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Comparison of the parameters of a flat solar collector with a tubular collector to ensure energy flexibility in smart buildings

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Abstract

This study examines the application and implementation of energy-efficient measures and strategies for use in buildings aimed at achieving the goal of virtually zero energy consumption by buildings. In particular, the aim of the study is to introduce integrated solar devices into the building, functioning as a functional component of the structure for heat storage, in order to increase the flexibility of the structure while maintaining comfortable conditions inside. This article discusses an experimental comparison of flat and tubular solar collectors in the southern and northern regions of Kazakhstan. Compared to glass (S = 3), a tubular solar collector has a coefficient of thermal conductivity that is two times lower for single-layer elements and 2.5 times lower for double-layer elements. This means that less heat is lost. A flat solar collector was also developed, a heat-insulating translucent double-glazed window with reduced pressure, and the coolant is made of thin-walled corrugated stainless-steel pipe. In this collector, there is a constant circulation of heat, which increases the efficiency of heat transfer by eliminating additional partitions between the panel and thermal insulation. A calculation was carried out that allowed us to determine the productivity and useful gain for two collectors. The annual increase in the useful energy of flat solar collectors is about 12780000 kJ/hour and 20100000 kJ/hour for tubular solar collectors; therefore, the annual increase in the useful energy of evacuated tubular collectors is 20% more than that of flat plate collectors in the northern region.

Keywords: Balance equation, Circulation, Flat solar collector, Heat carrier, Solar radiation, Thermal parameters, Tubular solar collector.

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1. Introduction

The world is going through such changes as global warming, a strong shift in population, a lack of resources, and urbanization, which have a full impact on our environment. Such impressive changes force us to think about various methods of minimizing or eliminating damage to the environment. Since this provision also applies to buildings, engineers are constantly looking for innovative methods that allow them to minimize the unrestrained opposition of construction to the environment. Currently, the need for maximum performance (optimization) is of primary importance, which affects not only energy efficiency but also the need to increase the degree of convenience for consumers. To ensure the stability of the structure for many years, it is necessary to achieve a better balance between comfort, energy efficiency, and safety.In the works Aggarwal, et al. [1] and Agarwal, et al. [2], compliance with the new norms on global warming and greenhouse gas emissions was considered, and a number of changes are required for the construction of energy-efficient, sustainable buildings.

In Zeng, et al. [3], using renewable energy sources to achieve this goal has gained extensive approval. In the article Bellos, et al. [4], solar energy is mainly an affordable source of clean energy with minimal costs and environmental impact. In the article Huang, et al. [5], applications based on solar thermal energy have been invented and have been widely used since the 1970s, after the beginning of the energy crisis. In Tzivanidis, et al. [6], the process of collecting solar rays in the form of energy and converting them into useful heat for heating water, air conditioning, and use in agriculture or industry was developed. In Nozik [7], an overview of solar water heating was developed, accounting for most of all applications on the market. In the article Lewis [8], the integration of heat pumps for thermal applications was developed, which could potentially eliminate these problems. The design of a heat pump with a solar collector for heating water has advantages over conventional solar water heaters in terms of performance and initial investment, as well as in unstable weather conditions. In Li [9], systems were developed and investigated in which water is used as a working fluid, and in mixed water heating systems, a refrigerant is used as a working fluid that transfers heat to water. The solar heat supply system solves the joint difficulties of classical systems associated with high investment costs for collector elements and problems arising from corrosion. The article by Tagliafico, et al. [10] describes how a solar heat supply system can work in moderate weather conditions with solar radiation, increasing the energy efficiency of buildings. In the article Alam, et al. [11], a numerical model of the potential of solar thermal collectors of hot water and their combination with heat pumps to reduce energy consumption at the facility in heating systems was developed. In Fernández-Seara, et al. [12], the operating mode of the solar heat supply system was experimentally analyzed in conditions of negative temperatures, and an increase in the course of water heating was also observed. The article by Li and Kao [13] examines the economic comparison of the solar heat supply system with the classical method for tropical and subtropical regions, demonstrating a reduction in annual operating costs, a noticeable payback period, and the need to use a variety of configurations depending on climatic changes. In the article Nuntaphan, et al. [14], a version of solar collectors with a corrugated metal roof and a copper pipe was developed and studied.

In Huan, et al. [15], a combined solar heat supply system with sequential and parallel modes was developed, and the results showed that in winter it is better to use a sequential mode, and in summer the parallel one is suitable. In the article Kong, et al. [16], a numerical simulation of the solar heat supply system was developed, which confirmed the effectiveness of the system in freezing conditions. In Cutic, et al. [17], an experimental installation of a solar heat supply system for indoor heating was developed and investigated, which made it possible to obtain a coefficient of performance (COP)of 2.5 in variable climatic conditions. The article byBastos, et al. [18] shows a new approach to the solar heat supply system, which is very efficient and environmentally friendly even under unstable weather conditions. A solar heat supply system was created by Buker and Riffat [19]. It was found that the COP level changes a lot as the amount of solar radiation changes. This is because of the theory of convection, which says that heat can be absorbed when the temperature of the air is higher and the temperature of evaporation is lower. In the article Chaturvedi, et al. [20], the developed solar heat supply system for heating water in residential premises was investigated using numerical modeling and experimental verification. In Amirgaliyev, et al. [21], a comparison between photovoltaic (PV) and solar collectors is considered. InBaydaulet, et al. [22]; Hamid, et al. [23]; Ismail, et al. [24]; Jia, et al. [25]; Rosli, et al. [26]; Sekhar, et al. [27]; Vokas, et al. [28] and Kalogirou and Tripanagnostopoulos [29], flat and tubular solar collectors for industrial energy consumption were developed and investigated.

2. Method of Research

The main parameter of a tubular solar collector is the cost of the thermal energy produced. The perfect energy consumption, dependability, service life, and efficiency of the solar collector all serve as indicators for this. Solar collectors can be made of expensive but durable materials based on reliable operation and a long service life. Solar collectors can also be made from affordable materials and be cheap, but they have the fewest work resources. Both options are true and in demand by life, and they will be in demand if the cost of thermal energy is lower than that of competing structures of similar purpose. However, in both variants, the significance and cost of the solar collector will be determined by new materials underlying it and the constructive, scientific, and technical ideas and solutions found. To achieve this goal, we have developed a fundamentally new solar collector, on the basis of which a standard-sized, numbered solar collector for water heating will be created. Two types of solar collectors are offered:

1. A tubular collector semi-cylindrical reflector (Figure1)
2. A tubular collector is the absorbing screen with a cellular transparent covering (Figure 2).

A classic example of such a solar collector is the tubular collector (drawing 2). It consists of the absorbing pipe 1, separate light transparent hollow cylindrical elements 2. Thus, the end (bottom) is opened, and the second end (mouth) is narrowed and covers densely absorbing pipe 1. Light transparent elements also have ledges 3 and 4 on a circle of cylinders. In the course of assemblage, elements are put on consistently, one after another. Thus, ledges 3 and 4 of the subsequent elements enter densely in the ledges of the previous elements so that continuous light is transparent in the cylinder, covering absorbing pipe 1. Separate elements 2 form tight cavities 5, round an absorbing pipe 1. As absorbing pipes, the thin-walled goffered pipes with a wall thickness of 0.5 mm and a diameter of 16 mm that form the register of pipes are chosen, and the bottom parts fasten to the hydraulic collector. The registers of pipes and absorbing screens are painted black. In an offered collector to a tubular absorber, it is also a function of a bearing design for transparent thermal protection. The quantity of elements is lowered to 6, and the quantity of operations to 12. The cellular structure of a transparent covering sharply reduces thermal losses, which increases efficiency in solar collector.

The basic difference between the two variants is that in the first case, sun rays are caught not only on the surface of an absorbing pipe but also at the expense of catching solar radiation by semi-cylindrical mirror reflectors, which increases the efficiency of a collector. Auxiliary absorbing screens, which, at the expense of heat conductivity, transfer energy to a tubular absorber, serve in a case as a surface for catching solar radiation. As we see the difference, it also basically works for the physicist in the process of catching solar radiation with a solar collector.

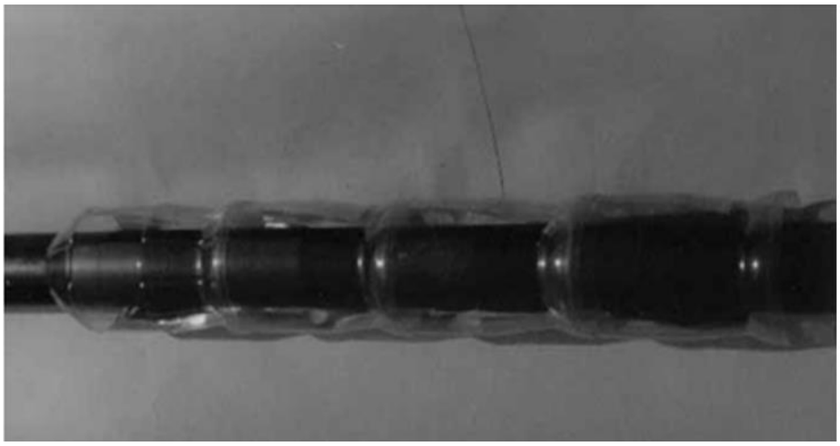

Figure 1.
The fragment of a tubular solar collector.

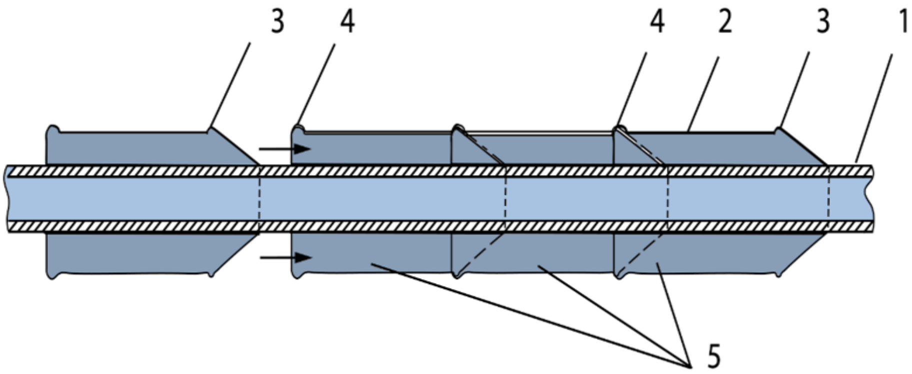

Figure 2.
The scheme tubular solar collector 1-absorbing pipe; 2-cylindrical light transparent an element; 3,4-ring ledges of cylindrical elements; 5-air cavities.

A light, transparent covering has cellular structure cells for improvement of heat-shielding properties. On redesigns and research, heat conductivity factor, and, hence, heat losses, decrease 2 times at single-layered cells and 2.5 times at two-layer cells in comparison with glass (S = 3 mm). The cellular structure light of a transparent covering gives it sufficient rigidity and durability, and at corresponding processing (enough simple) gets demanded spatial forms: elliptic, rectangular, etc. Thanks to the offered decision, the number of elemental solar collectors decreased to 8 and the quantity of operations to no more than 15.

Creation of cellular-cellular structure for transparent coverings that extinguishes current streams in an air cavity and, hence, the heat of loss through transparent isolation, a primary factor defining general heat of loss. Forms and flexibility of materials give the chance to make and type solar collectors in various configurations and designs. Depending on local conditions, the collector can gather in the form of parallel numbers and have curvilinear, spiral, or screw forms.

Offered designs of solar collectors possess high maintainability since the transparent cover is cheap and easily replaced. A definitive assemblage of tubular solar collectors with a reflector is presented in Figure 3.

Figure 3.
Tubular solar collector with a reflector after assemblage.

Solar radiation flux incident on a heat pipe consists of two components

$$E_{s.r} = E_{d.s.r.} + E_{sc.r} \quad (1)$$

Where $E_{d.s.r}$-The flow of direct solar radiation; $E_{sc.r}$-The flow of the scattered radiation. In turn, the solar energy is absorbed and converted into heat in the coolant flow in the heat receiving the tubular upper and lower portion.

$$E_{s.r} = E_t + E_{ref} \quad (2)$$

Where: E_t- total flux picked up by the surface of the heat receiver through the transparent cover; $E_{ref.}$- flux reflected from the mirror at the bottom. Taking into account a number of assumptions, formulate balance equations for individual nodes and elements of the heat reflector tube, as well as the coolant flowing through the heat sink channels: a) the amount of radiant solar energy absorbed by the surface of the tubular channel directly allocated to the unit length of the heat with the flow of coolant.

$$q_{l.нмк} = \frac{\pi d_1}{2} \cdot \left[\mathrm{E}_{abs} - K_{r,h.tr} \cdot \left(t_k - t_o \right) \right] \quad (3)$$

Where in d_1- outer diameter surface of the heat pipe; $K_{r.h.tr}$- reduced heat transfer coefficient of the heat-load-bearing elements.

b) The amount of solar energy reflected from the semi-cylindrical reflector surface absorbed warmly to perceive channel

$$q_{e.o.к} = \frac{\pi d_1}{2} \cdot \left[\mathrm{E}_{abs} - K_{r.h.tr} \cdot \left(t_k - t_o \right) \right] \quad (4)$$

c) The amount of heat from the outer surface of the tubular channel warmly to perceive to its inner surface

$$q_{out} = \frac{\lambda_k}{\delta_k} \cdot \pi d_2 \cdot \left(t_k - t_k^{в} \right) \quad (5)$$

d_2- diameter of the inner surface of the tubular heat receiver

g) The heat from the inner tubular wall surface to the coolant channel

$$q_{inner} = \alpha_{к} \cdot \frac{\pi d_2}{2} \cdot \left(t_k - t_p \right) \quad (6)$$

As a result, the solution (7)

$$q_{inner} = \frac{E_{abs} - K_{r.h.tr} \cdot (t_k - t_0)}{d_1 + \dfrac{K_{r.h.tr}}{\dfrac{\lambda_k}{\delta_k} \cdot \pi d_2}} \qquad (7)$$

This study is unique because it creates thermosiphon circulation solar heat supply system with a flat solar collector that is a heat-insulating, clear double-glazed window with low pressure. The coolant is made of thin-walled, wavy stainless steel pipe. The heat received from the solar flux heats the liquid in the flask, which is removed from the collector, and cold water from the siphon takes its place. There is a continuous circulation of heat, which increases the efficiency of heat transfer by eliminating additional bridges between the panel and thermal insulation. As mentioned above, a solar system with thermosiphon circulation can absorb heat from a solar source.

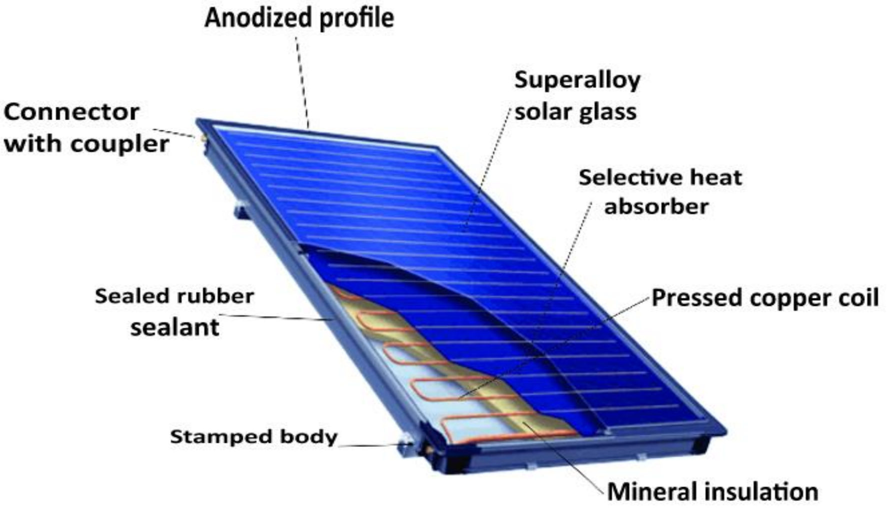

Figure 4.
Principal diagram of flat solar collector.

Figure 4 shows a sample of a flat solar collector. The basis and novelty of the proposed one lie in the fact that, unlike the well-known design principle, the collector contains a transparent double-glazed double-glazed window with reduced pressure, as well as a frame around the perimeter. The lower part of the wooden frame is made of plywood with a thickness of 8 mm, and a thermal insulation film with foil is glued to it. A flexible thin-walled, stainless steel tube with a diameter of 4-16 mm in the form of a roll is placed in the gap formed between the double-glazed windows and the lower part of the frame. The pipe edges are attached to the producing inlet and outlet posts.

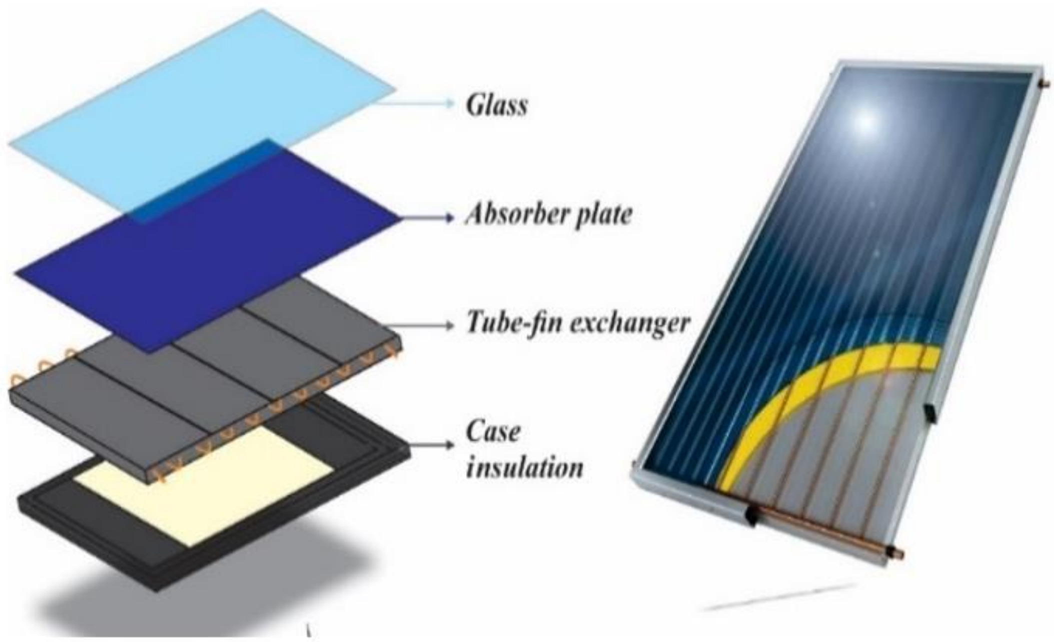

Figure 5.
Principal diagram of flat solar collector in parts.

As shown in Figure 5, the solar energy passes through the glass and hits the absorber plate, which heats up, converting solar energy into thermal energy. Heat is transferred to the working fluid, which passes through tubes attached to the absorber plate.

Figure 6.
Flat solar collector mockup.

Figure 6 shows a full-scale modification of a flat solar collector. The solar collector appears to be the key heat-generating apparatus of a solar installation. To achieve this goal, a fundamentally new flat solar collector has been developed, on the basis of which all kinds of solar systems will be built, both in size and design, used for water heating and room heating.

Table 1 presents the selected performance characteristics of a flat solar collector.

Table 1.
Selected performance capabilities of flat solar collector.

Parameters	Value
Absorbing plate material	Copper
Absorber plate dimensions	2 m×1 m
Plate thickness	0.4 mm
Glazing material	Hardened glass
Glazing sizes	2 m×1 m
Glazing thickness	4 mm
Insulation	Foam plex (Foam polyurethane)
Collector tilt	45^0
Absorber heat conductivity	401 W/(m K)
Insulation heat conductivity	0.04 W/(m K)
Transmittance-absorption factor	0.855
Apparent sun temperature	4350 K
Environmental temperature	303 K
Irradiation intensity	1000 W/m^2

3. Results

The figure shows the solar radiation of a hot and cold climate for the southeastern region of the Almaty region in the month of June 2023. As can be seen from this figure, solar radiation in the month of June for the south-eastern region of Kazakhstan is hotter in the summer than in the winter.

Figure 7 illustrates the radiation of a hot and cold climate on a typical July day in Almaty.

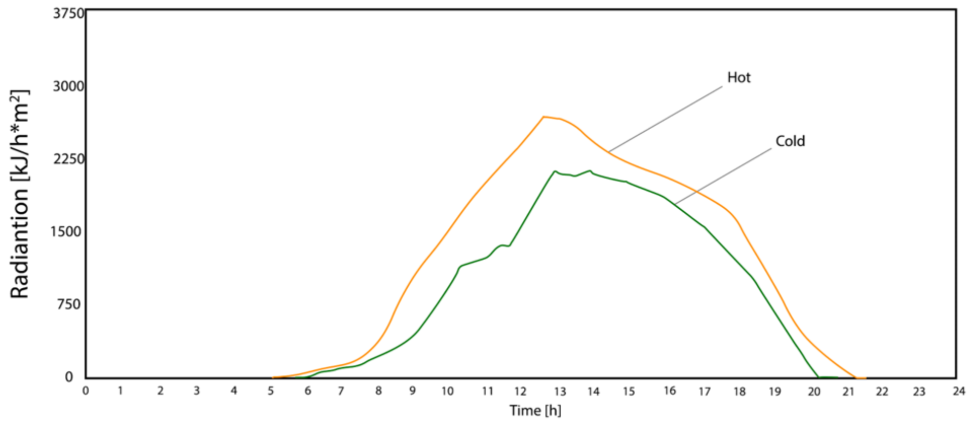

Figure 7.
Radiation of hot and cold climate for a typical day in July in Almaty.

Figures 8 and 9 show the temperatures at the outlet of a flat and tubular solar collector on a July day in a cold climate. Figure 8shows the outlet temperature for the first, second, and third flat plate collectors, which is 60°C, 50°C, and 38°C, respectively, for flat plate collectors. In addition, the outlet temperatures for evacuated tubular collectors are 53 °C, 50 °C and 38 °C, as shown in Figure 9.

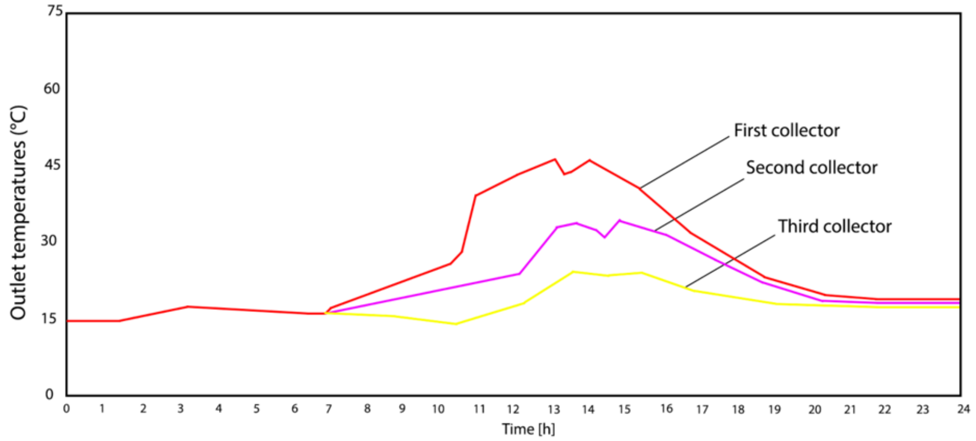

Figure 8.
Temperature at the outlet of a flat solar collector in July for the northern region of Kazakhstan.

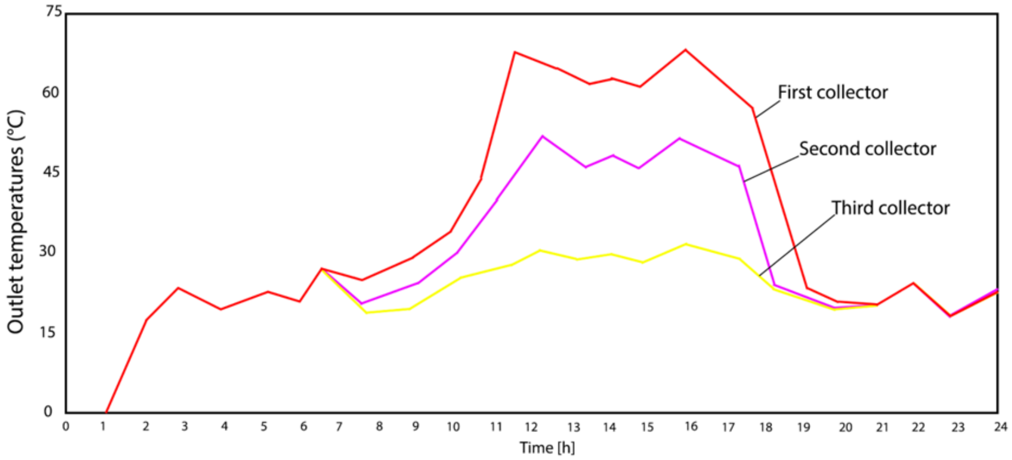

Figure 9.
Temperature at the outlet of the tubular collector for the July day for the northern region of Kazakhstan.

The temperature at the outlet of a flat and tubular solar collector on the same day in a hot climate is shown in Figures 10 and 11, respectively. As can be seen from the data in Figures 8, 9, 10, and 11, the outlet temperature of tubular solar collectors is higher than that of flat solar collectors in hot and cold climates. We can also observe that for a cold climate, this difference in outlet temperature is greater than for a hot climate.

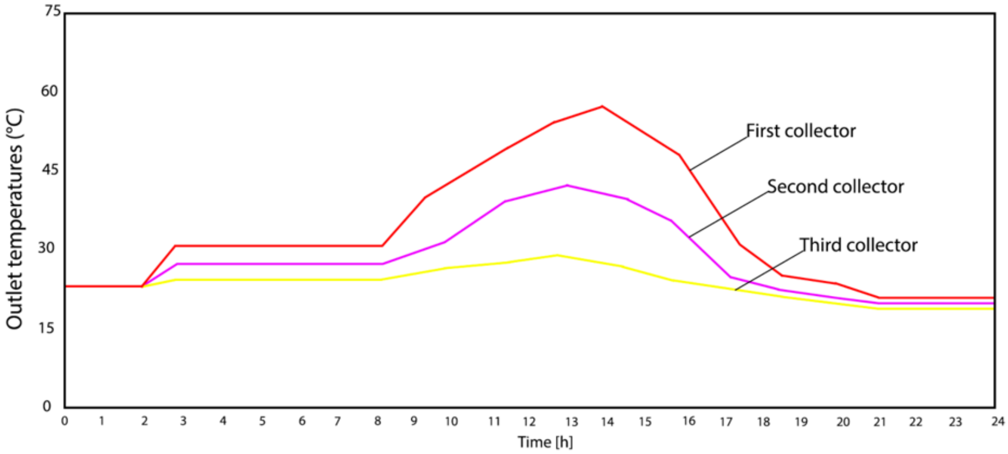

Figure 10.
Temperature at the outlet of a flat solar collector for a July day for the southern regions of Kazakhstan.

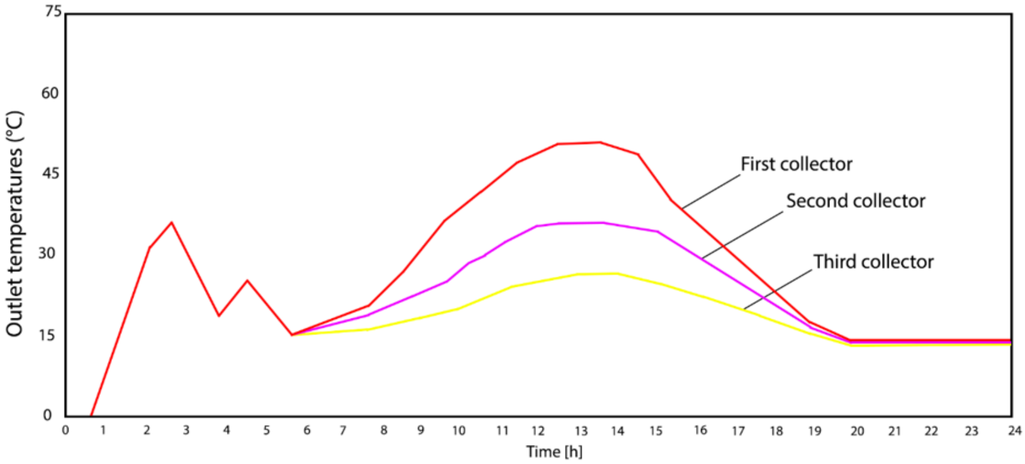

Figure 11.
Temperature at the outlet of the tubular solar collector of the July day for the southern regions of Kazakhstan.

The useful energy gain for flat and tubular solar collectors is shown in Figures 10 and 11on the same day. As we can see from these figures, the useful energy gain for flat solar collectors is greater than for tubular solar collectors, and the useful energy gain in the southern region is greater than in the cold region for both flat and tubular solar collectors.

Figure 12 illustrates the useful energy gain for flat solar collectors on a July day in the northern regions of Kazakhstan.

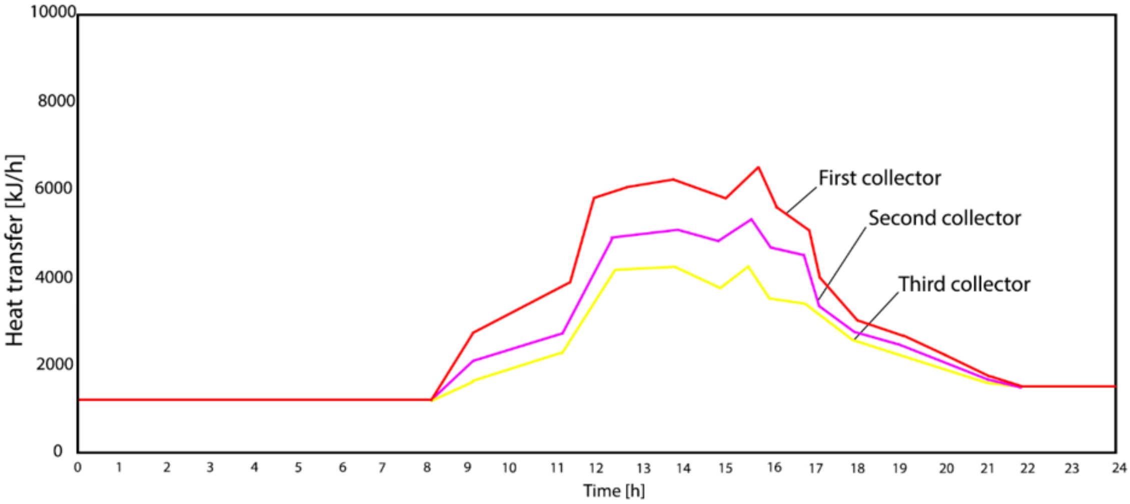

Figure 12.
Useful energy gain for flat solar collectors on a July day for the northern regions of Kazakhstan.

Figure 13 illustrates the useful energy gain for tubular solar collectors on a July day in the northern regions of Kazakhstan.

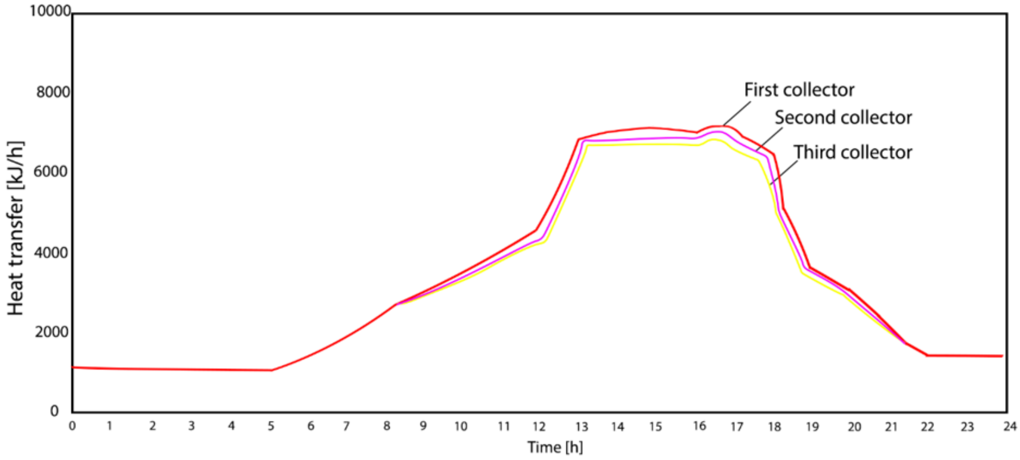

Figure 13.
Useful energy gain for tubular solar collectors on a July day for the northern regions of Kazakhstan.

In Figures 12,13,14, and 15, as we see, the increase in tubular solar collectors and is lower than in flat solar collectors, and the effect of an increase in inlet temperature on a decrease in efficiency in flat collectors is greater than in tubular solar collectors.

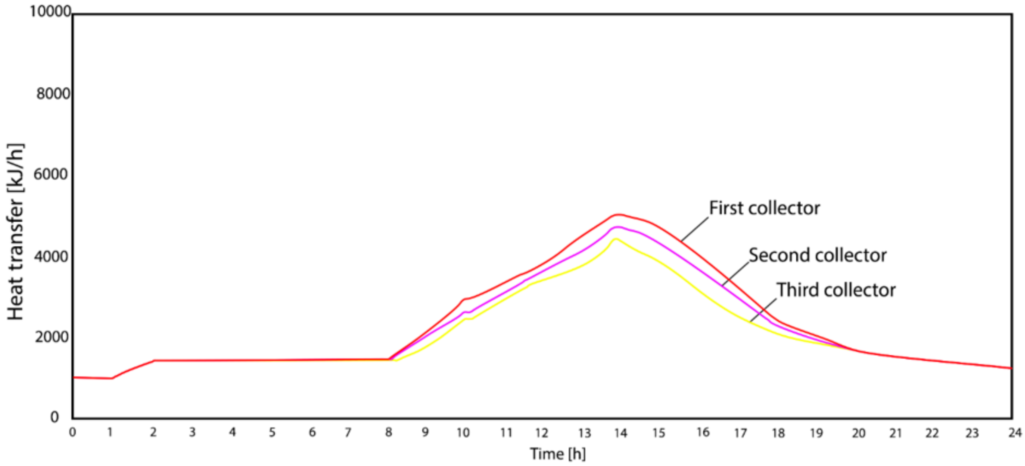

Figure 14.
Useful energy gain for flat solar collectors on a July day for the southern region of Kazakhstan.

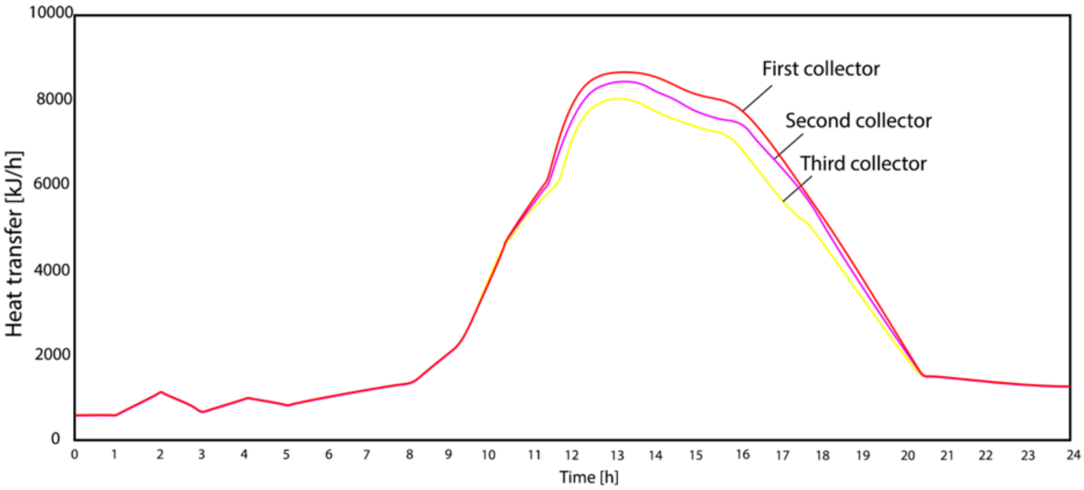

Figure 15.
Useful energy gain for tubular solar collectors on a July day for the southern region of Kazakhstan.

The annual useful energy gain from four flat and tubular solar collectors for the northern regions of Kazakhstan is shown in Figure 16. This figure shows that the annual useful energy gain of flat solar collectors is about 12780000 kJ/hour and 20100000 kJ/hour for tubular solar collectors, so the annual useful energy gains of evacuated tubular collectors are 20% greater than those of flat plate collectors in the northern region.

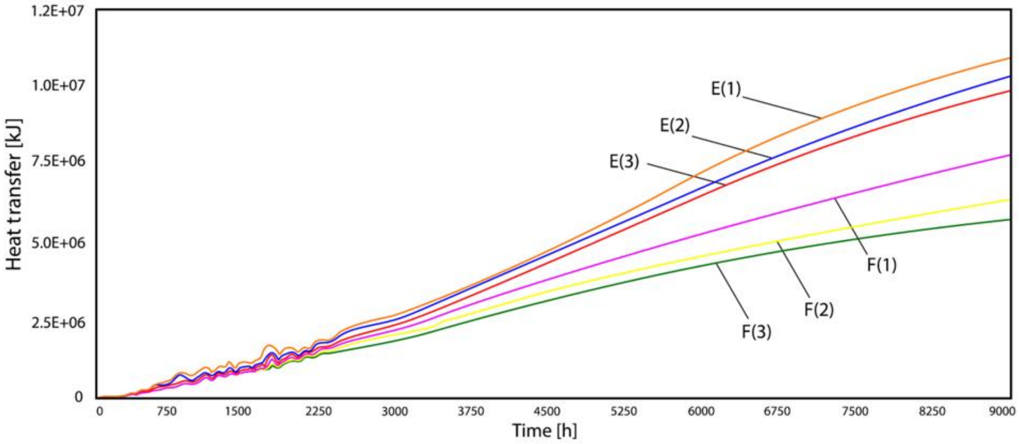

Figure 16.
Annual useful energy gains from three ETC and FPC for a cold climate.

4. Conclusion

This article experimentally compares the performance results of a tubular collector and a flat collector for two climatic regions of Kazakhstan. According to the results of the study, it was found that the performance of tubular collectors in the southern region is better than in the northern region. It was also calculated that the performance of flat solar collectors depends more on climatic conditions and inlet temperature than on tubular solar collectors. The annual useful energy gain from tubular solar collectors is 10% more than that of flat solar collectors in the southern region and 20% in the southern regions of Kazakhstan.

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