heat transfer coefficient of the solar collector; m is capacity of the outer layer of the solar collector to transmit solar radiation; l is absorption of solar radiation by the inner layer of the solar collector; W is heat loss of the solar collector, $\mathrm{W/(m^2 \cdot °C)}$; T_{vch}, T_{vych} are inlet/outlet temperatures of the heat carrier in the solar collector's pipelines, °C.

It is necessary to consider heat losses of the solar collector as total sums. That is why it is necessary to single out separately heat lost through the upper and lower surfaces, as well as through the side walls of the body frame [9]

$$W = W_v + W_n + W_b \,, \tag{3}$$

where W_v, W_n, W_b are heat losses through the upper, lower and side surfaces of the collector, $W/(\mathrm{m^2 \cdot °C})$.

Heat loss through the side walls is extremely low provided that the thermal insulation is sufficient. We accept that $W_b \approx 0\ \mathrm{W/(m^2 \cdot °C)}$ in the solar collector chosen for our study. Thus, the calculation of heat loss through the upper and lower surfaces is as follows [9, 10]:

$$W_v = \left(\frac{N}{\frac{344}{T_P} \cdot \left(\frac{T_P - T_V}{N + f} \right)^{0.31}} + \frac{1}{h_{konv}} \right)^{-1} +$$

$$+ \frac{\sigma \cdot (T_P + T_V) \cdot ({T_P}^2 + {T_V}^2)}{(\varepsilon_P + 0.0425N(1 - \varepsilon_P)) + \left(\frac{2N + f - 1}{\varepsilon_S} - N \right)} \,, \tag{4}$$

$$W_n = \frac{1}{\frac{a_1}{b_1} + \frac{a_2}{b_2}} \,, \tag{5}$$

where N is the number of glass surfaces, pcs; σ is Stefan-Boltzmann constant, $\mathrm{W/(m^2 \cdot} K^4)$; ε_P is emissivity factor of the plate; ε_S is emissivity factor of the glass; T_P is temperature of the plate, °C; T_V is air temperature within the collector, °C; h_{konv} is plate convection coefficient, $\mathrm{W/(m^2 \cdot °C)}$; f is convection function [11]; a_1, a_2 are thickness of the insulating layer and the wall, m; b_1, b_2 are heat transfer coeficient of the insulating layer and the wall, m.

If you want to determine a heat transfer coefficient q_o, you must have data about the efficiency of the whole collector E_{gk} and the efficiency of its individual fin E_r. These parameters are calculated by the formula [10]:

$$q_o = \frac{G \cdot c_t}{W} \cdot \left(1 - e^{\frac{-W \cdot E_{gk}}{G \cdot c_t}} \right), \tag{6}$$

$$E_{gk} = \frac{1}{\left(\frac{d \cdot W}{\pi \cdot D \cdot h} \right) + \left(\frac{d \cdot W}{P} \right) + \left(\frac{d}{(d - D) \cdot E_r + D} \right)}, \tag{7}$$

$$E_r = \frac{th \sqrt{W/_{k \cdot \upsilon}} \cdot \frac{1 - D}{2}}{\sqrt{W/_{k \cdot \upsilon}} \cdot \frac{1 - D}{2}} \,, \tag{8}$$

where G is heat carrier flow rate through the solar collector, m³/h; c_t is specific heat capacity of the heat carrier in the solar collector, J/(kg · °C); E_{gk} is solar collector efficiency; d is distance between the pipelines of the solar collector, m; D is outer diameter of the collector pipeline, m; h is intensity of heat transfer from the pipeline wall to the heat carrier; P is conductivity of the connection of the surface with the pipeline, m· °C/W; E_r is efficiency index of the solar collector fin; k is coefficient of thermal conductivity of the plate, W/(m ·°C); υ is plate thickness, m.

We calculated solar radiation on sloped surfaces depending on geographical position in our previous studies [11]. In order to enhance performance, we can adjust the collector's orientation in two different ways. We can adjust the inclination angle of the collector's receiving surface β annually or monthly. Thus, the orientation conditions are described by the following equations:

$$\beta^g = \varphi \,, \tag{9}$$

$$\beta_n^{mes} = \varphi + \mu_n^{mes} \,, \tag{10}$$

where φ is latitude of the geographical point, rad; μ_n^{mes} is additional angle in a certain time period, rad (Table 1) [12].

Table 1 – Additional angle β_n^{mes} in certain time periods, rad

Time period	Gradation	β_n^{mes}	μ_n^{mes}
December 8 – January 22	1	β_1^{mes}	$\mu_1^{mes} = +23.5$
January 23 – February 7	2	β_2^{mes}	$\mu_2^{mes} = +20$
January 8 – January 21	3	β_3^{mes}	$\mu_3^{mes} = +15$
January 22 – March 6	4	β_4^{mes}	$\mu_4^{mes} = +10$
March 7 – March 21	5	β_5^{mes}	$\mu_5^{mes} = +5$
March 22 – April 2	6	β_6^{mes}	$\mu_6^{mes} = 0$
April 3 – April 16	7	β_7^{mes}	$\mu_7^{mes} = -5$
April 17 – April 30	8	β_8^{mes}	$\mu_8^{mes} = -10$
May 1 – May 21	9	β_9^{mes}	$\mu_9^{mes} = -15$
May 22 – June 5	10	β_{10}^{mes}	$\mu_{10}^{mes} = -20$
June 6 – July 7	11	β_{11}^{mes}	$\mu_{11}^{mes} = -23.5$
July 8 – August 11	12	β_{12}^{mes}	$\mu_{12}^{mes} = -20$
August 12 – August 25	13	β_{13}^{mes}	$\mu_{13}^{mes} = -15$
August 26 – September 8	14	β_{14}^{mes}	$\mu_{14}^{mes} = -10$
September 9 – September 21	15	β_{15}^{mes}	$\mu_{15}^{mes} = -5$
September 22 – October 5	16	β_{16}^{mes}	$\mu_{16}^{mes} = 0$
October 6 – October 18	17	β_{17}^{mes}	$\mu_{17}^{mes} = +5$
October 19 – November 2	18	β_{18}^{mes}	$\mu_{18}^{mes} = +10$
November 3 – November 22	19	β_{19}^{mes}	$\mu_{19}^{mes} = +15$
November 23 – December 7	20	β_{20}^{mes}	$\mu_{20}^{mes} = +20$

The prognostic meteorological approach to regulating operation cycles of a heat supply system is implemented in our previous research [13]. The study is based on the principle of combining a primary heat source with adjusting the temperatures in the supply and return pipelines taking into account the meteorological factor to reduce the overall fuel and energy costs.

We take a flat-plate solar collector FKF240 as an example to perform our calculation [14] (Fig. 1). Its technical specification is presented in Table 2.

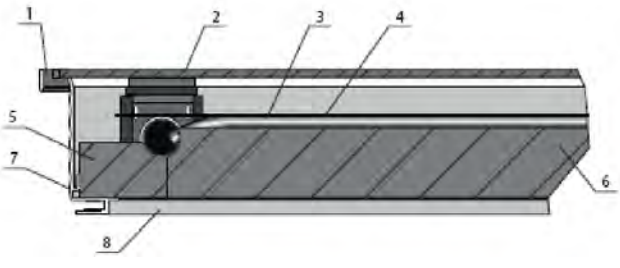

Figure 1 – FKF240 (1 – sealing; 2 – protective glass; 3 – heat pipe; 4 – absorber; 5, 6 – thermal insulation (side and bottom); 7 – frame; 8 – base

Table 2 – FKF240 technical characteristics

Size: L x W x H, mm	Heat carrier flow rate, m³/h	Pipeline diameter, mm	Absorber material	Plate heat transfer, W/(m · °C)	Plate thickness, mm
2100 x 1200 x 115	15-40	22	Al	197	5

The collector is installed at 51,889803° N. lat., 23,812028° E. long. (Belarus, Brest region, Stradech). The measurements were taken from 10:00 to 17:00 on December 22, 2021.

The solar radiation reaching the collector in the daytime is presented in Figure 2.

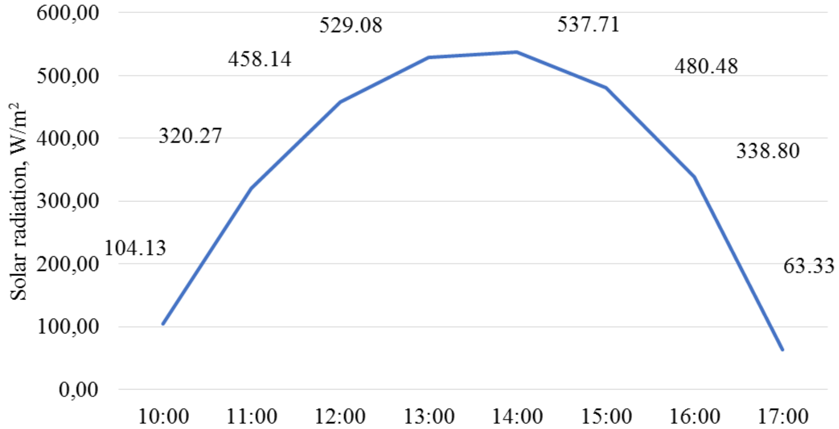

Figure 2 – The course of total solar radiation (22.12.2021)

After adjusting the heat medium parameters in the heating system with prognostic meteorological approach the temperature values reduced (Table 3).

Table 3 – Temperature fluctuations in inlet and outlet pipelines adjusted for meteorological data (22.12.2021)

Time	00:00	03:00	06:00	09:00	12:00	15:00	18:00	21:00
Ambient temperature, °C	-4.1	-4.9	-7.6	-8.4	-8.7	-7.9	-7.4	-10.8
Inlet pipeline temperature, °C	65.9	66.3	70.7	72.5	72.8	71.1	70.4	76.3
Outlet pipeline temperature, °C	56.1	57.9	60.3	70.4	70.6	60.8	60.2	62.8

The cost of energy resources is reduced by 16 % by using meteorological indicators in the collector's work. However, the more data about outside weather conditions are available, the more accurate calculation might be done. In our further studies we suppose to take into consideration wind and precipitation dynamic parameters under different conditions.

The results of our calculation for the solar collector as a primary heat source are given in Table 4.

Table 4 – Solar radiation. Collector's efficiency at different time

Time	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
Q, W/m²	104.13	320.27	458.14	529.08	537.71	480.48	338.80	63.33
$Q_{гк}$, W/m²	19.34	87.18	149.8	193.09	204.79	163.85	99.98	8.18
η, %	8.64	12.66	15.21	16.97	17.71	15.86	13.73	6.01

Thus, the collector's efficiency at the zenith on the winter solstice is around 18 %. We observe that the heat medium temperature decreases while the overall fuel and energy saving of the secondary heat source increases. However, the results obtained are reliable in the conditions with no external disturbance such as dust deposition, snow covering a solar collector, and cloudiness.

Conclusion

Implementing solar systems into the energy supply structure in Belarus climate depends directly on improving their operational efficiency. Although we have quite sufficient climate resources to develop solar energy industry, economically justified energy generation can be achieved through the combined use of several energy-efficient approaches.

Using solar thermal collectors as an alternative energy source operating according to certain meteorological factors allows us to increase their efficiency, maintain them in an environmentally friendly manner and find the most effective combinations of their application.

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References

1. Weiss, Werner. Solar Heat Worldwide. Global Market Development and Trends in 2020. Detailed Market Data 2019 / Werner Weiss, Monika Spörk-Dür // IEA Solar Heating & Cooling Programme, 2021. – Gleisdorf, Austria. – 2021 Edition. – p. 86.
2. 2022 UNECE Renewable Energy Status Report / REN21, 2022. – Paris, France. – 2022. – p. 168.
3. Meshik, O. P. Ocenka gelioenergeticheskih resursov klimata Belarusi / O. P. Meshik, M. V. Borushko, V. A. Morozova // Vestnik Brestskogo gosudarstvennogo tekhnicheskogo universiteta. Seriya: Vodohozyajstvennoe stroitel'stvo, teploenergetika i geoekologiya. – 2020. – № 2. – S. 93–99. https://doi.org/10.36773/1818-1212-2020-120-2.1-93-99
4. Severyanin, V. S. Meteoprognosticheskoe regulirovanie temperaturnogo rezhima pomeshchenij avtomatizirovannymi sistemami otopleniya / V. S. Severyanin, K. O. Meshik // Vestnik Brestskogo gosudarstvennogo tekhnicheskogo universiteta. Seriya: Vodohozyajstvennoe stroitel'stvo, teploenergetika i geoekologiya. – 2019. – № 2. – S. 74–77.
5. SN 4.02.03-2019 «Otoplenie, ventilyaciya i kondicionirovanie vozduha». / Ministerstvo arhitektury i stroitel'stva. – 2019. – s. 73.
6. Arhiv meteorologicheskih nablyudenij [Elektronnyj resurs] / Belgidromet. – Rezhim dostupa: http://www.pogoda.by/meteoarchive/#. – Data dostupa: 10.08.2022.
7. API Yandeks. Pogody [Elektronnyj resurs] / Yandeks.Pogoda. – Rezhim dostupa: https://yandex.ru/dev/weather/doc/dg/concepts/-about.html. – Data dostupa: 12.07.2022.
8. Bekman, U. A. Raschet sistem solnechnogo teplosnabzheniya / U. A. Bekman, S. A. Klejn, Dzh. A. Daffi // M. : Energoizdat. – 1982. – s. 80.
9. Daffi, Dzh. A. Teplovye processy s ispol'zovaniem solnechnoj energii / Dzh. A. Daffi, U. A. Bekman // M. : Mir. – 1977. – s. 413.
10. Salamov, O. M. Raschet srednesutochnogo koefficienta poleznogo dejstviya ploskogo solnechnogo kollektora / O. M. Salamov // Mezhdunarodnyj nauchnyj zhurnal «Al'ternativnaya energetika i ekologiya». – Nauchno-tekhnicheskij centr «TATA». – 2015. – №6 (170). – S. 17–23.
11. Estimation of operational efficiency of fixed and solar tracking PV systems in Belarus climate / O. P. Meshyk [et al.] // Vestnik of Brest State Technical University. – 2021. – № 3 (126). – P. 85–87.
12. Otchet eksperta A.B. Dyus'mikeeva Proekt PROON/GEF Proekt «Povyshenie energeticheskoj effektivnosti zhilyh zdanij v Respublike Belarus'» Proektirovanie stroitel'nyh konstrukcij s uchetom energoeffektivnyh inzhenernyh sistem. Energoobespechenie inzhenernyh sistem i mest obshchego pol'zovaniya solnechnymi fotoelektricheskimi panelyami [Elektronnyj resurs]. – Rezhim dostupa: https://docplayer.ru/53937169-Proon-gef-proekt-povyshenie-energeticheskoy-effektivnosti-zhilyh-zdaniy-v-respublike-belarus-ispolnitel.html. – Data dostupa: 10.07.2022.
13. Meshik, K. O. Upravlenie parametrami teplonositelya sistem otopleniya na osnove meteodannyh / K. O. Meshik // Innovacionnye tekhnologii v vodnom, kommunal'nom hozyajstve i vodnom transporte [Elektronnyj resurs] : materialy respublikanskoj nauchno-tekhnicheskoj konferencii, 20-21 maya 2021 g. / redkol.: S. V. Haritonchik [i dr.]. – Minsk : BNTU, 2021. – S. 27–31.
14. Geliosistemy i prinadlezhnosti. [Elektronnyj resurs] / Flamco meibes. – Rezhim dostupa: https://meibes.by/product-category/katalog/geliosistemy-i-prinadlezhnosti/. – Data dostupa: 10.08.2022.

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