



# Mobil fotoelektrik-issiqlik qurilmasining tajriba-sinov natijalari tahlili

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**Dolzarbli:** So'nggi yillarda aholi sonining jadal o'sishi qayta tiklanadigan energiya manbai, xususan quyosh energiyasi, asosida ishlovchi energetik qurilmalardan foydalanishga bo'lgan talabni sezilarli darajada oshirdi. Bugungi kunda qazib olinadigan yoqilg'ilar va boshqa qayta tiklanmaydigan resurslar yuqori energiya iste'moli tufayli tez kamayib bormoqda. Bundan tashqari, asosiy energiya manbalaridan haddan tashqari foydalanish jiddiy ekologik zararlarni, jumladan, ob-havo o'zgarishi, global isish, ozon qatlamining yemirilishi kabi muammolarga olib keldi. Shu sababli, dunyo olimlari uchun uzoq muddatli energiya manbalarini topish asosiy vazifalardan biri hisoblanadi. Quyosh energiyasi texnologiyalari isitish tizimlari, havoni mo'tadillashtirish va elektr energiyasi ishlab chiqarishda muqobil energiya manbalaridan oqilona foydalanish uchun qulay usuldur. Quyosh energiyasi bugungi kunda eng muhim va qayta tiklanadigan energiya manbalaridan biri bo'lib, undan foydalanishning eng samarali turlaridan hisoblanadi. Fotoelektrik quyosh qurilmalari an'anaviy energiya manbalaridan o'zining ishonchlilik, barqarorligi va ko'chma usulda foydalanish imkoniyati bilan ajralib turadi. Ushbu qurilmalar ko'plab sohalarda jadal qo'llanilmoqda, ba'zi hududlarda ularni an'anaviy energiya tarmoqlariga integratsiyalashgan holda ishlatish mumkin bo'lsa-da, asosan markazlashmagan energiya tarmoqlari mavjud bo'lmagan hududlarda foydalanish yanada maqsadga muvofiqdir.

**Maqsad:** markazlashgan energiya ta'minotidan uzoqda joylashgan energiya iste'molchilari uchun mo'ljallangan avtonom energiya ta'minoti tizimiga ega bo'lgan hamda bir vaqtning o'zida elektr energiyasi va issiq suv ishlab chiqaradigan mobil fotoissiqlik qurilmasini tajriba namunasini ishlab chiqish, sinovdan o'tkazish va tajriba natijalarini tahlil qilish.

**Usullari:** eksperimental ma'lumotlarga asoslangan tadqiqot ishi suv asosidagi modul sirtini sovutish tizimini mobil fotoissiqlik qurilmasida sinovdan o'tkazish orqali olingan ma'lumotlarga asoslangan.

**Natijalar:** asosiy energiya ta'minotidan uzoqda joylashgan aholi va ijtimoiy soha obyektlarini kafolatlangan elektr energiya va issiq suv bilan ta'minlash mobil fotoissiqlik qurilmasi orqali amalga oshirilishi tajriba orqali aniqlandi. Quyosh energiyasi asosidagi fotoissiqlik qurilmasining foydali ish koeffitsiyenti asosan unga tushayotgan quyosh nurlanish intensivligiga bog'liqligi va quyosh elementlarining ishchi haroratiga teskari proporsionalligidan kelib chiqib, suvga asoslangan sovutish texnologiyasini qo'llash orqali modul tomonidan ishlab chiqarilayotgan quvvatning oshishiga erishildi.

**Kalit so'zlar:** mobil fotoissiqlik qurilma, elektr energiya, issiq suv, quvvat, quyosh energiyasi, sovutish texnologiyasi, energiya samaradorligi.

## Анализ результатов экспериментального испытания мобильной фотоэлектрической тепловой установки

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**Актуальность:** в последние годы быстрый рост населения значительно увеличил спрос на использование энергетических установок, работающих на основе возобновляемых источников энергии, в частности солнечной энергии. В настоящее время ископаемые виды топлива и другие не возобновляемые ресурсы быстро истощаются из-за высокого потребления энергии. Кроме того, чрезмерное использование основных источников энергии привело к серьезным экологическим проблемам, включая изменение погоды, глобальное потепление, истощение озонового слоя и другие. Поэтому поиск долгосрочных источников энергии является одной из основных задач для мировых ученых.

Технологии солнечной энергии — это удобный способ рационального использования альтернативных источников энергии в системах отопления, кондиционирования воздуха и производства электроэнергии. Сегодня солнечная энергия является одним из наиболее важных и возобновляемых источников энергии и одним из самых эффективных видов ее использования. Фотоэлектрические солнечные установки отличаются от традиционных источников энергии своей надежностью, стабильностью и портативностью. Эти устройства активно используются во многих областях, и, хотя в некоторых регионах их можно интегрировать в традиционные энергетические сети, их использование более целесообразно в децентрализованных районах без доступа к традиционным энергетическим сетям.

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**Цель:** Разработка, испытание и анализ результатов экспериментального образца мобильной фото термической установки, предназначенной для потребителей энергии, удаленных от централизованного энерго-снабжения, имеющей автономную систему энергоснабжения и одновременно обеспечивающей как электрическую энергию, так и горячую воду.

**Методы:** исследовательская работа, основанная на экспериментальных данных, базируется на данных, полученных в результате испытаний системы охлаждения поверхности модуля на водной основе в мобильной фото термической установке.

**Результаты:** Экспериментально установлено, что гарантированное снабжение электроэнергией и горячей водой населения и объектов социальной сферы, расположенных вдали от основного энергоснабжения, может быть обеспечено с помощью мобильной фото термической установки. Исходя из того, что коэффициент полезного действия фото термической установки на основе солнечной энергии в основном зависит от интенсивности падающего на нее солнечного излучения и обратно пропорционален рабочей температуре солнечных элементов, было достигнуто увеличение вырабатываемой мощности модуля за счет применения технологии охлаждения на водной основе.

**Ключевые слова:** мобильная фото термическая установка, электрическая энергия, горячая вода, мощность, солнечная энергия, технология охлаждения, энергоэффективность.

## Analysis of experimental test results of a mobile photovoltaic-thermal device

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**Relevance:** in recent years, rapid population growth has significantly increased the demand for energy devices utilizing renewable energy sources, particularly solar energy. Currently, fossil fuels and other non-renewable resources are rapidly depleting due to high energy consumption. Furthermore, the excessive use of primary energy sources has led to serious environmental damages, including climate change, global warming, ozone layer depletion, and more. Therefore, finding long-term energy sources is one of the main challenges for scientists worldwide.

Solar energy technologies offer a convenient way to rationally utilize alternative energy sources in heating systems, air conditioning, and electricity generation. Today, solar energy is one of the most important and renewable energy sources and one of the most effective types of its utilization. Photovoltaic solar devices stand out from traditional energy sources due to their reliability, stability, and portability. These devices are rapidly being implemented in many areas; while they can be integrated into traditional energy grids in some regions, their use is more suitable in decentralized areas where traditional energy grids are unavailable.

**Aim:** development, testing, and analysis of experimental results of a mobile photovoltaic-thermal device designed for energy consumers located far from centralized energy supply, equipped with an autonomous energy supply system, and simultaneously providing both electricity and hot water.

**Methods:** the research work, based on experimental data, relies on data obtained from testing a water-based module surface cooling system in a mobile photovoltaic-thermal device.

**Results:** It has been experimentally determined that the guaranteed supply of electricity and hot water to populations and social facilities located far from the main power supply can be achieved through a mobile photovoltaic-thermal (PV-T) device. Based on the fact that the efficiency of a solar-powered PV-T device primarily depends on the intensity of incident solar radiation and is inversely proportional to the operating temperature of the solar cells, an increase in the power output of the module was achieved by applying water-based cooling technology.

**Keywords:** mobile photovoltaic-thermal device, electrical energy, hot water, power, solar energy, cooling technology, energy efficiency.

### 1. Introduction

The rapid growth of the population in recent years has led to a significant increase in the demand for solar energy as a sustainable renewable energy source. Today, primary energy sources such as fossil fuels and other non-renewable resources are being rapidly depleted due to high energy consumption [1]. Furthermore, over-reliance on these primary energy sources has caused serious environmental problems, including climate change, global warming, ozone layer depletion, and other negative consequences. Therefore, finding long-term energy sources is one of the most important tasks for scientists around the world [2].

A lot of reforms are being carried out in Uzbekistan regarding the transition to "green energy". Specifically, in accordance with the Decree of the President of the Republic of Uzbekistan No. PQ-133 of April 1, 2025, "On improving measures for preventing illegal use and waste of fuel and energy resources and increasing energy efficiency" and the Resolution of the Cabinet of Ministers No. 13 of

January 8, 2024, "On regulating and developing the sphere of organizing energy supply based on renewable energy sources", the wide-scale implementation of the "green energy" system in the sectors of the economy and various social facilities is a priority task [3, 4].

Currently, the decrease in the electrical efficiency of solar cells due to the increase in the surface temperature of solar cells as a result of the solar radiation flux throughout the day is a pressing issue for scientists worldwide.

As an effective solution to this problem, research is being conducted on the integration of a thermal collector onto the backside of the photovoltaic battery (PV).

Considering the growing need for solar energy and its applications, the electrical efficiency of crystalline silicon-based solar cells can reach up to 22%.

This means that a significant portion of the incoming solar energy is gathered as heat and can be utilized for low-temperature heating needs.

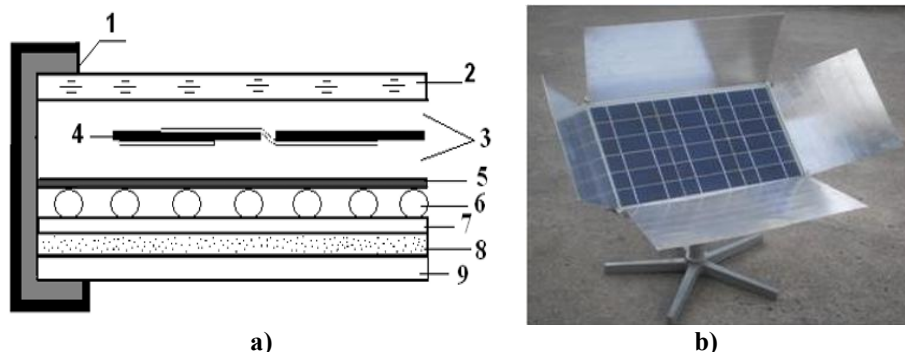
Accordingly, many studies are focused on developing photovoltaic-thermal (PV-T) device technology, which uses water or air as the working fluid [5].

The main advantage of PV/T technology is the simultaneous production of both energy types by transferring the heat accumulated on the surface of the solar panel to the cooling fluid. Scientific sources indicate that using water-based PV/T modules, the temperature of PV cells can be reduced by 8-18 °C, which leads to an increase in electricity generation of up to 6-12 % [6].

Additionally, the thermal energy efficiency in PV/T devices ranges from 35-55 %, meaning almost half of the incoming solar energy can be collected as useful heat. Consequently, the total, electrical and thermal, energy efficiency reaches 60-75 %, which allows achieving a performance nearly double that of conventional PV panels [7]. Using a cooling fluid (usually water) in PV/T systems is considered the most optimal option as a heat carrier, because water has a high specific heat capacity (4.18 kJ/kg·°C) and helps to stably manage the module's temperature due to its rapid heat absorption. For example, with a water flow rate of 1 kg/s, the PV module temperature can be reduced by up to 15 °C, allowing for the recovery of 800-1100 W of heat in the thermal circuit [8]. Researchers have also noted that by increasing the water flow rate in PV/T systems, the module's surface temperature is managed even more consistently. For instance, when the water flow rate was increased from 0.02 kg/s to 0.08 kg/s, an increase in electrical efficiency of 8-11 % was observed [9]. Therefore, cooling photovoltaic panels is one of the most optimal technologies for the purpose of increasing electrical efficiency. PV/T systems that use water as the working fluid allow for the generation of hot water along with a significant increase in electrical power. Research shows that through the heat absorbed in the PV/T system, the water temperature can be raised to 25-35 °C, and even 40-45 °C hot water can be obtained under optimal conditions [10].

## 2. Methods and materials

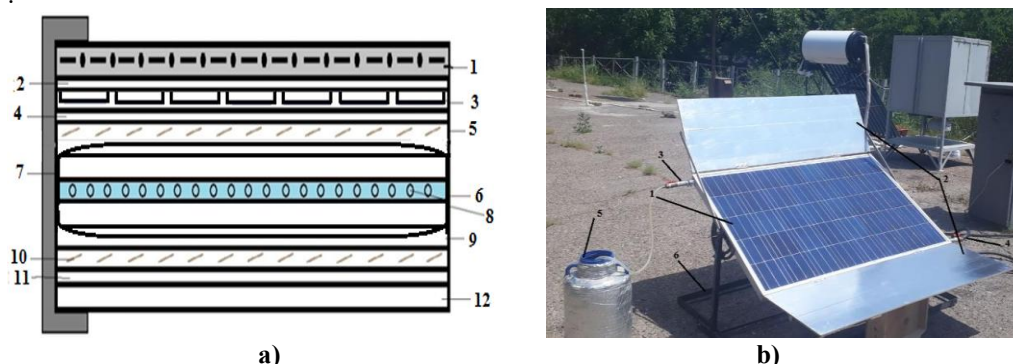
A number of Uzbek scientists have conducted research on PV/T technologies. Specifically, in a study conducted by I.A. Yuldoshev [11], the solar radiation flux density was increased by 1.6 times using additional reflectors, the PV power increased by 18%, the thermal system power increased by 47%, and the PV efficiency increased by 2%. However, the study did not include aspects such as economic analysis and the comparison of various working fluids. Figure 1 below shows the principal diagram and general view of the experimental PV/T device sample used by the scientist for the research:



**Fig. 1.** a) Principal diagram of a combined photo-thermoelectric generator device  
b) Front view of the experimental device

1 – frame, 2 – tempered glass (5 mm thickness), 3 – sealing material, 4 – solar cell, 5 – Aluminum sheet (0.3 mm thickness), 6 – tube in the shape of a “twisted spiral pipe”, 7 – reflective foil, 8 – thermal insulation material, 9 – back casing.

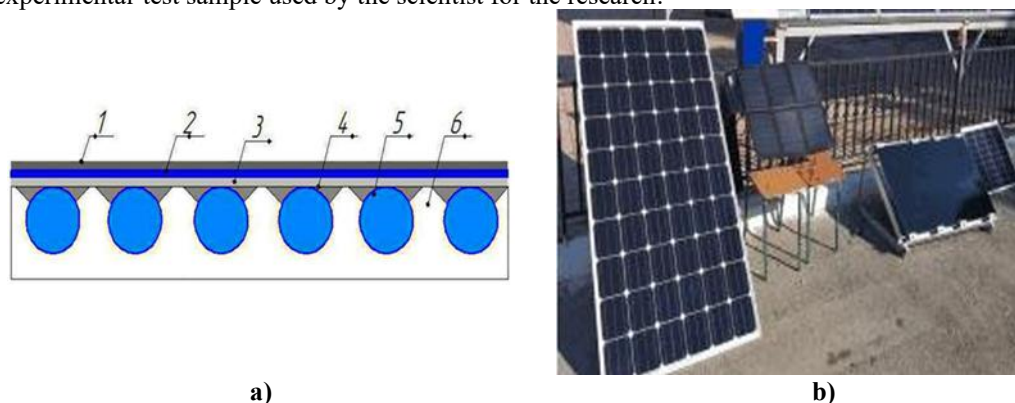
In the scope of the research conducted by S.Q. Shoguchkarov [12], spectrophotometric methods, volt-ampere and volt-watt characteristics, modeling of the electrophysical and thermal parameters and characteristics of a solar cogeneration device, and modern computational theory methods were used. However, the exergetic efficiency parameters and the technical-economic aspects of the cogenerated PV/T-TEG device were not fully modeled.



**Fig. 2.** Principal diagram and experimental-test sample of the PV/T-TEG cogeneration device

1- protective glass, 2-4 – EVA layer, 3 – solar cells, 5 – protective polymer coating, 6 – polymer film (water protection), 7 – plastic pipe for hot water flow, 8 – polymer tubes, 9 – cold water supply pipe, 10 – sealant based on polymer material, 11 – Aluminum layer polymer for thermal insulation, 12 – back casing.

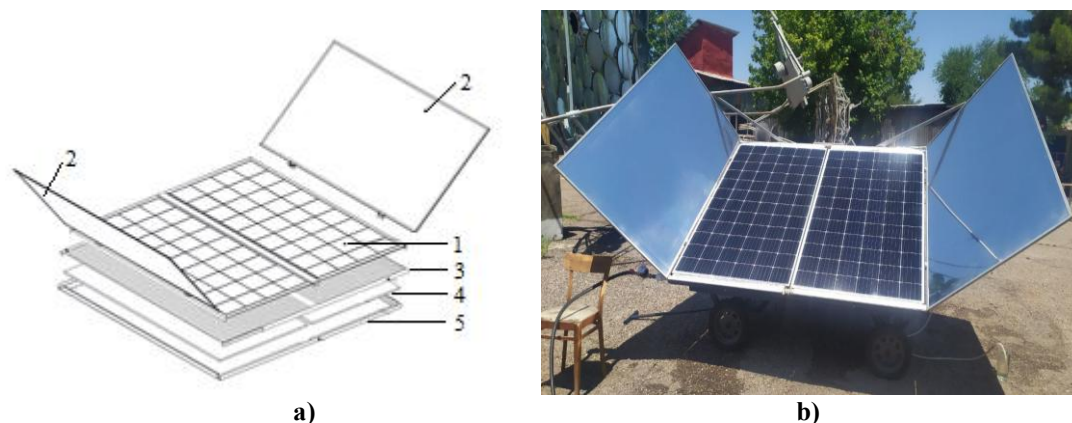
In the research work of I.R. Jurayev [13], a thin-film CdTe-based PV/T device was proposed; it was determined that the temperature of the PV module could be lowered by 8.6-21.5 % with forced water cooling, which can increase the efficiency by 1.7-2.5 %. However, this scientific research did not fully cover aspects such as the long-term degradation of the PV/T system and its in-depth modeling of economic efficiency. Figure 3 below illustrates the principal diagram and general view of the experimental-test sample used by the scientist for the research:



**Fig. 3.** Principal diagram and experimental sample of the thin-film CdTe-based PV/T device

1-PV/T frontal glass, 2-PV layer, 3-PV/T back glass, 4-absorber, 5-heat exchanger tube with cooling water, 6-insulation layer

Considering the parts that were implemented in the above-mentioned research work and those that remained unstudied, experimental research is being carried out on an improved PV/T device. This device is capable of increasing the solar radiation flux density incident on the module surface by 1.4–1.6 times by using high-reflectivity reflectors, and reducing the module surface temperature by 0.6–0.8 times by utilizing moving water as the working fluid in a parallel-channel polycarbonate heat collector. Furthermore, this PV/T device practically differs from the works mentioned above in that it is mobile (portable) and intended for energy consumers located far from the centralized energy supply. Figure 4 below illustrates the principal diagram and the view during the experimental testing process of this device.



**Fig. 4.** Principal diagram and view during the experiment of the 600 W capacity PV/T device used for experimental testing

1 – two PV modules, each with a power of 300 W, 2 – flat reflectors, 3 – parallel-channel polycarbonate collector, 4 – insulation layer, 5 – back casing

The cooling system is realized without additional energy consumption by ensuring water flow through a multi-channel polycarbonate layer. This polycarbonate-based multi-channel cooler absorbs the excess heat accumulated in the PV module uniformly, due to being in full and even thermal contact with the back surface of the panel. Based on this, the current study also utilized a Lexan ID-309 type multi-channel polycarbonate heat collector which forms a complete thermal contact with the water-based cooling system, with the aim of achieving high energy efficiency. The conductive properties of this heat collector allow for a 1.2-1.3 times increase in maximum power output by removing heat from the PV module surface 10-15 % faster. A series of experimental studies have shown that the intensity of solar radiation depends on the climatic conditions and the location of the sun in the area. The experimental-test work was carried out on June 3, 2025, in the climatic conditions of Tashkent city (at 41° geographic latitude), at the heliopolygon of the S.A. Azimov Physics-Technical Institute of the Academy of Sciences of the Republic of Uzbekistan. Measurements were taken during the sunny period of the day (from 06:00 to 18:00). The operating principle of the developed photovoltaic-thermal (PV-T) cogeneration device is based on the effective conversion of solar radiation into two types of energy. The device is integrated with high-reflectivity reflectors to sharply increase the overall efficiency of the system. These reflectors typically consist of polished aluminum coated surfaces with a light reflectivity capacity of over 90 %, and their main advantage is concentrating the solar flux incident on the photovoltaic module surface with a concentration coefficient  $C$  ranging from 1.5 to 3. Through the concentrated photon flux, the electrical energy efficiency of monocrystalline silicon modules (typically from 15 % to 18 %) is actively maximized.

**Table 1. Parameters of the 600 W PV-T module**

Parameter name	Measurement value
PV panel type	Monocrystalline silicon
Nominal electrical power	600 W
Useful surface area	3.25 m <sup>2</sup>
Open-circuit voltage ( $U_{oc}$ )	21,6 V
Short-circuit current ( $I_{sc}$ )	17,7 A
Dimensions (mm)	1640 x 990 x 35
Cooling method	Water-based, multi-channel polycarbonate layer
Installation angle (tilt angle)	41° (optimized for geographical latitude)
Location of experiment	Heliopolygon, S.A. Azimov Physics-Technical Institute, Tashkent, Uzbekistan
Measurement timeframe	Sunny hours (06:00 - 18:00)

Simultaneously, the excess heat energy generated as a result of radiation concentration is continuously removed through a special liquid or air cooling system on the back side of the module, and this heat is used for hot water supply at a temperature ranging from 27 °C to 45 °C. The mobile autonomous energy supply PV/T device stands out from other scientific research with its capability to provide up to 600 W of electrical power and hot water at 30-35 °C for autonomous energy consumers



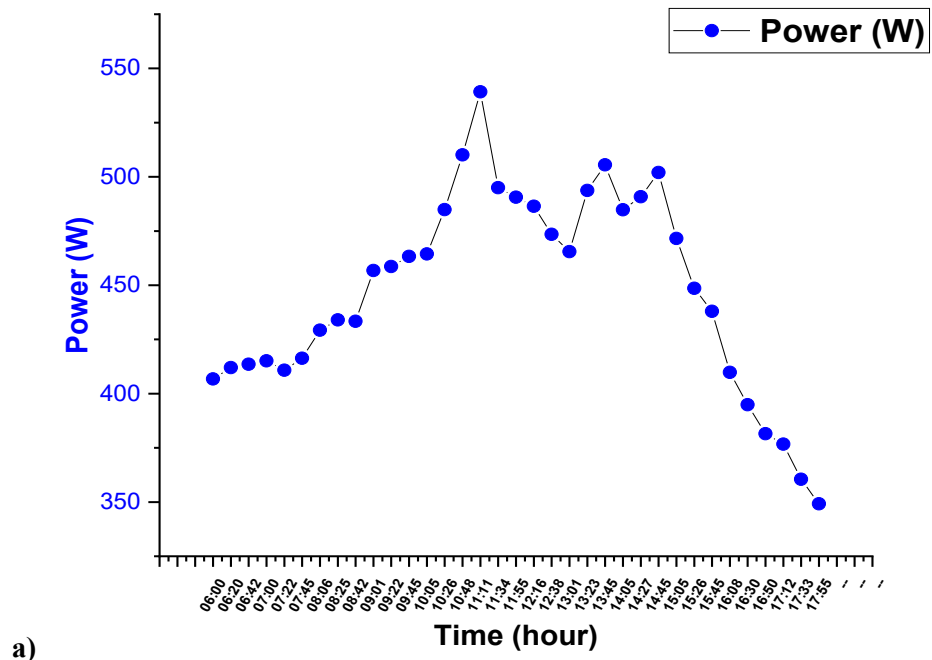
located far from the centralized electric and heat supply, such as in desert areas, mountainous villages, or field conditions. Table 1 below presents the technical and measurement parameters of the experimental photovoltaic-thermal device.

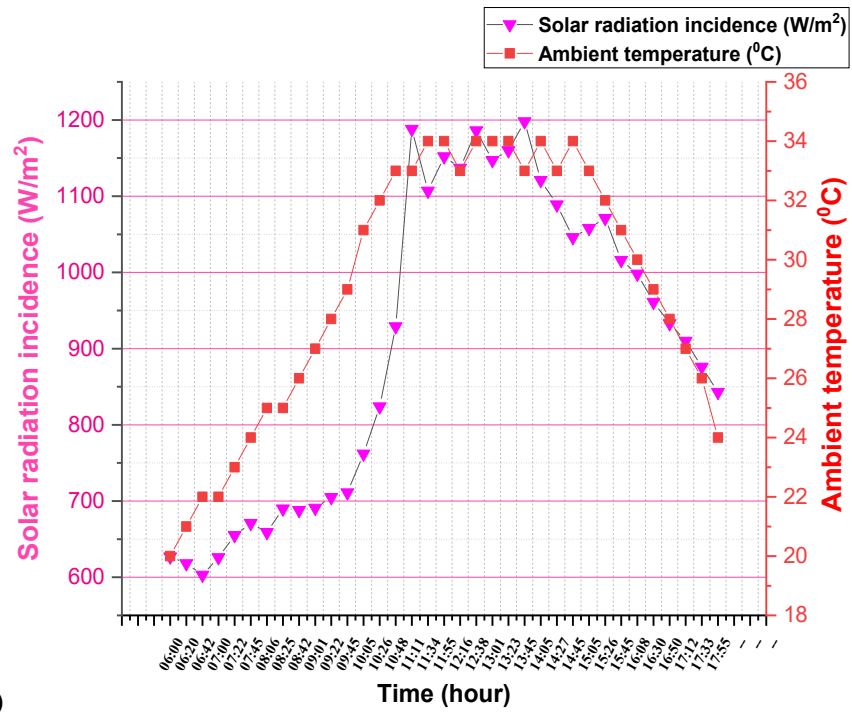
In the device, cellular polycarbonate (Lexan ID-309) was used as a collector to cool the SC (solar cells). Parallel-channel polycarbonate is a polymeric substance used as a translucent, high-heat-resistant material. Its physical and technical properties are presented in Table 2.

**Table 2. Physical and technical parameters of parallel-channel polycarbonate**

Parameter Name	Numerical value
Density	1200 kg/m <sup>3</sup>
Modulus of elasticity	2300-2400 MPa
Ultimate strength	over than 70 MPa
Sound absorption degree	15-20 dB
Thermal conductivity	0,2-3,9 W/m °C
Specific heat capacity	1100 J/kg·°C
Coefficient of linear thermal expansion	6,5·10 <sup>-5</sup> °C <sup>-1</sup>
Operating temperature range	from -100 °C to +135 °C
Melting temperature	from +280 °C to +310 °C
Dielectric permittivity (at 50 Gs)	3
Specific resistivity	10 <sup>13</sup> Ω·m
Light transmittance	90±1 %
Refractive index	1,585 ± 0,001
Outdoor service life	10 years

In terms of energy, solar cells have an electrical energy conversion coefficient in the range of approximately 16–18% under standard test conditions (STC) of 1000 W/m<sup>2</sup> solar radiation [10]. However, this efficiency sharply decreases as the temperature rises. For example, in crystalline silicon solar cells, an increase in temperature of every 1 °C reduces the electrical efficiency by an average of 0.3-0.5 %. For this reason, an increase in the operating temperature of the PV module from 25 °C to 60 °C leads to a decrease in electrical power of approximately 14-18 %. This confirms the necessity of implementing cooling mechanisms once again.





**Fig. 5.** Graph of the time-dependent change in generated power, solar radiation, and ambient temperature

As can be seen from the data in Table 2 parallel-channel polycarbonate has many advantages. Its low density indicates that it is quite light relative to its volume. The parallel-channel polycarbonate is positioned on the back surface of the SC (solar cell) in the device such that the material's elasticity and linear thermal expansion are taken into account. Although the thermal conductivity of polycarbonate is lower than that of copper, its flat surface ensures that it has better thermal contact with every point of the SC, which provides a superior heat exchange compared to a copper collector. Since the specific heat capacity values of the hermetic layer and the polymer protective coating on the back side of the SC are close to that of polycarbonate, they have excellent thermal contact and transmit the SC's heat to the water. According to the experimental results, when the SC heats up significantly, its back side temperature does not exceed 90 °C

The graph of the dynamic change in solar radiation incident on the surface of the mobile PV/T device with an autonomous energy supply system under study, and the power output indicators generated by this experimental device are illustrated in Figure 5 below:

The level of heat flux incident on the surface of the photovoltaic-thermal (PV-T) device (or the level of hot air flow flux) and the level of heat subsequently lost due to several factors are calculated as follows [14]:

$$Q_o = U_L A (T_p - T_a) \quad (1)$$

where,  $U_L$  is the heat loss coefficient

$T_p$  is the temperature of the PV module, °C

$T_a$  is the ambient temperature, °C

The portion of solar energy absorbed by the absorber is determined according to the following equation:

$$Q_{abs} = \tau \alpha_a G = I(\tau \alpha) \cdot A \quad (2)$$

where,  $I$  is the intensity of solar radiation,  $\frac{W}{m^2}$

$\tau$  is the heat transmissivity

$\alpha$  is the absorptivity of the absorber

$A$  is the surface area of PV-T module,  $m^2$

The amount of useful energy obtained from the solar radiation flux can be determined by calculating the difference between the intensity of radiation incident on the device surface and its absorbed portion, as shown in the following Eq.3 [15]:

$$Q_{use} = Q_{in} - Q_{out} = I \tau \alpha A - U_L A (T_p - T_a) \quad (3)$$

The thermal efficiency of an autonomous photovoltaic-thermal (PV-T) device in producing hot water is determined by the following equation:



$$\eta_{coll} = \frac{Q_{use}}{AI} \quad (4)$$

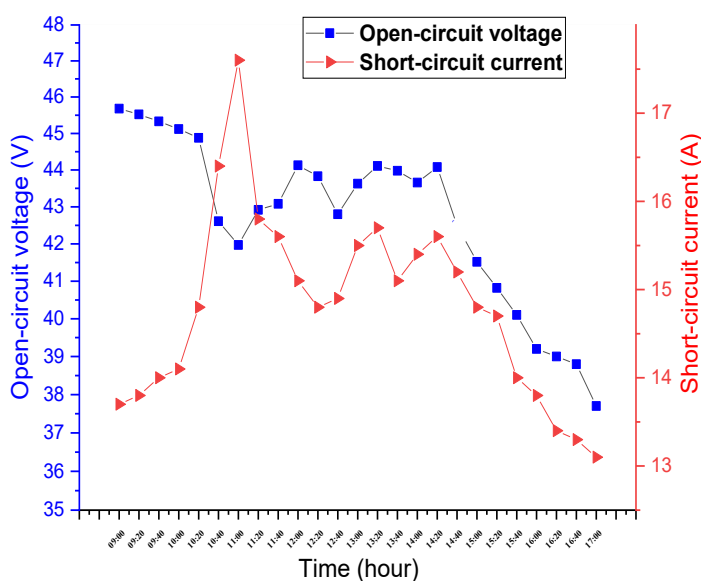
The electrical energy production efficiency of the mobile photovoltaic-thermal (PV-T) device, which was the subject of the research, can be calculated using the following Equation 5 [16]:

$$\eta_{el} = \frac{P_{use}}{P_{rec}} = \frac{IU\gamma}{AG} \quad (5)$$

where,  $P_{use}$  is the power output obtained from PV-T system,  $W$   
 $P_{rec}$  is the power received,  $W$   
 $\gamma$  is the fill factor of PV module for VAX

### 3. Research results and their analysis

Based on the experimental research results conducted on June 3, 2025, at the S. Azimov Physics-Technical Institute of the Academy of Sciences of the Republic of Uzbekistan, and taking into account the influence of several factors on the effective utilization of solar energy,



**Fig. 6.** Graph of the time-dependent change in short-circuit current ( $I_{sc}$ ) and open-circuit voltage ( $V_{oc}$ ).

Figure 2 shows the graph of the daily change in the short-circuit current ( $I_{sc}$ ) and open-circuit voltage ( $V_{oc}$ ) of the photovoltaic-thermal (PV-T) device during daylight hours.

As can be seen from the above Figure 6, both parameters—the short-circuit current ( $I_{sc}$ ) and the open-circuit voltage ( $V_{oc}$ )—show a tendency to increase in the first half of the day and decrease in the second half. At 9:00, the short-circuit current was 14.5 A, and the open-circuit voltage was 45.5 V (Figure 2, Note: This figure reference likely intended to be Figure 6 or a previous, non-sequential figure mentioned in the source text). By 11:00, the current sharply increased to 16.7 A, while the voltage dropped to 42.3 V.

The experimental results were analyzed using the average solar radiation data based on a 24-hour interval from the GLOBAL SOLAR ATLAS website [17]. As shown in Figure 5, at the beginning of the experimental-test process (at 06:00), the value of solar radiation energy was  $627 \text{ W/m}^2$ , and the generated power was 406.8 W. After 10:00, the ambient temperature, solar radiation, and the amount of power generated by the PV/T module significantly increased. By midday, the solar radiation incident on the system and the amount of power generated by the system reached their maximum points; here, the solar radiation flux density was  $1188 \text{ W/m}^2$ , and the power output was 539.2 W. In the afternoon, starting from 15:00, the values of all three parameters presented in the graph decreased. By 17:00, the solar radiation flux density dropped to  $843 \text{ W/m}^2$ , and the generated power decreased to 349.2 W.

### 4. Conclusion

The efficiency of a solar-powered photovoltaic-thermal (PV-T) device primarily depends on the intensity of the incident solar radiation and is inversely proportional to the operating temperature of the solar cells [18].



The research results showed that the mobile photovoltaic-thermal (PV-T) device, which has a nominal power of 600 W and a useful working surface area of 3.25 m<sup>2</sup>, achieves high efficiency by using a water-based cooling system and integrating high-reflectivity reflectors.

During the experimental tests, the module's generated power was 539.2 W under conditions where the maximum solar radiation flux was 1188 W/m<sup>2</sup>. By effectively managing the operating temperature of the solar cells, this experimental device not only increases electrical energy efficiency but also provides the capability to supply hot water at temperatures ranging from 27 °C to 40 °C.

From a practical application perspective, it was determined through experiments that the PV-T device can meet the demand for up to 600 W of electrical power and hot water for autonomous consumers located far from the centralized energy supply.

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