VOL. 4, No. 1
Journal of Osh State University. Mathematics. Physics. Technical Sciences
2025
Journal of Osh State University
Journal homepage: https://mpht-oshsu.com/en
**UDC** 662.997.534
**DOI:** 10.52754/16948645_2025_4(1)_70
**Article's History:**
Received 29.01.2025 Revised 02.05.2025 Accepted 19.06.2025

# Design of heat losses calculation method in elements of double-circuit solar water heating collectors

**Sayit Sultanov***
PhD in Technical Sciences, Associate Professor
Osh State University
723500, 331 Lenin Str., Osh, Kyrgyz Republic
https://orcid.org/0000-0003-4330-025X

**Idirisbek Kenzhaev**
Doctor of Technical Sciences, Professor
Osh State University
723500, 331 Lenin Str., Osh, Kyrgyz Republic
https://orcid.org/0000-0002-8094-2553

**Zhanbolot Tursunbaev**
PhD in Technical Sciences, Associate Professor
Osh Technological University
723503, 81 Isanov Str., Osh, Kyrgyz Republic
https://orcid.org/0009-0006-8465-7879

**Ilyas Ryskulov**
Senior Lecturer
Institute of Innovative Technologies and Energy
721405, 5 Studencheskaya Str., Tash-Kumyr, Kyrgyz Republic
https://orcid.org/0000-0002-5680-7554

**Abstract.** With the increasing interest in the use of renewable energy sources, in particular solar collectors, improving their energy efficiency has become particularly important. One of the key factors affecting the overall performance of such installations is heat losses through structural components. However, in practice, there is a lack of universal methods that allow for accurate assessment of these losses for collectors of different types. This determines the need to develop a flexible approach applicable to installations of different designs, which determines the relevance of this study. The aim of the study was to develop a method for calculating heat losses in elements of solar water heating collectors and to establish factors that directly affect its efficiency and performance. In these studies, computational and analytical research methods and thermodynamic analysis methods were used, and on their basis detailed information on heat losses in the collector elements was obtained. Based on the results of the conducted research, it was established that the main factors influencing the values of heat losses and the efficiency of double-circuit water heating collectors are the solar radiation density, the temperature of the environment and the working water. The obtained results make it possible to calculate the heat losses value through the construction elements of the collector. It was found that the greatest heat losses were observed from the collector's face covering. A heat balance equation was derived, and a thermal diagram of the solar water heating system was presented. Theoretically, changes in the heat transfer coefficient depending on ambient temperature and wind speed were investigated. The results obtained in the course of the study have scientific significance for further development and improvement of solar water-heating collector designs. In particular, the identified dependence of heat losses on the structural features of the collector's front side enables researchers and engineers to focus on its optimisation in order to reduce convective losses. This creates a foundation for the development of more effective engineering solutions in the design of such systems and can be used in the modelling, calculation, and testing of new solar collector designs

**Keywords:** solar radiation; heat transfer coefficient; heat exchange; heat balance; heat-absorbing surface; convection; radiation

**Suggested Citation:**
Sultanov S, Kenzhaev I, Tursunbaev Zh, Ryskulov I. Design of heat losses calculation method in elements of double-circuit solar water heating collectors. J Osh State Univ Math Phys Tech Sci. 2025;4(1):70–80. DOI: 10.52754/16948645_2025_4(1)_70

*Corresponding author

## Introduction

The development and construction of power plants based on renewable energy sources is an important engineering task. Solar radiation is characterised by abundant resources, environmental friendliness, and availability, making it one of the most promising forms of renewable energy. Therefore, solar energy installations attract considerable interest. Considering this, the study of thermal characteristics of solar water heating collectors (SWC) and ways to improve their efficiency is significantly important.

The interest in solar water heating systems (SW) is growing due to their environmental friendliness and the possibility of saving energy costs. In a review by M.R. Al-Mamun *et al*. [1], modern SWC designs are analysed in detail, including flat and evacuated tube collectors, as well as the use of nanofluids to enhance heat transfer. The authors note the effectiveness of nanofluids (for example, MWCNT and $Al_2O_3$) in increasing efficiency by 28-35%, but point out the lack of models for double circuits, which emphasises the need to develop adaptive methods for calculating heat losses. In the study by A. Bouhdjar *et al*. [2], an improved method for calculating the total heat loss coefficient in flat-plate collectors is proposed, considering materials temperature dependence and thermal resistance. The authors presented an analytical model and experimentally confirmed its effectiveness for metal absorbers. However, the model is not adapted to complex geometries, such as tubular or double-loop structures, which requires further expansion.

The work of B.E. Khayriddinov *et al*. [3] was devoted to mathematical modelling of heat accumulation processes in double-loop flat solar water heating systems taking into account the stratification of the coolant. The authors developed an experimental module and compared the results of numerical modelling with practical observations, which made it possible to establish a relationship between the parameters of the heat exchanger (including the coil in the storage tank) and the efficiency of heat transfer. In the study particular attention is paid to the creation of a mathematical model of thermal accumulation using a system of equations implemented in a software environment. The data obtained demonstrated a high degree of agreement between theoretical and experimental results; however, the study is limited to stationary operating conditions and does not cover the influence of external climatic factors. R. Roy [4] focused on non-stationary thermal analysis of absorbers under conditions of changing solar radiation. The model developed in their study takes into account the thermal inertia of the material and allows predicting the point in time at which heat loss exceeds the useful heat flow. Despite its high theoretical accuracy, the work does not cover the influence of external factors such as wind and humidity, which limits its practical application in real installations. In the work of A.R. Kalair *et al.* [5], a numerical simulation of solar water heating systems was performed using various types of collectors, including flat, vacuum and parabolic concentrators. The authors showed that vacuum tube collectors have the highest seasonal efficiency, providing up to 50% coverage of hot water needs under favourable climatic conditions. The importance of selecting a collector design considers regional insolation and the thermal properties of the heat carrier is emphasised. N. Temirbaeva *et al*. [6] analysed the potential of solar energy in Kyrgyzstan and showed that the insolation level in the republic averages 6.4-6.7 kW h/m$^2$ per day, with more than 2,800 sunny hours per year. This makes solar energy particularly promising for autonomous and hybrid solutions. Despite the significant resource, the authors note the lack of effective engineering methods for calculating the performance of solar thermal systems taking into account local climatic conditions. J. Beringer's bachelor's thesis [7], completed at HAW Hamburg, contains an analysis of solar thermosyphon systems in rural areas of Kyrgyzstan. The author records high heat losses at night and insufficient insulation of pipelines, proposing to strengthen thermal protection and introduce bimetallic absorbers. The work is important from the point of view of regional applicability, but requires quantitative verification of the proposals.

In light of the above, the research and development of solar hot water supply systems using dual-circuit solar collectors represents a highly relevant and promising area of study. The aim of this work was to develop and validate a method for calculating the thermal parameters of a solar water heating system with a double-circuit collector, and to identify the factors that directly influence its efficiency and performance.

## Materials and Methods

Heat exchange processes in solar water heating collectors (SWC) occur continuously, beginning from the moment when solar radiation reaches the surface of the collector, then converts into thermal energy and further heating of the coolant. These losses occur during the heat transfer process and directly affect the productivity and technical and economic indicators of the entire system.

The methodological basis of this study was the approaches developed in classical works by J.A. Duffy & W.A. Beckman [8], as well as R.R. Avezov [9], aimed at calculating heat losses in the SWC. In addition, the work relies on a series of earlier studies [10-11], in which the analysis of thermal characteristics was based on the assumption that incoming solar radiation is converted into useful heat spent on heating the intermediate coolant (water), while the remaining part is accumulated in the structural elements and subsequently lost into the environment.

A distinctive feature of the heat loss calculation method proposed in this paper is its adaptation to the custom design of a double-circuit solar water heating collector, developed by the authors and protected under patent KR No. 1706 [12]. The system differs from standard models in several structural and operational characteristics, which necessitated an individualised approach to modelling heat exchange processes.

To enable a more accurate assessment of heat losses, a thermal diagram was utilised, reflecting energy flows and the interaction of components within the system. The theoretical foundation for the analysis was a heat balance model, modified to account for the specific structural features of the studied installation. This approach enables more precise localisation of zones with the highest thermal losses and facilitates optimisation of the design for improved energy efficiency. The heat balance equation for solar water heating collectors during energy distribution is formulated as follows:

$$E = Q_p + Q_a + Q_{tp}, \tag{1}$$

where $Q_p$ – useful energy expended to heat the consumed water in the solar collector; $Q_a$ – energy accumulated in the main elements of solar collectors; $Q_{tp}$ – heat losses from solar collector elements to the environment (through the top, sides and bottom). The efficiency of solar collectors is defined as:

$$\eta = \frac{Q_p}{E} = 1 - \frac{Q_a + Q_{tp}}{E}. \tag{2}$$

Consideration should be given to the heat accumulated in the components of solar collectors ($Q_a$) during the initial phase of system operation, or when significant fluctuations in solar radiation intensity occur throughout the day. However, when analysing the thermal performance of solar collectors at a specific moment in time, this component may be considered negligible. In such cases, the efficiency of the solar collectors can be expressed using the following equation:

$$\eta = \frac{Q_p}{E} = \frac{E - Q_{tp}}{E} = 1 - \frac{Q_{tp}}{E}. \tag{3}$$

The density of total solar radiation supplied to the surface of the water heating collector is determined as:

$$E = E_o FTA. \tag{4}$$

For double-glazing:

$$E = E_o FT^2 A, \tag{5}$$

$$Q_p = g(t_n - t_k), \tag{6}$$

$$Q_{tp} = Fk\Delta t, \tag{7}$$

where $E_o$ – the density of total solar radiation falling on the surface of a solar collector; $F$ – area of the solar collector's beam-receiving surface; $T$ – light transmittance coefficient of glass coating; $A$ – heat absorption coefficient of the heat-receiving surface; $k$ – heat absorption coefficient of the heat-receiving surface; $\Delta t$ – the difference between the indoor and outdoor air temperatures. The density of total solar radiation passing through single or double-layer upper glazing and reaching the heat-absorbing surface of a solar water heating collector, at:

$$E_0 = 0 \div 850\ \text{W/m}^2;$$
$$F_1 = 0.47\ \text{m}^2;\ F_2 = 0.4\ \text{m}^2;$$
$$T = 0.95;\ A = 0.95$$

is within $E = 0 \div 342\ \text{W/m}^2$.

Heat losses from solar water heating collectors are generally defined as:

$$Q_{tp} = Q_a + Q_b + Q_c, \tag{8}$$

where $Q_a$ – heat losses from the upper part of solar water heating collectors (from the glass cover side); $Q_b$ – heat losses from the sides of solar water heating collectors; $Q_c$ – heat losses from the bottom of solar water heating collectors.

To calculate heat losses in the structural elements of a solar water heating collector, heat balance equations were used, previously issued in the form of patents Patent No. 5284 [13], No. 5930 [14], Patent KR No. 1605 [15]. These equations are applicable to all types of installations created according to a similar scheme and examine the combined effects of heat transfer, energy storage and losses. Heat losses in the system were determined based on the following expression, reflecting the overall energy balance of the collector:

$$Q_{tp} = Q_a + Q_b + Q_c = \Delta t(k_a F_a + k_b F_b + k_c F_c), \tag{9}$$

where $k_a + k_b + k_c$ – heat transfer coefficients respectively through the top, sides and bottom of solar water heating collectors; $F_a + F_b + F_c$ – areas of the above-mentioned parts of solar water heating collectors.

To visualise heat exchange processes in the collector design, a thermal diagram developed by the authors was used, reflecting the interaction of the installation components, energy transfer and the direction of heat loss. Figure 1 shows the specified thermal diagram of a solar water heating collector with an intermediate water coolant. According to the given model, heat losses to the environment occur from the surface of all structural elements mainly due to convection and radiation.

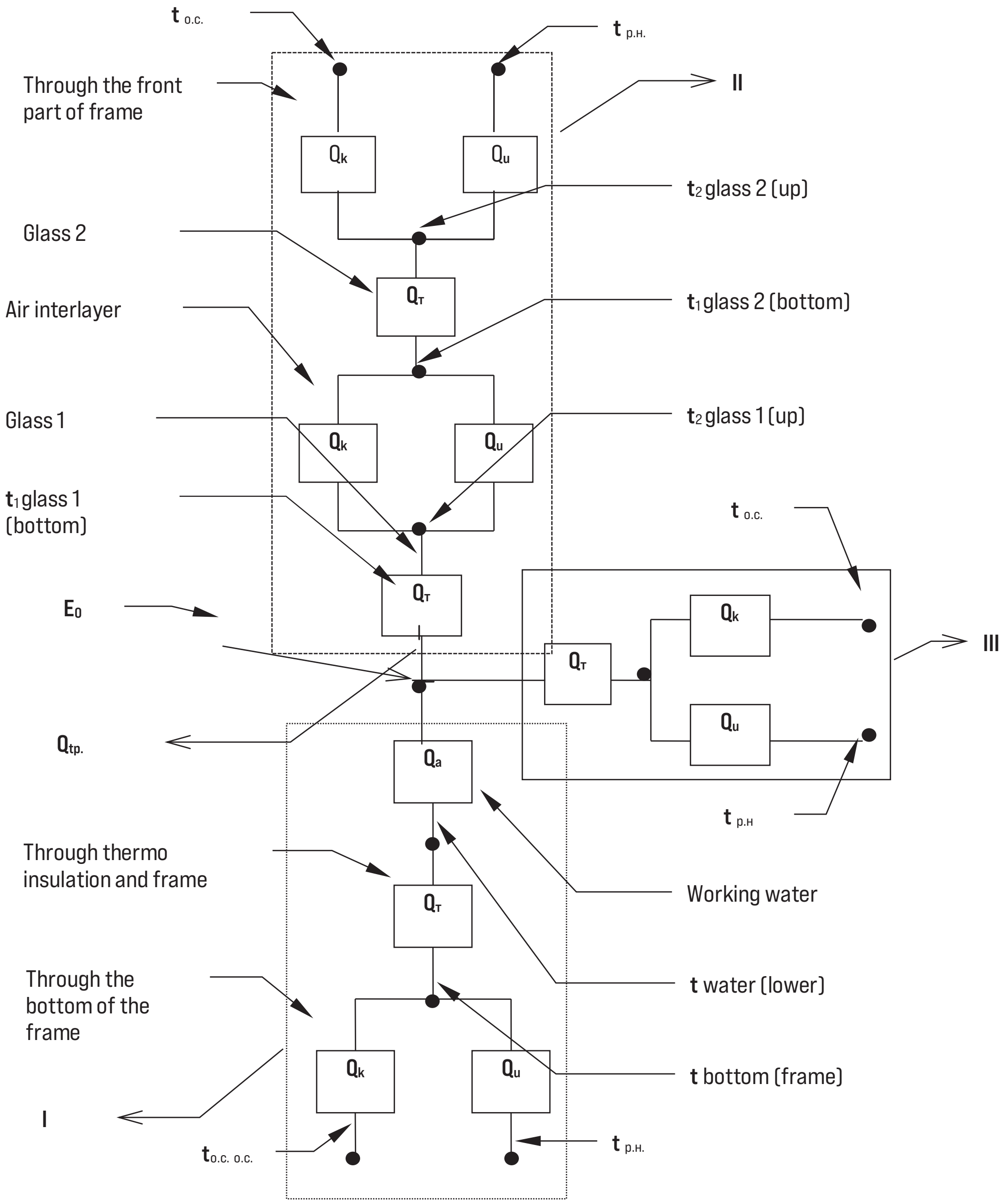


**Figure 1.** Thermal diagram of a solar water heating collector with an intermediate water coolant
**Note:** I, II, III – heat losses respectively through the bottom, upper part and side surfaces of the solar water heating collectors; $Q_T$, $Q_K$, $Q_U$ – respectively heat flows transferred by thermal conductivity, convection and radiation; $E_0$ – density of incident solar radiation; $Q_a$ – heat accumulated by the solar water heating collector; $Q_{tp}$ – useful heat
**Source:** created by authors

The heat transfer coefficient through the upper part of solar water heating collectors is determined by the formula:

$$k_a = \left(\frac{1}{k_1+k_1^1} + \frac{1}{k_2+k_2^1}\right)^{-1}, \qquad (10)$$

where $k_1$ – coefficient of convective heat transfer between glass coatings in a solar water heating collector; $k_1^1$ – coefficient of radiant heat transfer between glass coatings; $k_2$ – coefficient of convective heat exchange between the top glass covering and the environment; $k_2^1$ – coefficient of heat transfer by radiation from a glass covering to the sky. In turn $k_1$ is determined by formula:

$$k_1 = \frac{k_{T_g}}{k_{10}} = 1 - 0.0018(T_{av} - 10), \qquad (11)$$

where $k_{10} = 1.14\frac{\Delta T^{0.31}}{l^{0.07}}$ – empirical formula for determining the coefficient of convective heat exchange between the glass coatings of a solar water heating collector, in the case where the temperature difference between the outer and inner surfaces of the solar water heating collector is ~ 10 °C, which is an acceptable value. Then:

$$k_1 = \left[1 - 0.0018(T_{av} - 10)\right] \times 1.14 \frac{\Delta T^{0.31}}{l^{0.07}}, \quad (12)$$

where $l$ – distance between glass coverings; $T_{av}$ – average temperature of the outer part of the heat-absorbing surface and the average inner surface of the outer glass covering; $\Delta T$ – temperature difference between the average outer part of the heat-absorbing surface and the inner surface of the outer glass covering.

In this case, the inner glass coating is in direct contact with the polyethylene film of the container, and it can be considered that both of them simultaneously perform the function of the heat-absorbing surface. The coefficient of heat transfer by radiation from the heat-absorbing surface to the outer glass coating, located at a distance of 30 mm, is determined by the expression:

$$k_1^1 = \frac{\sigma(T_p + T_g)(T_p^2 + T_g^2)}{\frac{1}{\varepsilon n} + \frac{1}{\varepsilon g} - 1}, \quad (13)$$

where $\sigma$ – is the Stefan-Boltzmann constant; $T_p$ – temperature of the heat-absorbing surface of the solar water-heating collector; $T_g$ – temperature of the inner surface of the outer glass covering; is the emissivity of the heat-absorbing polyethylene film; $\varepsilon_n$ – emissivity of the glass covering of the solar water-heating collector.

The convective heat transfer coefficient from the surface of the solar water heating collector to the surrounding environment depends on the air velocity ($V_a$) and is determined by the following equation:

$$k_2 = 5.7 + 3.8\,V_a. \quad (14)$$

The coefficient of heat transfer by radiation from the outer glass surface of a solar water heating collector to the sky is determined by the expression:

$$k_2^1 = \varepsilon_g \sigma(T_o + T_n)(T_o^2 + T_n^2), \quad (15)$$

where $T_0$ – ambient temperature; $T_n = T_0 - 6$ – radiation temperature of the sky.

In this case, all parameter values are known except for the temperature of the outer surface of the inner glass coating ($T_g$), for which the iteration method was used. First, the temperature value was accepted and the heat transfer coefficient value was determined at the top of the solar water heating collector. To determine the temperature value of the inner surface of the outer glass coating, the following formula was used:

$$T_g = T_p - \frac{k_a(T_p - T_o)}{k_1 + k_1^1}. \quad (16)$$

In this case, the $T_g$ temperature values are determined for the following values of the solar water heating collector parameters: $l = 0.03$m; $T_{av} = 58\,^\circ$C; $\Delta T = 44\,^\circ$C; $T_p = 80\,^\circ$C; $\varepsilon_n = 0.95$; $\varepsilon_g = 0.88$; $T_o = 35\,^\circ$C; $T_n = 29\,^\circ$C.

## Results and Discussion

Using formulas (12)-(15), the numerical values of the coefficients $k_1$, $k_1^1$, $k_2$, $k_2$ were determined. Substituting the values of the named coefficients into formula (10) and carrying out the corresponding calculations, it was established that the values of the heat transfer coefficient from the bottom, side and top parts of the solar water heating collector at wind speed $V_a = 0 \div 6$ m/sec are $k_a = 1.286 \div 2.865$ W/(m$^2$deg).

For the side and bottom parts of the solar water heating collector, the heat transfer coefficient values are the same and are determined by the expression:

$$k_b = k_c = \frac{1}{\frac{\delta_p}{\lambda_p} + \frac{\delta_i}{\lambda_i} + \frac{\delta_c}{\lambda_c}} + \frac{1}{k_2 + k_2^1}, \quad (17)$$

where $\delta_p$ and $\lambda_p$ – are the thickness and thermal conductivity coefficient of the polyethylene film, respectively; $\delta_i$ and $\lambda_i$ – are the same for thermal insulation; $\delta_c$ and $\lambda_c$ – are the same for the cinder concrete wall of the solar water heating collector housing $p = 1{,}500$ kg/m$^3$.

By substituting the numerical values of the parameters included in equations (17) and the calculations performed, the numerical values of the heat transfer coefficient $k_b$ through the sides and bottom of the solar water heating collector housing were determined, which amounted to $k_b = k_c = 0.82 \div 2.14$ W/(m$^2$deg).

The results of the calculations performed using formulas (10) and (17) are presented in Table 1. The calculations were performed for different temperatures of the heated water, taking into account the change in wind speed. The numerical values of the heat transfer coefficients from the bottom, side and upper parts of the solar water heating collector were determined.

**Table 1.** Heat transfer coefficients depending on wind speed and working water temperature $k_a$, $k_b$, $k_c$ W/(m$^2$deg)

| No. | Temperature of working water in SWH, ˚C | Wind speed, m/sec | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| 1.For the top of the solar water heating collectors | 40 | 1.286 | 1.413 | 1.476 | 1.513 | 1.538 | 1.555 | 1.569 |
| | 50 | 1.647 | 1.860 | 1.970 | 2.040 | 2.084 | 2.116 | 2.141 |
| | 60 | 1.830 | 2.100 | 2.242 | 2.328 | 2.387 | 2.430 | 2.463 |
| | 70 | 1.950 | 2.260 | 2.426 | 2.527 | 2.600 | 2.650 | 2.687 |
| | 80 | 2.045 | 2.385 | 2.570 | 2.685 | 2.764 | 2.820 | 2.865 |

Table 1. Continued

| No. | Temperature of working water in SWH, ˚C | Wind speed, m/sec | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| 2. For bottom and sides solar water heating collectors | 40 | 0.82 | 0.88 | 0.98 | 1.19 | 1.31 | 1.43 | 1.58 |
| | 50 | 0.96 | 1.05 | 1.15 | 1.26 | 1.38 | 1.50 | 1.63 |
| | 60 | 1.10 | 1.19 | 1.31 | 1.43 | 1.58 | 1.75 | 1.94 |
| | 70 | 1.22 | 1.31 | 1.45 | 1.62 | 1.76 | 1.90 | 2.06 |
| | 80 | 1.31 | 1.44 | 1.58 | 1.74 | 1.80 | 1.97 | 2.14 |

**Source:** created by authors

Analysis of the heat transfer coefficient values at the bottom, sides, and top of the solar water heating collector, as presented in Table 1, indicates that an increase in ambient wind speed leads to a corresponding rise in these coefficients. It is also noteworthy that higher temperatures of the working water result in a more pronounced increase in heat transfer coefficient values.

By substituting the obtained coefficients corresponding to different water temperatures into equation (9), the heat losses through the structural components of the solar water heating collectors were calculated. Table 2 presents the results of these calculations, showing total heat losses as a function of air velocity and working water temperature.

It was found that for a solar water heating collector with an area of $F_a = 0.47$ m$^2$, $F_b + F_c = 0.531$ m$^2$ total heat losses according to the calculations were within the range: $Q_{tp} = 9.4 \div 189.5$ W [12].

**Table 2.** Heat losses from the bottom, sides and top of solar water heating collectors depending on wind speed and working water temperature $Q_a$, $Q_b$, $Q_c$, *W*

| Main elements of the collector | Temperature of working water in SWH, ˚C | Wind speed, m/sec | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| 1. For the top of solar water heating collectors, $Q_a$ | 40 | 3.4 | 3.6 | 3.7 | 3.8 | 3.8 | 3.8 | 3.8 |
| | 50 | 12.3 | 13.3 | 13.9 | 14.4 | 14.8 | 15.0 | 15.2 |
| | 60 | 24.1 | 26.4 | 27.8 | 28.6 | 29.2 | 30.3 | 30.6 |
| | 70 | 32.6 | 35.8 | 37.6 | 38.4 | 39.2 | 40.0 | 41.0 |
| | 80 | 40.8 | 44.6 | 49.4 | 52.1 | 53.6 | 55.1 | 56.0 |
| 2. For side parts of solar water heating collectors, $Q_b$ | 40 | 0.6 | 0.7 | 0.7 | 0.8 | 0.8 | 0.8 | 0.8 |
| | 50 | 1.8 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 2.4 |
| | 60 | 3.2 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.8 |
| | 70 | 5.4 | 6.8 | 7.6 | 8.2 | 8.5 | 8.7 | 8.9 |
| | 80 | 6.8 | 8.4 | 10.2 | 11.8 | 12.4 | 13.2 | 14.0 |
| 3. For the bottom of solar water heating collector housings, $Q_c$ | 40 | 5.4 | 6.1 | 6.4 | 6.5 | 6.7 | 6.8 | 6.9 |
| | 50 | 22.2 | 25.8 | 28.4 | 28.9 | 29.8 | 30.1 | 32.2 |
| | 60 | 39.7 | 47.3 | 51.1 | 53.3 | 54.9 | 55.2 | 57.4 |
| | 70 | 62.0 | 74.6 | 80.6 | 83.4 | 86.2 | 88.6 | 89.8 |
| | 80 | 87.8 | 104.7 | 110.8 | 114.4 | 116.8 | 118.2 | 119.5 |

**Source:** created by authors

Based on the results presented in Tables 1 and 2, it can be concluded that the heat transfer coefficient at the bottom, sides, and top of the solar water heating collector depends on both the working water temperature and wind speed. Specifically, as these parameters increase, the heat transfer coefficients of the collector's protective components also rise. These findings confirm that the heat exchange between the collector and the surrounding environment becomes more pronounced with higher water temperatures and varying external conditions.

The maximum heat transfer coefficient for the upper part of the collector using an intermediate water coolant was calculated as 2.865 W/(m$^2$deg), while the corresponding values for the bottom and side sections were 2.14 W/(m$^2$deg). The resulting maximum heat losses were as follows: 119.5 W from the upper part with a surface area of 0.47 m$^2$; 14 W from the side walls with an area of 0.101 m$^2$; and 56 W from the bottom with an area of 0.43 m$^2$.

For the given collector geometry and operating conditions – maximum solar radiation intensity, working water temperature in the polyethylene container, and wind speed – the total heat loss was estimated at 189.5 W. The results also showed that as the intensity of total solar radiation increased, the temperature of the working fluid rose accordingly. This, in turn, led to a greater temperature difference between the fluid and ambient air, thereby increasing heat losses from the collector's structural elements.

Given that heat losses depend on both the working water temperature and the solar radiation intensity, the efficiency of the solar water heating collector was calculated using equations (3) and (4). During the experiments, the maximum solar radiation intensity measured on the collector surface reached 860 W/m². Based on the obtained efficiency values, graphical dependencies were constructed to illustrate efficiency as a function of solar radiation intensity and ambient temperature at an air speed of 3 m/s (Fig. 2).

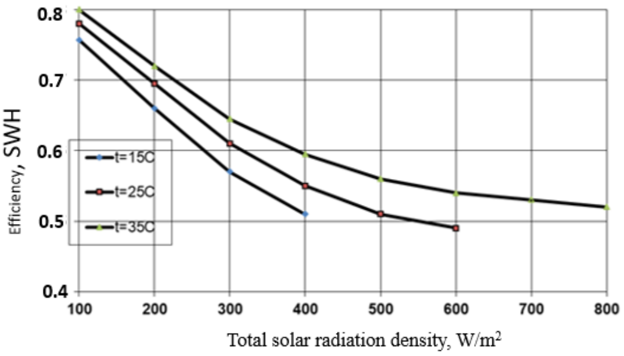


**Figure 2.** Dependence of the efficiency value of a solar water heating collector with an intermediate water coolant on the density of the total solar radiation and the ambient temperature
**Source:** compiled by the authors

It is evident from Figure 2 that as the density of total solar radiation increases, the efficiency decreases depending on the ambient temperature. This suggests that with an increase in the temperature of the working fluid in the solar water heating collector, heat losses increase correspondingly, leading to a decrease in overall efficiency.

The data obtained from the calculations enable a more detailed assessment of heat transfer and heat loss characteristics in the design of double-circuit solar water heating collectors (SWC) with an intermediate water coolant. Analysis of the results revealed that increases in working fluid temperature and wind speed lead to higher heat transfer coefficients, thereby resulting in greater heat losses through the collector body. The upper and lower sections of the collector were most sensitive to external factors, whereas the side walls demonstrated greater stability. This highlights the necessity for improved thermal insulation in specific zones of the SWC during the design stage. Furthermore, calculations of the efficiency coefficient (EC) showed that an increase in solar radiation intensity is accompanied by a decrease in collector efficiency, due to increased heat losses at higher fluid temperatures.

Comparison with other studies supports the reliability of these findings. For example, in the work by Sh.I. Klychev *et al*. [16], the heat losses of a three-layer underground cylindrical heat accumulator used in solar installations were examined. The authors demonstrated that the efficiency of heat storage is significantly influenced by the thermal properties of each layer, the foundation depth, and system operating time. The greatest losses occurred through the lower layer in contact with the ground, while the internal layer ensured more stable heat retention. The developed model enabled the calculation of temperature distribution over time and space, which is vital for optimising long-term solar heating systems.

The data obtained are particularly relevant for regions with high solar radiation, such as Kyrgyzstan. According to E. Dyikanov [17], the average annual sunshine duration in the country is 2,800-3,000 hours, and the solar radiation level reaches 6.5 kWh/m² per day, making the application of solar water heating systems highly promising. Given that hot water supply in the public sector accounts for up to 20% of total energy consumption, enhancing the efficiency of SWCs – by reducing heat losses and optimising design – can significantly contribute to energy conservation and lower operational costs.

The calculation results were compared with data from several previously published studies. In the work by W. Beckman *et al*. [18], a classical methodology for estimating heat losses in solar collectors was proposed, based on heat balance equations with differential analysis of heat transfer through transparent covers, side walls, and the collector base. According to their findings, at an average water temperature of 60°C, heat losses through glazing reached approximately 30-33 W/m², and total losses under intense solar radiation amounted to 90-100 W. In the present study, a similar method was adapted for a dual-circuit system with an intermediate coolant, allowing for additional losses associated with material thermal inertia and temperature stratification to be considered. Under these conditions, maximum losses from the upper part of the collector reached 119.5 W, exceeding the values in W. Beckman *et al.* model, which can be attributed to the complexity of the design and the presence of an additional heat exchange circuit.

In the study by D.M. Rakhimov [19], optimisation conditions for a single-circuit solar installation with intensive water heating were analysed. It was shown that as the coolant temperature exceeded 70°C, heat losses rose sharply, reaching 140-150 W in cases of insufficient insulation. The observed patterns align well with those of the present study, which similarly established the influence of working fluid temperature and wind speed on heat transfer coefficient growth and subsequent heat loss. The key difference lies in the system configuration: Rakhimov examined a direct heating setup, whereas this study focuses on a two-circuit scheme, which ensures more stable temperatures due to the intermediate fluid.

In the work of T.T. Omorov & D.M. Rakhimov [20], a low-inertia solar installation was developed that could reach steady-state conditions within 10-12 minutes at a solar radiation intensity of 850 W/m². Their calculations indicated a system efficiency of 62%, with minimal heat losses due to the absence of thermal storage components. In contrast, the present study employed a solar water heating collector with an intermediate coolant, which required more than 20 minutes to reach thermal equilibrium. This is attributed to the need to heat both the intermediate fluid and the massive structural elements, resulting in increased thermal inertia and slower system response to external fluctuations.

The mathematical model proposed by J.J. Tursunbaev *et al*. [21] described a solar installation operating on natural circulation via the siphon effect. The model incorporated parameters such as gravitational pressure and hydrodynamic resistance, achieving high energy efficiency with minimal power consumption. Maximum losses from the upper section of the unit were approximately 95 W at a water temperature of 75°C. Unlike the present study, that model did not involve forced circulation or account for stratification and thermal storage, both of which are key components of the current system. Consequently, the energy stability and application range of Tursunbaev's model are limited to specific non-pumped conditions, whereas the collector examined here demonstrated consistent performance across a broader range of loads and environmental conditions.

In a review by F. Eze *et al*. [22], modern solar water heating technologies were evaluated with a focus on design parameters influencing heat loss and cost efficiency. Key factors included the type of glazing, insulation thickness and properties, and overall system geometry. The authors concluded that employing double glazing and polyurethane insulation could reduce heat loss to 18-20% of total heat flux. These conclusions are corroborated by the present study, where the highest heat losses were recorded at the upper (119.5 W) and lower (56 W) parts of the installation, which utilised multilayer materials with varying thermal conductivities. The alignment of results underscores the significance of structural insulation in enhancing solar collector efficiency.

## Conclusions

In this study, a method was developed to determine heat losses through the structural components of double-circuit solar water heating collectors, taking into account their specific design features. The authors proposed a thermal model that enables a detailed analysis of heat exchange processes and the direction of heat losses within the system, significantly simplifying the modelling of heat flows and the assessment of collector efficiency. Based on this model, heat transfer coefficients were calculated for the upper, side, and bottom parts of the structure at various temperatures of the working fluid and wind speeds.

The conducted investigations revealed that in double-circuit installations, the intermediate water coolant is heated first and subsequently transfers thermal energy to the consumed water, thus providing greater thermal inertia compared to conventional single-circuit collectors. Convective heat exchange between the coolant and the heat exchanger determines the rate of heat transfer and is a key factor in the overall efficiency of the system.

The calculations established that the greatest heat losses occurred through the collector's front cover, with values 2 to 2.5 times higher than those from the bottom and 8 to 9 times higher than those from the side walls. The maximum heat transfer coefficients were found to be 2.865 W/($m^2$deg) for the upper part and 2.14 W/($m^2$deg) for the side and bottom parts. Analysis of the dependence of these coefficients on fluid temperature and wind speed demonstrated a natural increase in losses as these parameters rise.

Thus, the proposed methodology and thermal model enable a comprehensive evaluation of the thermal performance of double-circuit solar water heaters and identify key strategies for minimising heat loss. Future research should focus on experimental validation of the methodology, the development of advanced thermal insulation materials, and the adaptation of the model to varying climatic conditions to enhance system energy efficiency.

## Acknowledgements

This research article was prepared as part of the ERASMUS+ SILKWAY Project (No. 101179683), which aims to generate electricity and thermal energy from renewable energy sources.

## Funding

None.

## Conflict of Interest

None.

## References

[1] Al-Mamun MR, Roy H, Islam MS, Ali MR, Hossain MI, Aly MAS, et al. State-of-the-art in solar water heating (SWH) systems for sustainable solar energy utilization: A comprehensive review. Sol Energy. 2023;264:111998. DOI: 10.1016/j.solener.2023.111998

[2] Bouhdjar A, Semai H, Amari A. New technique to evaluate the overall heat loss coefficient for a flat plate solar collector. J Energy Technol. 2023;14(1):11–25. DOI: 10.18690/jet.14.1.11-25.2021

[3] Khayriddinov BE, Ergashev SH, Ganiyev SYu. Mathematical modeling of the heat accumulation system in a hot water collector using solar energy. Int J Adv Res Sci Eng Technol. 2023;10(8):20918–23.

[4] Roy R. Appropriate transient thermal analysis of an absorber plate in flat-plate solar collectors from beginning to end operational conditions. J Mod Thermodyn Mech Syst. 2022;4(1):12–37.

[5] Kalair AR, Seyedmahmoudian M, Saleem MS, Abas N, Rauf S, Stojcevski A. A comparative thermal performance assessment of various solar collectors for domestic water heating. Int J Photoenergy. 2022;(1):9536772. DOI: 10.1155/2022/9536772

[6] Temirbaeva N, Sadykov M, Osmonov Zh, Osmonov Y, Karasartov, U. Renewable energy sources in Kyrgyzstan and energy supply to rural consumers. Mach Energy. 2024;15(3):22–32. DOI: 10.31548/machinery/3.2024.22

[7] Beringer J. Solar thermal systems for space heating in cold climates: A validated case study from Kyrgyzstan [Bachelor thesis]. Ingolstadt: Technische Hochschule Ingolstadt; 2022.

[8] Duffy JA, Beckman WA. Thermal processes using solar energy. Moscow: Mir; 1997. 420 P.

[9] Avezov RR. Solar heating and hot water supply systems. Tashkent: Fan; 2008. 288 P.

[10] Ismanzhanov AI, Sultanov SK. Study of the technical and economic characteristics of solar water-heating installations made from alternative materials. Appl Sol Energy. 1999.

[11] Ismanzhanov AI, Sultanov SK. Comparative operating characteristics of solar water-heating collectors. Appl Sol Energy. 2001.

[12] Patent KR No. 1706. Solar water heating installation ISR-1. Bishkek, Kyrgyzstan; 2014. 6 P.

[13] Patent No. 5284. Solar water heater. Republic of Uzbekistan; 1998. 4 P.

[14] Patent No. 5930. Solar water-heating collector. Republic of Uzbekistan; 1999. 4 P.

[15] Patent KR No. 1605. Solar water heating installation. Bishkek, Kyrgyzstan; 2012. 4 P.

[16] Klychev ShI, Kenzhaev IG, Bagyshev AS, Bakhramov SA, Kadyrgulov DE. Thermal losses of a three-layer underground cylindrical heat accumulator of solar installations. Appl Sol Energy. 2020;57(6):523–7. DOI: 10.3103/S0003701X21060116

[17] Dyikanov E. Renewable energy and energy efficiency in the Kyrgyz Republic [Internet]. 2013 Oct 7 [cited 2025 March 7]. Available from: https://www.energycharter.org/fileadmin/DocumentsMedia/Events/20131007-9RECA_S2_EDyikanov_ru.pdf

[18] Beckman WS, Klein J, Duffy J. Calculation of solar heating systems. Moscow: Energoizdat; 1982. 280 P.

[19] Rakhimov DM. (2024). Optimisation of parameters of solar water heating installation with intensive water heating. Res Focus Int Sci J. 2023;2(12):22–6.

[20] Omorov TT, Rakhimov DM. Development and research of low-inertia solar water heating plant. Int Sci J. 2023;2(4):58–63.

[21] Tursunbaev JJ, Matisakov TK, Ergashov MO. Mathematical model for solar heat supply system with siphon effect. Proc Univ Kyrgyzstan. 2023;(5).

[22] Eze F, Egbo M, Anuta UJ, Ntiriwaa OB, Ogola J, Mwabora J. A review on solar water heating technology: Impacts of parameters and techno-economic studies. Bull Natl Res Cent. 2024;48:29. DOI: 10.1186/s42269-024-01187-1

# Эки контурлуу күн суу жылытуу коллекторлорунун элементтериндеги жылуулук жоготууларын эсептөө методологиясын иштеп чыгуу

**Сайит Султанов**
Техника илимдеринин кандидаты, доцент
Ош мамлекеттик университети
723500, Ленин көч., 331, Ош ш., Кыргыз Республикасы
https://orcid.org/0000-0003-4330-025X

**Идирисбек Кенжаев**
Техникалык илимдердин доктору, профессор
Ош мамлекеттик университети
723500, Ленин көч., 331, Ош ш., Кыргыз Республикасы
https://orcid.org/0000-0002-8094-2553

**Жанболот Турсунбаев**
Техника илимдеринин кандидаты, доцент
Ош технологиялык университети
723503, Н. Исанов көч., 81, Ош ш., Кыргыз Республикасы
https://orcid.org/0009-0006-8465-7879

**Ильяс Рыскулов**
Улук окутуучу
Инновациялык технологиялар жана энергетика институту
721405, Студент көч., 5, Таш-Көмүр ш., Кыргыз Республикасы
https://orcid.org/0000-0002-5680-7554

**Аннотация.** Энергиянын кайра жаралуучу булактарын, атап айтканда, күн коллекторлорун пайдаланууга кызыгуунун жогорулашынын шартында алардын энергетикалык натыйжалуулугун жогорулатуу милдети өзгөчө мааниге ээ болууда. Мындай орнотмолордун жалпы иштешине таасир этүүчү негизги факторлордун бири конструкциялык элементтер аркылуу жылуулукту жоготуу болуп саналат. Бирок иш жүзүндө ар кандай типтеги коллекторлор үчүн бул жоготууларга так баа берүүгө мүмкүндүк берген универсалдуу методдор жетишсиз. Бул ар кандай конструкциядагы орнотууларга колдонулуучу ийкемдүү ыкманы иштеп чыгууну талап кылат, бул изилдөөнүн актуалдуулугун аныктайт. Изилдөөнүн максаты күн суу жылытуу коллекторлорунун элементтериндеги жылуулук жоготууларын эсептөө методологиясын иштеп чыгуу жана анын эффективдүүлүгүнө жана натыйжалуулугуна түздөн-түз таасир этүүчү факторлорду аныктоо болгон. изилдөөлөр эсептөө жана аналитикалык изилдөө ыкмаларын жана термодинамикалык талдоо ыкмаларын колдонгон; алардын негизинде коллектордук элементтердеги жылуулук жоготуулары боюнча толук маалымат алынган. Изилдөөлөрдүн натыйжалары боюнча, жылуулук жоготууларынын маанилерине жана кош контурлуу суу жылытуу коллекторлорунун эффективдүүлүгүнө таасир этүүчү негизги факторлор күн радиациясынын тыгыздыгы, айлана-чөйрөнүн температурасы жана жумушчу суунун экендиги аныкталган. Алынган натыйжалар коллектордун структуралык элементтери аркылуу жылуулук жоготууларынын маанилерин аныктоого мүмкүндүк берет. Жылуулуктун эң чоң жоготуулары коллектордун бет капталынан байкалаары аныкталган. Жылуулук балансынын теңдемеси түзүлүп, сууну жылытуу үчүн күн коллекторлорунун жылуулук диаграммасы келтирилген. Айлана-чөйрөнүн температурасына жана шамалдын ылдамдыгына жараша жылуулук берүү коэффициентинин өзгөрүүсү теориялык жактан изилденген. Изилдеенун журушунде алынган натыйжалар сууну жылытуучу кун коллекторлорунун конструкцияларын мындан ары иштеп чыгуу жана еркундетуу учун илимий мааниге ээ. Атап айтканда, жылуулук жоготууларынын коллектордун бетинин структуралык өзгөчөлүктөрүнөн көз карандылыгы конвективдик жоготууларды азайтуу үчүн аны оптималдаштырууга көңүл бурууга мүмкүндүк берет. Бул мындай установкаларды долбоорлоодо кыйла натыйжалуу инженердик чечимдерди иштеп чыгуу үчүн негиз түзөт жана күн коллекторлорунун жаңы конструкцияларын моделдөө, эсептөөлөр жана сыноолордо колдонулушу мүмкүн

**Негизги сөздөр**: күн радиациясы; жылуулук берүү коэффициенти; жылуулук алмашуу; жылуулук балансы; жылуулук кабыл алуучу бети; конвекция; радиация

# Разработка методики расчета тепловых потерь в элементах двухконтурных солнечных водонагревательных коллекторов

**Сайит Султанов**
Кандидат технических наук, доцент
Ошский государственный университет
723500, ул. Ленина, 331, г. Ош, Кыргызская Республика
https://orcid.org/0000-0003-4330-025X

**Идирисбек Кенжаев**
Доктор технических наук, профессор
Ошский государственный университет
723500, ул. Ленина, 331, г. Ош, Кыргызская Республика
https://orcid.org/0000-0002-8094-2553

**Жанболот Турсунбаев**
Кандидат технических наук, доцент
Ошский технологический университет
723503, ул. Н. Исанова, 81, г. Ош, Кыргызская Республика
https://orcid.org/0009-0006-8465-7879

**Ильяс Рыскулов**
Старший преподаватель
Институт инновационных технологий и энергетики
721405, ул. Студенческая, 5, г. Таш-кумыр, Кыргызская Республика
https://orcid.org/0000-0002-5680-7554

**Аннотация.** В условиях увеличения интереса к использованию возобновляемых источников энергии, в частности солнечных коллекторов, особенно важной становится задача повышения их энергетической эффективности. Одним из ключевых факторов, влияющих на общую производительность таких установок, являются тепловые потери через конструктивные элементы. Однако на практике существует недостаток универсальных методик, позволяющих точно оценивать эти потери для коллекторов различных типов. Это обуславливает необходимость разработки гибкого подхода, применимого к установкам разной конструкции, что и определяет актуальность настоящего исследования. Целью проведенного исследования являлась разработка методики расчета тепловых потерь в элементах солнечных водонагревательных коллекторов и установление факторов, непосредственно влияющих на его эффективность и производительность работы. В исследованиях использовались расчетно-аналитические методы исследования и методы термодинамического анализа на их основе получена подробная информация о тепловых потерях в элементах коллектора. В результате проведённых исследований установлено, что основными факторами, влияющими на значения тепловых потерь и на коэффициент полезного действия двухконтурных водонагревательных коллекторов являются плотность солнечного излучения, температуры окружающей среды и рабочей воды. Получены результаты, позволяющие определять значения тепловых потерь через конструктивные элементы коллектора. При этом установлено, что наибольшие тепловые потери наблюдались со стороны лицевого покрытия коллектора. Составлено уравнение теплового баланса и приведена тепловая схема солнечных коллекторов для нагрева воды. Теоретически исследованы изменения коэффициента теплопередачи в зависимости от температуры окружающей среды и скорости ветра. Полученные в ходе исследования результаты представляют научную значимость для дальнейших разработок и совершенствования конструкций солнечных водонагревательных коллекторов. В частности, выявленная зависимость тепловых потерь от конструктивных особенностей лицевой стороны коллектора позволяет сосредоточить внимание на её оптимизации с целью снижения конвективных потерь. Это создаёт основу для разработки более эффективных инженерных решений при проектировании подобных установок и может быть использовано при моделировании, расчётах и испытаниях новых конструкций солнечных коллекторов

**Ключевые слова:** солнечная радиация; коэффициент теплопередачи; теплообмен; тепловой баланс; тепловоспринимающая поверхность; конвекция; излучения