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# Mathematical Modeling of the Combined Heat Supply System of a Solar House

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**Abstract.** Today, increasing energy efficiency in residential heating systems, saving fuel and energy resources, and improving the efficiency of using devices based on renewable energy sources is an urgent issue. The purpose of the article is to develop a mathematical model of the heat balance and conduct a theoretical study of one-story rural houses based on the use of solar energy in a non-stationary mode. To achieve this goal, an experimental one-story solar house with autonomous heat supply was built. The heat supply of the experimental solar house mainly uses solar energy, and when the heat supply load exceeds this load, the traditional boiler device is used. The power supply of the experimental solar house is provided by a solar panel (photovoltaic converter). A heat balance scheme for a solar house with autonomous heat supply and an electrothermal scheme of a physical model are proposed. Based on the proposed schemes, a mathematical model of heat balance and a calculation algorithm based on the heat balance equation of the dynamic state of the heat supply system of a one-story experimental solar house in a non-stationary mode have been developed. On the basis of mathematical modeling, the influence of the heat capacity of the wall structure on the temperature regime of the building was studied. On the basis of the MATLAB-Simulink program, the main temperature characteristics were built, on which the change in the temperature of the internal air of the building was analyzed depending on the ambient temperature. On the basis of the program, a modular scheme of the dynamic model was built. Based on the modular scheme, the results of the experiment on changing the air inside the solar house and the outdoor temperature are presented in the form of a graph. The mathematical model of the thermal balance of the building in dynamic mode and the obtained calculation results are recommended for use in the development of energy-efficient solar houses.

**Keywords:** solar radiation, thermal resistance, heat balance, dynamic model, mathematical modeling, solar house

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# Математическое моделирование комбинированной системы теплоснабжения солнечного дома

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**Реферат.** Вопросы экономии топливно-энергетических ресурсов, повышения эффективности систем теплоснабжения жилых помещений, а также использования устройств на основе возобновляемых источников энергии на сегодняшний день имеют особую актуальность. Цель статьи – разработать математическую модель теплового баланса и провести теоретическое исследование одноэтажных сельских домов, использующих солнечную энергию в нестационарном режиме. Для ее реализации построен экспериментальный одноэтажный солнечный дом с автономным теплоснабжением на основе преимущественно солнечной энергии. В случаях, если нагрузка на теплоснабжение превышает солнечную нагрузку, применяется традиционное котельное устройство. Электроснабжение экспериментального дома обеспечивается солнечной панелью (фотоэлектрическим преобразователем). Предложены схема теплового баланса солнечного дома с автономным теплоснабжением и электротепловая схема физической модели. На их основе разработаны математическая модель и алгоритм расчета, базирующийся на уравнении теплового баланса динамического состояния системы теплоснабжения экспериментального дома в нестационарном режиме. Исследовано влияние теплоемкости стеновой конструкции на температурный режим здания. В среде моделирования MATLAB-Simulink построены основные температурные характеристики, на которых проанализировано изменение температуры внутреннего воздуха здания в зависимости от температуры окружающей среды. Построена модульная схема динамической модели, результаты эксперимента по изменению воздуха внутри солнечного дома и температуры наружного воздуха представлены в виде графика. Математическая модель теплового баланса здания в динамическом режиме и результаты расчетов могут использоваться при разработке энергоэффективных солнечных домов.

**Ключевые слова:** солнечное излучение, тепловое сопротивление, тепловой баланс, динамическая модель, математическое моделирование, солнечный дом

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## Introduction

At present, a number of reforms are being carried out in Uzbekistan to the rationally use of natural fuel and energy resources, to introduce energy-saving technologies in the economy, to introduce widely modern technologies through radical modernization of production. These reforms are regulated, in particular, by Law of the Republic of Uzbekistan ZRU-539 of May 21, 2019 “On the Use of Renewable Energy Sources”, of May 26, 2017 PQ-3012 “On the Program of Measures for Further Development of Renewable Energy, Energy Efficiency in the Economy and Social Spheres for 2017–2021” and by PQ-3379 “On Measures to Ensure the Rational Use of Energy Resources” dated November 8, 2017 [1–4]. Decisions on energy and resource consumption, widespread introduction of energy-saving technologies in the manufacturing sector, expansion of the use of renewable energy sources, increasing energy efficiency in the economy are identified as priorities.

At present, the development of innovative technologies based on the use of renewable energy sources, the introduction of scientific and technological developments, increasing the energy efficiency of renewable energy devices, encouraging the expansion and localization of their production is carried out at the state policy level [5, 6]. It is important to conduct research based on modeling the heat balance of buildings to assess the feasibility of using solar energy in the heat supply of residential buildings, the development and implementation of solar-based heat supply systems.

Research on improving the efficiency of the use of solar energy in the heat supply of buildings is carried out by specialized scientists around the world [7–13]. The issues of modeling of solar collector heat supply systems and evaluation of the efficiency of application of solar collector in the heat supply of residential buildings, optimization and management of parameters of solar heat supply systems have been studied in detail [14–17]. Scientific research on the use of solar energy in various technological processes in the climatic conditions of the City of Karshi [18–25] have been performed. However, the analysis of scientific research shows that the creation and implementation of combined systems of solar and traditional heat supply of rural houses has not been sufficiently studied.

The article discusses the issue of modeling the heat balance of an experimental solar house based on a combined heat supply system. The general view of the experimental solar house is shown in Fig. 1 and the heat balance diagram is shown in Fig. 2.

*Fig. 1.* General view of the experimental solar house (Karshi)

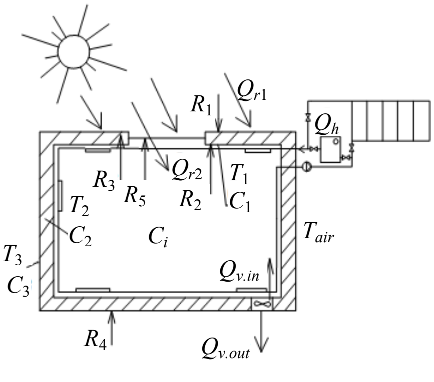

*Fig. 2.* Scheme of the heat balance of a solar house with autonomous heat supply

In Fig. 2 $Q_{r1}$ is the influx of heat directly from the sun on the facade of the building, W; $Q_{r2}$ is the influx of heat from the sun within the zone,W; $Q_{v.out}$ is heat transfer due to ventilation outside the area, W; $Q_{v.in}$ is heat transfer due to ventilation within the zone, W; $Q_h$ is heat provided to heat the house from an external source, W; $T_1$ is interior wall temperature, °C; $T_2$ is temperature of the inside of the structure, °C; $T_3$ is outside temperature of the structure, °C; $T_{air}$ is outside air temperature, °C; $C_i$ is air volume inside, J/K; $C_1$ is heat capacity of the building facade, J/K; $C_2$, $C_3$ are heat capacityes of the structure, J/K; $R_1$ is convective resistance of the building facade, K/W; $R_2$ is convective resistance of the inner side of the structure, K/W; $R_3$ is convective resistance of the structure, K/W; $R_4$ is convective resistance of the outer side of the structure, K/W; $R_5$ is total thermal resistance through glass (total thermal resistance of glass), K/W.

A dynamic model of the heat balance equation of a solar house with a combined autonomous heat supply was developed, and on this basis a mathematical model of the process was constructed according to the developed block diagram.

In the mathematical modeling of the object of study, a thermal-electrical scheme was first constructed that took into account the physical aspects of the model. For this purpose, the components of the indoor environment and its heat capacity were determined. The amount of heat delivered or consumed according to the specified quantities, its effect on the change in internal ambient temperature, the thermal resistance of the heat-receiving layer and other factors leading to changes in the total heat capacity were mathematically expressed on the basis of electro-thermal similarity theory. The electro-thermal scheme of the mathematical model is shown in Fig. 3.

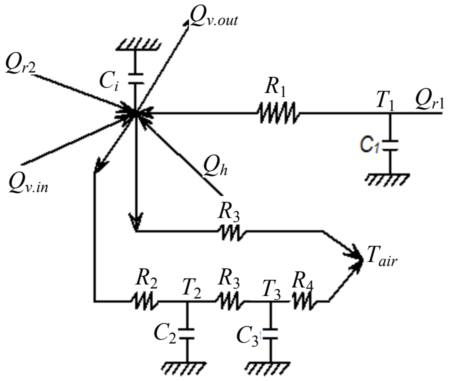

*Fig. 3.* Electrothermal scheme of a model built for an experimental solar house (designations are the same as in Fig. 2)

## Methods and materials

The dynamic mode of operation of the research object can be modeled using a system of linear differential equations. It will be possible to express these equations first in the form of matrices and then convert them into a dynamic model view using the MATLAB-Simulink program. The heat balance equation for the dynamic state of the solar house heat supply system has the following form:

$$\begin{cases} c_1 m_1 \dfrac{dt_1}{d\tau} = \alpha_{in} F\left(t_{in} - t_1\right) - \dfrac{F}{R_1}\left(t_1 - t_2\right); \\ c_2 m_2 \dfrac{dt_2}{d\tau} = \dfrac{F}{R_1}\left(t_1 - t_2\right) - \dfrac{F}{R_2}\left(t_2 - t_3\right); \\ c_3 m_3 \dfrac{dt_3}{d\tau} = \dfrac{F}{R_2}\left(t_2 - t_3\right) - \dfrac{F}{R_3}\left(t_3 - t_4\right) - \alpha_{out} F\left(t_4 - t_{out}\right) + q_{rad} F k_{trans} \alpha_{trans.coeff}; \\ c_{in} m_{in} \dfrac{dt_{in}}{d\tau} = G_w c_w \left(t_{in} - t_{out}\right) + q_{rad} F_{wind} k_{trans.wind} \alpha_{trans.coeff.wind} - G_{air} c_{air} \left(t_{in} - t_{out}\right) - \\ \qquad - kF\left(t_{in} - t_{out}\right) - \dfrac{F_{wind}}{R_{wind}}\left(t_{in} - t_{out}\right), \end{cases} \tag{1}$$

where $c_1$, $c_2$, $c_3$, $c_w$, $c_{air}$, $c_{in}$ are heat capacities of building front wall, building structure, water, air and indoor air, respectively, J/K; $m_1$, $m_2$, $m_3$, $m_{in}$ are the mass of the front wall of the building, the structure of the building and the air inside the building, respectively, kg; $F$, $F_{wind}$ are the surface of the building wall and the window part of the building, respectively, m$^2$; $\alpha_{in}, \alpha_{out}, \alpha_{trans.coeff}$, $\alpha_{trans.coeff.wind}$ are coefficients of heat transfer to the indoor air, to the outside of the building, from the building wall, and from the building window, respectively, W/(m$^2$·K); $q_{rad}$ is radiation flux density, W/м$^2$; $k_{tran}$ is heat transfer through the building structure, W/(m$^2$·K); $G_w$, $G_{air}$ is consumption of water and air, kg/s; $R_1$, $R_2$, $R_3$, $R_{wind}$ are convective resistance of building front wall, building interior wall, building structure and building glass, respectively, K/W; $t_{in}$, $t_1$, $t_2$, $t_3$, $t_4$, $t_{out}$ are temperatures of building interior air, building interior wall, building interior, building exterior, building exterior wall and exterior air, respectively, K.

The heat transfer coefficient and the thermal resistance of the layers were found from formula (2) [22]

$$k = \frac{1}{\dfrac{1}{\alpha_{in}} + \dfrac{\delta_1}{\lambda_1} + \dfrac{\delta_2}{\lambda_2} + \dfrac{\delta_3}{\lambda_3} + \dfrac{1}{\alpha_{out}}}, \tag{2}$$

where $\delta_1, \delta_2, \delta_3$ are the thickness of the front side of the building wall, of the building structure and the inner wall of the building, m; $\lambda_1, \lambda_2, \lambda_3$ are heat transfer coefficients of the front side of the building wall, the building structure and the internal wall of the building, W/(m·K).

By simplifying the right and left sides of equation (1), we get the following equations:

$$\frac{dt_1}{d\tau} = \frac{\left(-\alpha_1 F - \dfrac{F}{R_1}\right)}{m_1 c_1} t_1 + \frac{F}{R_1 m_1 c_1} t_2 + \frac{\alpha_1 F t_{in}}{m_1 c_1}; \tag{3}$$

$$\frac{dt_2}{d\tau}=\frac{F}{R_2m_2c_2}t_1+\frac{-\frac{F}{R_1}-\frac{F}{R_2}}{m_2c_2}t_2+\frac{F}{R_2m_2c_2}t_3; \tag{4}$$

$$\frac{dt_3}{d\tau}=\frac{F}{R_2m_2c_3}t_2+\frac{-\frac{F}{R_2}-\frac{F}{R_3}}{m_3c_3}t_3+\frac{-\frac{F}{R_3}\alpha_{out}F}{m_3c_3}t_4+\frac{\alpha_{out}F}{m_3c_3}t_{out}+\frac{Fk_{trans}\alpha_{trans}}{m_3c_3}q_{wind}; \tag{5}$$

$$\frac{dt_{in}}{d\tau}=\left(\frac{-G_{air}c_{air}-kF-\frac{F_{wind}}{R_{wind}}}{m_{in}c_{in}}t_{in}+\left(\frac{-G_wc_w+kF+\frac{F_{wind}}{R_{wind}}}{m_{in}c_{in}}\right)t_{out}+\right. \tag{6}$$

$$\left.+\left(\frac{1}{m_{in}c_{in}}\right)Q_h+\left(\frac{k_{trans.wind}\alpha_{trans.wind}F_{wind}}{m_{in}c_{in}}\right)q_{rad}\right).$$

Equations (5), (6) can be expressed in matrix form:

$$x'=Ax+Bu; \tag{7}$$

$$y=Cx+Du. \tag{8}$$

Vector indicators of equations (7), (8):

$$x=\begin{bmatrix}t_1\\t_2\\t_3\\t_{in}\end{bmatrix};\ x'=\begin{bmatrix}t_1'\\t_2'\\t_3'\\t_{in}'\end{bmatrix};\ y=\begin{bmatrix}t_1\\t_2\\t_3\\t_{in}\end{bmatrix};\ u=\begin{bmatrix}t_4\\t_{out}\\Q_h\\q_{rad}\end{bmatrix};$$

$$c=\begin{bmatrix}1000\\0100\\0010\\0001\end{bmatrix};\ D=\begin{bmatrix}1000\\0100\\0010\\0001\end{bmatrix}.$$

$$A=\begin{bmatrix}\dfrac{\left(-\alpha_1F-\dfrac{F}{R_1}\right)}{m_1c_1};\ \dfrac{F}{R_1m_1c_1};\ 0;\ \dfrac{\alpha F}{m_1c_1};\\ \dfrac{F}{R_1m_2c_2};\ \dfrac{-\dfrac{F}{R_1}-\dfrac{F}{R_2}}{m_2c_2};\ \dfrac{F}{R_2m_2c_2};\ 0;\\ 0;\ \dfrac{F}{R_3m_3c_3};\ \dfrac{-\dfrac{F}{R_2}-\dfrac{F}{R_3}}{m_3c_3};\ 0;\\ 0;\ 0;\ 0;\dfrac{-G_{air}c_{air}-kF-\dfrac{F_{wind}}{R_{wind}}}{m_{in}c_{in}}.\end{bmatrix}$$

$$
B = \begin{bmatrix}
0;\ 0;\ 0;\ 0; \\
0;\ 0;\ 0;\ 0; \\
\dfrac{\left(-\dfrac{F}{R_3} - \alpha_{out} F\right)}{m_3 c_3};\ 0;\ 0;\ \dfrac{F k_{trans} \alpha_{trans}}{m_3 c_3}; \\
0;\ \dfrac{G_{air} c_{air} + kF + \dfrac{F_{wind}}{R_{wind}}}{m_{in} c_{in}};\ \dfrac{1}{m_{in} c_{in}};\ \dfrac{k_{trans.wind} \alpha_{trans.wind} F_{wind}}{m_{in} c_{in}}.
\end{bmatrix}
$$

## Results and Discussions

According to the results of mathematical modeling, the analysis of the thermal regime of the research object is performed by entering the dynamic model into the MATLAB-Simulink program. A modular schematic of a dynamic model written in the MATLAB-Simulink programming language is shown in Fig. 4.

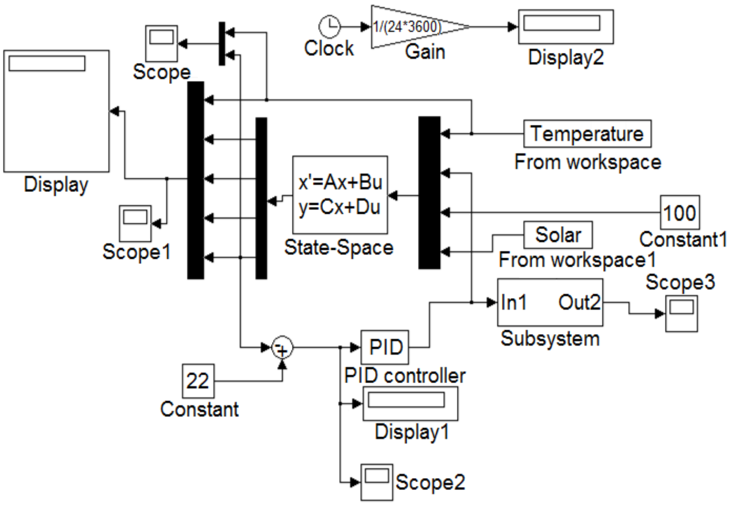

*Fig. 4.* Modular scheme of the dynamic model of the object

The object, i. e. the construction of the solar house, is affected by its indoor air temperature (Fig. 5). Given that the heating season of the solar house consists of November – March for the southern regions of the Republic of Uzbekistan, it is possible to analyze the change in indoor air temperature for a month depending on the outside air temperature.

Figures 5a, 5b show that from December 26 to January 7, 2020, the air temperature cooled to (–5)–(–10) degrees. This situation was also repeated on 20–22 January (Fig. 5b). Due to the cloudy weather at this time, the indoor air temperature of the research object was maintained at 22–24 °C using a water heating boiler. In Fig. 5b, 5c, 5d organic fuel savings were achieved as a result of not using a water heating boiler for heating purposes, as the average outdoor air temperature during the day was around 20 °C.

Figure 6 shows the temperature characteristics for the characteristic days of the study (December 29, 2020 and January 4, 2021).

As a result of modeling and calculation of the thermal regime of the object, the possibility of setting the required temperature in the solar house without increasing the thickness of the thermal insulation layers, i. e. material and resource costs, was assessed.

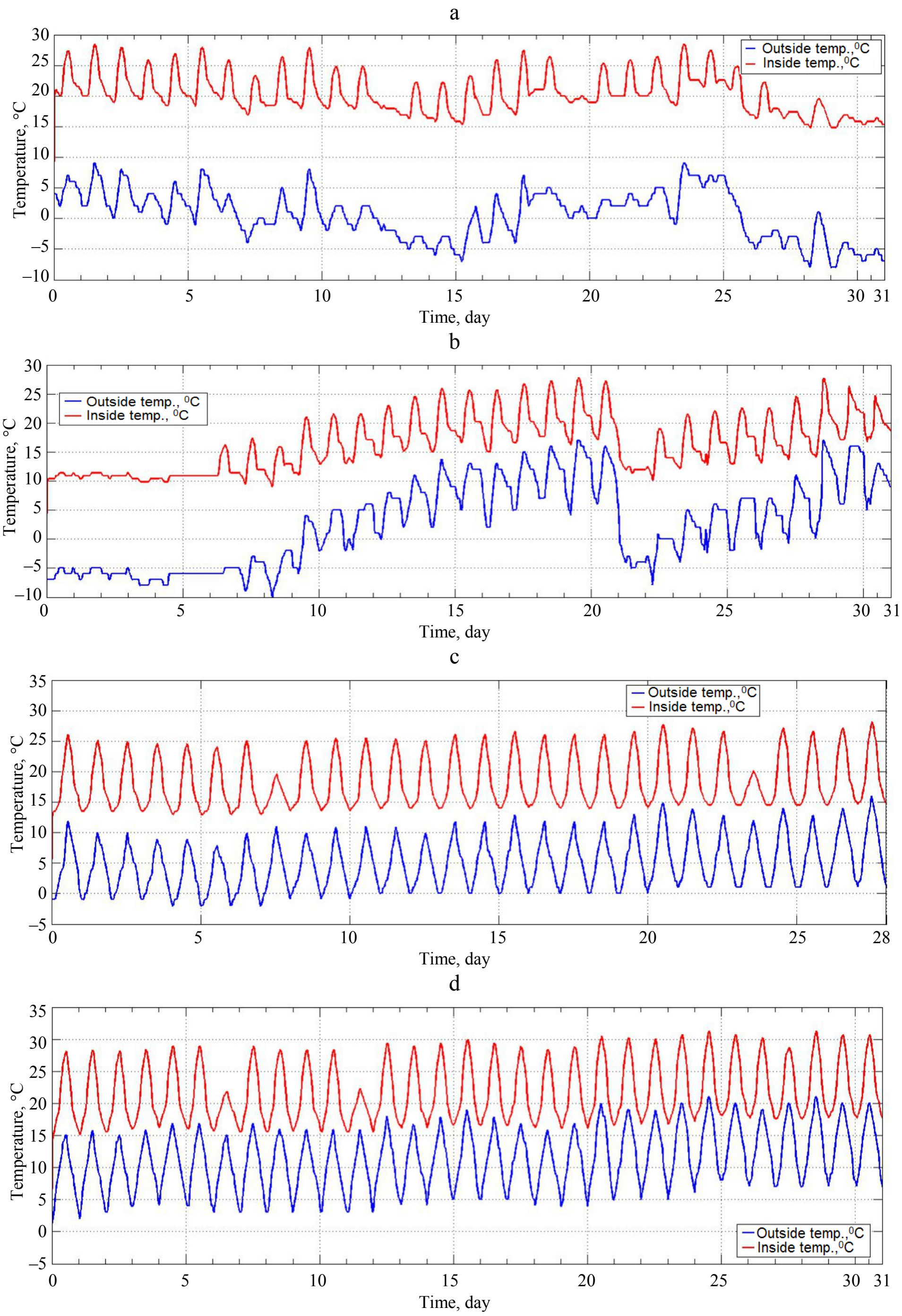

*Fig. 5.* Temperature characteristics of the solar house (obtained using the MATLAB-Simulink program): a – for December; b – January; c – February; d – March

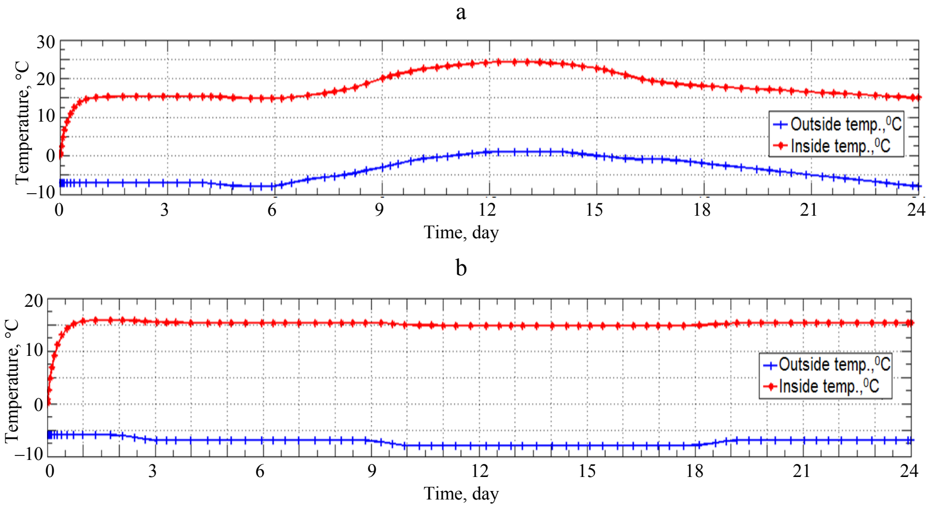

*Fig. 6.* Temperature characteristics of a solar house for typical days:
a – December 29, 2020; b – January 4, 2021

## CONCLUSIONS

1. A mathematical model of the heat balance of a country house in non-stationary mode was developed and a calculation algorithm was proposed.
2. On the basis of mathematical modeling, the effect of the heat capacity of the wall structure on the temperature regime of the building was studied.
3. The proposed model makes it possible to analyze temperature changes of indoor air depending on the ambient temperature.
4. Mathematical model of heat balance of the building in dynamic mode and the obtained results can be used in the development of energy efficient solar houses.

## REFERENCES

1. On the Use of Renewable Energy Sources. Law of of the Republic of Uzbekistan ZRU-539 of May 21, 2019. Available at: https://lex.uz/docs/-4346831 (in Uzbek).
2. On the Program of Measures for Further Development of Renewable Energy, Energy Efficiency in the Economy and Social Spheres in 2017–2021. Resolution of the President of the Republic of Uzbekistan, May 26, 2017, No PP-3012. Available at: https://lex.uz/ru/docs/-3221894 (in Uzbek).
3. On Measures to Ensure the Rational Use of Energy Resources. Resolution of the President of the Republic of Uzbekistan, November 8, 2017, No PP-3379. https://lex.uz/uz/docs/-3405580 (in Uzbek).
4. Missoum M., Hamidat A., Loukarfi L. (2014) Energetic Performance Analysis of a Solar Combisystem. Application to a Rural House in Chlef Region (Algeria). *Energy Procedia,* 50, 512–519. https://doi.org/10.1016/j.egypro.2014.06.062.
5. Gashimov A. M., Rakhmanov N. R., Akhmedova S. T. (2013) Hybrid Systems of Distributed Generation with Renewable Sources: Modeling and Analysis of Their Operational Modes in Electric Power System. *Energetika. Izvestiya Vysshikh Uchebnykh Zavedenii i Energeticheskikh Ob'edinenii SNG = Energetika. Proceedings of CIS Higher Education Institutions and Power Engineering Associations,* (2), 20–30 (in Russian).
6. Mironchuk V. I., Velchenko A. A. (2021) Increasing the Efficiency Factor of Solar Power Plants Due to Solar Energy Localizing. *Energetika. Izvestiya Vysshikh Uchebnykh Zavedenii i Energeticheskikh Ob'edinenii SNG = Energetika. Proceedings of CIS Higher Education Institutions and Power Engineering Associations,* 64 (1), 15–26. https://doi.org/10.21122/1029-7448-2021-64-1-15-26 (in Russian).
7. Shcheklein S. E., Korzhavin S. A., Danilov V. Yu., Velkin V. I. (2012) Experimental Study of the Efficiency of a Combined Solar Heat Generation System. *Alternativnaya Energetika i Ekologiya = Alternative Energy and Ecology*, (3), 77–81 (in Russian).

8. Nazarova T. B., Guseva K. P., Zhilina T. S. (2017) Heating Using Solar Collectors in the City of Orenburg. *Molodoy Ucheniy* [Young Scientist], (8), 40 (in Russian).
9. Krivoshein Y. O., Tsvetkov N. A., Tolstykh A. V., Khutornoy A. N., Kolesnikova A. V., Petrova A. V. (2020) Effective Solar Hot Water System for Northern Territories. *Vestnik Tomskogo Gosudarstvennogo Arkhitekturno-Stroitel'nogo Universiteta = Journal of Construction and Architecture,* 22 (6), 119–131. https://doi.org/10.31675/1607-1859-2020-22-6-119-131 (in Russian).
10. Zuev I. A., Tolstoy M. Yu., Tunik A. A. (2016) Development of a New Solar Collector Sun 3 for Heat Supply and Hot Water Supply of the Objects of Social and Residential Sphere of Irkutsk Region. *Izvestiya Vuzov. Investitsii. Stroitelsvo. Nedvizhimost = Proceedings of the Universities. Investment. Construction. Real Estate,* 4 (19), 100–113 (in Russian).
11. Yumaev N. R. (2018) On the Possibility of Using Solar Collectors to Obtain Thermal Energy in the Climatic Conditions of Tajikistan. *Tekhnicheskie Nauki: Teoriya i Praktika: Materialy IV Mezhdunar. Nauch. Konf. (g. Kazan', Noyabr' 2018 g.)* [Technical Sciences: Theory and Practice: Materials of the IV Intern. Scientific Conf. *(*Kazan, November 2018)]. Kazan, Molodoi Ucheniy Publ. 32–36.
12. Mohammed Kamil Ali Ghazi (2015) Modes of Operation and Diagnostics of Power Plants for Heat Supply on the Basis of Solar Heaters. *Izvestiya Vuzov. Severo-Kavkazskii Region. Tekhnicheskie Nauki = University News. North-Caucasian Region. Technical Sciences Series*, (2), 104–106. http://doi.org/10.17213/0321-2653-2015-2-104-106 (in Russian).
13. Issam A. (2009) *Modeling of Thermal Modes of Operation of the Building with the Use of the System MATLAB/Simulink. Izvestiya Vuzov. Severo-Kavkazskii Region. Tekhnicheskie Nauki = University News. North-Caucasian Region. Technical Sciences Series,* (1), 95–99 (in Russian).
14. Efremova O. A., Khvorova L. A. Mathematical Modeling of Solar Heating Systems. *Izvestiya Altaiskogo Gosudarstvennogo Universiteta = Izvestiya of Altai State University,* (4), 98–103. http://doi.org/10.14258/izvasu(2017) 4-17 (in Russian).
15. Onishchenko S. V. (2009) *Autonomous Energy-Efficient Manor-Type Buildings*. Moscow (in Russian).
16. Ivanov G. S., Podolyan G. S. (2001) Power Supply in Buildings. *Novosti Teplosnabzheniya* [Heat Supply News], (7), 8–13 (in Russian).
17. Uzakov G. N., Khamraev S. I., Khuzhakulov S. M. Rural House Heat Supply System Based on Solar Energy. *IOP Conference Series: Materials Science and Engineering*, 1030, 012167 https://doi.org/10.1088/1757-899X/1030/1/012167.
18. Khuzhakulov S. M., Uzakov G. N., Vardiyashvili A. B. (2013) Effectiveness of Solar Heating Systems for the Regeneration of Adsorbents in Recessed Fruit and Vegetable Storages. *Applied Solar Energy,* 49 (4), 257–260. https://doi.org/10.3103/S0003701X13040075.
19. Uzakov G. N., Vardiyashvili A. B. (2011) Intensity Influence of Solar Radiation on Shrinkage of Goods in Fruit and Vegetable Stores. *Applied Solar Energy*, 47 (1), 27–30. https://doi.org/10.3103/S0003701X11010178.
20. Uzakov G. N. (2012) Technical and Economic Calculation of Combined Heating and Cooling Systems Vegetable Store-Solar Greenhouse. *Applied Solar Energy*, 48 (1), 60–61. https://doi.org/10.3103/S0003701X1201015X.
21. Sychov A., Kharchenko V., Vasant P., Uzakov G. (2018) Application of Various Computer Tools for the Optimization of the Heat Pump Heating Systems with Extraction of Low-Grade Heat from Surface Watercourses. *Intelligent Computing & Optimization. ICO 2018. Advances in Intelligent Systems and Computing,* 866. Springer, Cham. https://doi.org/10.1007/978-3-030-00979-3_32.
22. Uzakov G. N. (2011) Calculation of the Heat Engineering Characteristics of a Combined System of a Vegetable Storage Facility and Solar Greenhouse. *Applied Solar Energy*, 47 (3), 248–251. https://doi.org/10.3103/S0003701X11030200.
23. Kharchenko V. V., Sychov A. O., Uzakov G. N. (2019) Innovative Instruments for Extraction of Low-Grade Heat from Surface Watercourses for Heating Systems with Heat Pump. *Innovative Computing Trends and Applications,* 59–68. https://doi.org/10.1007/978-3-030-03898-4_7.
24. Avezova N. R., Avezov R. R. (2016) A Procedure for Accelerated Determination of Main Heat Engineering Parameters of Flat-Plate Solar Collectors for Heating of a Heat Transfer Fluid. *Applied Solar Energy*, 52, 93–96. https://doi.org/10.3103/S0003701X16020080.
25. Avezov R. R., Orlov A. Yu. (1998) *Solar Heating and Hot Water Systems.* Tashkent, Fan Publ. 288 (in Russian).

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