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Fundamentals of Designing Hybrid Concentrator Solar Systems

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Abstract. The paper considers the technique of hybrid concentrator solar plants developing with a new design that increases the optical concentration ratio and utilizes additionally diffuse solar radiation. The circulation of heat carrier passes in divided PV modules and thermal collectors circuits on a common carrier platform with the implementation of resetting heat in a counter flow mode in the linear heat exchangers. Described data experiments and calculations of specific performance of electric and thermal energy for different concentration ratio and at different installation latitudes as well as the cost of energy production calculations.

Keywords: solar cells, mirror reflectors, concentrators, thermal collector, heat transfer agent, heat exchanger.

INTRODUCTION

On the photovoltaic market has appeared a flexible silicon solar cell capable to work with growth of concentration of solar radiation to increase the generation of electricity and heat, which is intensively retracted from cells by heat transfer fluid [1]. The level of the peak power of silicon solar cells is sufficient for the production of concentrator photovoltaic-thermal (CPVT) systems, fully providing electricity and heat to private households and a number of such units can forming microgrids for heat and electricity supply to the remote villages, tourist centers e.t.c. The literature widely discussed works on the application of photovoltaic-thermal (PVT) solar systems with a low-temperature heat carrier [2], in which the solar cells are placed on a flat cooled walls of different geometry and are protected by thermal glass. The authors of [3] went around this drawback by using a low-temperature heat carrier capacity of the heat exchanger to preheat the salt water in the solar distillers, with the result that increase the productivity of fresh water produce at ≈ 30%. In [4] it is shown that with the use of PVT collector with aluminum reflectors mounted on both sides solar radiation intensity increases from ≈ 43% to ≈ 65%, generates electric power 17% higher, and the heat by 55% higher compared with PVT collectors without concentration. It is possible to increase of the heat transfer temperature with the use of GaAs solar cells [5], effectively operating in the temperature range up to 250 ^{0}C, however, they have a small footprint and high cost. The authors of [6] studied the characteristics of silicon solar cells with a p-n junction and the Schottky barrier in the temperature range of 25-170 ^{0}C with various concentrations of solar radiation and recommend their use in the construction of hybrid solar systems. In [7] presented the study of PVT systems with cooled solar cells, located in the focal region of parabolic reflector, which showed unexpectedly low values of productivity compared to conventional flat collectors and PV modules. Analysis of international experience in the field of CPVT systems has shown that their energy potential is far from exhausted. In this study substantiates the recommendations of design and method of working elements calculation, and to increase productivity of CPVT plants and reduce their costs.

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EXPERIMENTS AND CALCULATIONS

The concept of a low-voltage concentrator solar energy industry has been developed by authors in [8,9]. Figure 1a shows the experimental stand for the measurement of output characteristics of CPVT systems, and Fig. 1b shows the mounting of the concentrator with two sections of mirror reflectors.

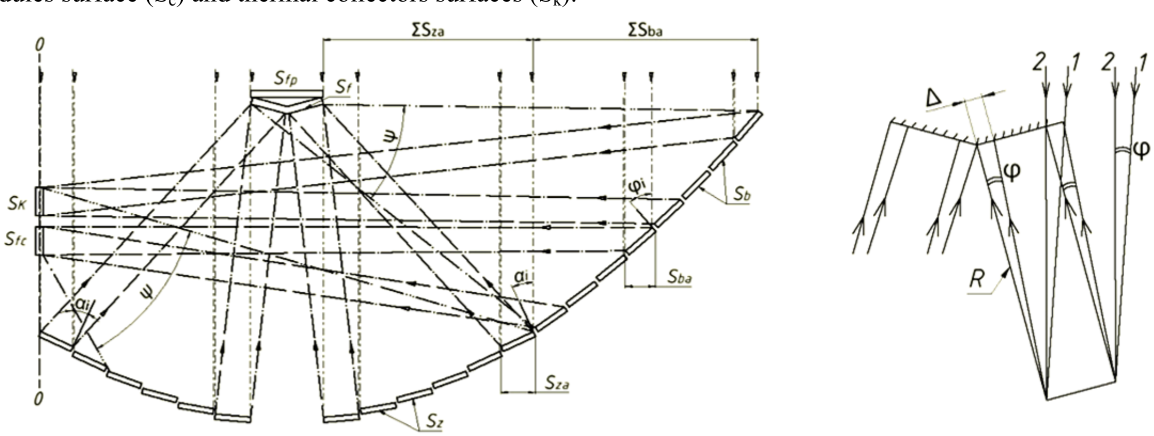
a) b)

FIGURE 1. Laboratory model of CPVT system; a) experimental stand for testing b) assembly of the concentrator mirrors.

On the carrier platform mounted flat-plate collectors (or vacuum tubes), flat and v-shaped PV modules with solar cells which are working with solar concentration, heat exchangers, and sun tracking system.Years of research and constant upgrading of laboratory installations have allowed to make recommendations for enhance their energy efficiency, reliability and ease of maintenance.

The first rule of design CPVT systems consists in the necessity to use flexible silicon cells with a relatively large area and back arrangement of a contact grid, which can draw back a lot of heat through the surface. Only three manufacturers in the world produce such solar cells, among which the American firm SunPower [8]. Flexible photocells Maxeon operate with 10-fold concentration of solar radiation, have a large area Si = 0,0156 m^2 with convenient interface for the mounting on the cooling channels walls. The heat generated on the cells is transferred through the copper strips to the coolant within the cooling channels. The relatively large area of solar cells promotes the usage of a simple sun tracking system, and the cells number is a multiple of the dimensions of PV modules, consistent with the level of battery charge voltage.

According to experiments, the simplest and most reliable way to track the sun of oversized two-piece concentrator could be made with a rotation of carrying platform along the polar axis. Figure 2a shows a diagram of uniform reflected solar radiation formation on the working surface of planar v-shaped PV modules (S_f), flat PV modules surface (S_c) and thermal collectors surfaces (S_k).



a) b)

FIGURE 2. Optical scheme of sunlight focusing on the surface of: a) PV modules and b) thermal collectors.

The aperture area of two-section CPVT system provide eight identical modular concentrators for planar PV modules and four identical modular concentrators for thermal collectors and PV modules placed below them. Because of the earth's rotation with an angular velocity $\varphi = 2\pi /24\cdot 60$ degrees per minute, carrier platform standstill time – τ, which is given by the controller program, there is a shift of the light reflection along the surface of linear receivers. Figure 2b shows the geometry of the occurrence of this shift Δ during the sun moved from point 1 to point 2, from which we obtain an analytic expression to determ the working area of the receiver:

$$S_f = n * S_i + 2 * \tau * \mathrm{R} * \left(\frac{2\pi}{24} * 60\right) * \mathrm{L} \qquad (1)$$

where n and S_i - amount of photocells and their area; R- distance from receiver and concentrator mirrors; L - length of receivers. The foregoing gives grounds to recommend second design rule – single axis sun tracking along the longitudinal axis within daytime by means of controllers and trackers with a periodic (every two days) adjustment along latitude.

Reflected sun's rays are sent to the receivers through the protective glass, on which they are partially reflected and absorbed. To reduce the proportion of the reflected rays authors have suggested [10] the usage of a receivers surface bending. We have developed a bending idea and as a third rule is to create aligned in a single plane with planar PV modules, one of which is v-shaped and an array of Maxeon solar cells, and a second flat and comprises, on the uncooled surface an array of solar cells of the same dimensions, but cheaper and working without sun concentration. The proposed construction increases the mechanical strength of the channels at a great length, solves the problem of heat carrier fluid transportation in two-part receivers and increase the aperture. Moreover, technologically facilitated the task of removing shading on adjacent mirrors due optimum combination of angles between the longitudinal frames of concentrators mounting and surfaces of v-shaped receivers. As the geometric characteristics of the concentrators with different mirror number (N) is considered average value of the cosine between the incident rays and the normal to the mirror surfaces: $\cos_{cp}\alpha_i = (\Sigma\cos \alpha_i)/N$. Then geometric concentration of PV modules is equal: $C_{gf} = (N \cdot S_z \cdot \cos_{cp} \alpha_i)/S_f$, and the geometric concentration of collectors: $C_{gk} \approx N_i \cdot S_b \cdot \cos_{cp} \varphi_i / S_k$.

In order to implement the method of seasonal redistribution of the reflected radiation on the PV modules and collectors surfaces their dimensions should be equal, i.e. $S_k \approx S_c \approx S_i \cdot n/2 + \Delta\cdot L$. Average side mirror concentrators mounted at an angle of 45^0 to the collector surface, from where the minimum area of side mirrors: $S_b = \sqrt{2}\cdot S_k$.

In [11] it is shown that as the number of mirrors exceeding 10 it is issue with cosine losses rises and windage concentrators, which is requires an increase in capital expenditures to ensure structural rigidity, proposed formula for calculating the optical concentration in the case of separately installed PV modules and collectors:

$$C_{op} = C_g * K_{ref} * D * (1 - K_{dif}) \qquad (2)$$

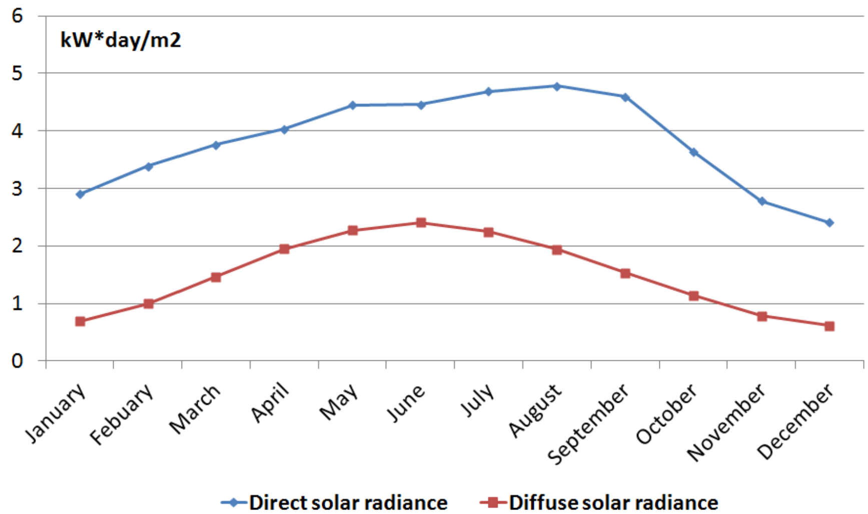
where C_g - geometric concentration; K_{ref} - the reflection coefficient of mirrors; D - coefficient taking into account the absorption and reflection of solar radiation in a protective glass; K_{dif} - component of diffuse radiation in the overall radiation.

The fourth rule is the necessity of mounting PV modules and collectors on a single carrier platform that allows the use of not only direct, but also a certain part of diffuse solar radiation. Figure 2 shows that by the law of geometrical optics on the photocells and thermal collectors surfaces comes reflected direct sun rays from their own concentrators, and the reflected diffuse rays passes off target. However, they supplied the energy of the diffuse radiation from the mirrors of adjacent concentrators, the value of which depends on the orientation angle of the adjacent concentrators, their areas, as well as place of system installation. Optical concentration ratio expresed:

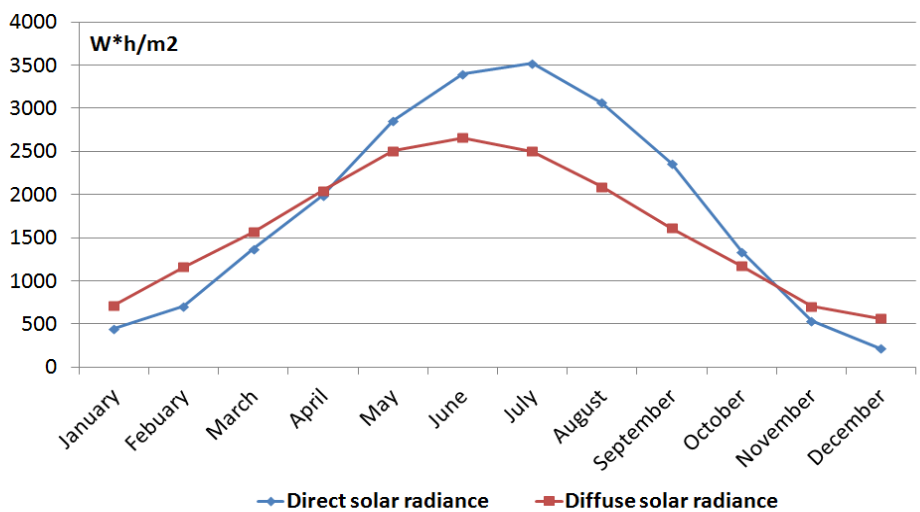
$$C_{op} = C_g * K_{ref} * D * (1 - K_{dif} + I * cos^2\left(\frac{\sigma}{2}\right) * \varphi/\pi \qquad (3)$$

where I - intensity of diffuse solar radiation; σ - angle of adjacent concentrator mirrors orientation to the horizon [12]; ψ/π - solid angle defining a flow of the diffuse radiation from the concentrator mirror surfaces.

The value of the intensity of diffuse solar radiation I, $W\cdot h/m^2$ on a flat surface are taken from meteorological observations. The solid angle φ is calculated by the value of the ratio of the radiation and the aperture of the receiver surface area adjacent concentrators and lies in the range of ($\pi/5 \div \pi/6$). Figure 3a shows the average daily direct and diffuse solar energy incident on the horizontal surface at a 43^0 latitude taken from the NASA data [13], and Fig.3b - direct and diffuse solar energy incident on the horizontal surface at a 47^0 latitude. [14]



a)



b)

FIGURE 3. Daily direct and diffuse solar radiation at a latitude of: a) 43^0 N.L., and b) 47^0 N.L

Graphics on the left shows that the proportion of diffuse solar radiation from January to June in the global insolation is ≈ 20% and from July to September is reduced to ≈ 17%. In winter, the proportion of diffuse solar radiation is greater than in the summer due to increased cloudiness, which clearly illustrate the graphs on the right figure. Whence it follows the fifth rule - as a recommendation to install and operate CPVT installation at a latitude where direct solar radiation is more than 75% of full insolation and utilize sun adjacent mirror concentrators to reflect the diffuse solar radiation on the receivers.

Following equation (3) the optical concentration depends on the four factors - geometrical concentration and three optical coefficients, so if one of them has a small value, overall optical efficiency remains low. Hence the sixth rule - necessary to select high-quality materials with optical coefficients ≥ 0,93. Today it is not difficult to make, for instance mirror films with a reflectance of ≈98% produces of Alanod company [15]. There is international experience of designing and manufacturing parabolic concentrators with Kref ≈ 0,96 [16]. The integrated absorption coefficient of solar radiation in the protective glass depends on the material and its total thickness. For instance, according to [17] 4 mm mirror glass and solar cells thermal protection glazing has an overall low solar radiation transmittance D ≈ 0,88. Due to our innovative design, we can use without any loss of mechanical strength more thinner thermal protective glass (less than 2 mm) that appears on the market [18], and receive the transmission coefficient D ≥ 0,96.

The seventh rule is to use a dual-circuit solar cells cooling system with additional movement of heat carrier under the influence of a temperature gradient in heat channels. This requires to place receivers and concentrators angle to the horizon. Transfer of the accumulated heat is conducted in the housing of a linear heat exchanger, which is located below the reservoir, in the mode of countercurrent heat carrier, which intensifies the heat exchange processes.

In [19] described the study of linear bilateral collectors, beneath which flat PV modules are installed, forming a protective thermal layer along the walls of the collectors. An increase in the thermal efficiency of the collector was up to 25%. The positive results of the experiments provide a basis to determine the eighth rule - below collectors should be placed flat bilateral PV modules with cooled Maxeon –type photocells.

The technical data sheets of silicon cells indicate characteristics at work with a single sun and a temperature of 25 ^{0}C. Hence the ninth rule - acquired Maxeon photocells to be tested at a different concentrations on the bench with solar radiation imitator. Figure 4 shows the results of such testing - graphs of the peak power and the solar cell fill factor. It is seen that in the concentration range up to 10-fold and peak power increases almost linearly.

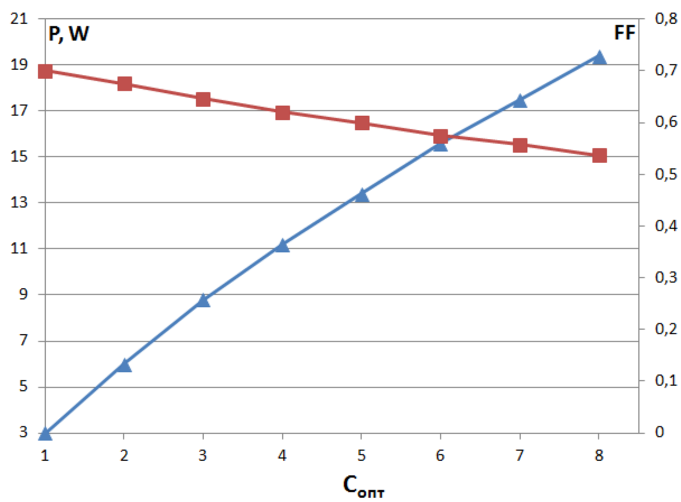


FIGURE 4. The dependence of the output power P and fil factor FF of solar cells Maxeon from the optical concentration of solar radiation.

According to the calculated value of the optical concentration C_{op} and the resulting graph define predicted peak power of a solar cell P_i. The electrical energy generated by Maxeon solar cells and uncooled cells on the upper side of the planar photo module is equal $P_{f1} \approx n\cdot(P_{i1} + P_0)W\cdot 1h$. Part of the energy from uncoolied solar cells P_H provides operation of circulation pumps and the tracker, while the rest goes to the energy storage system batteries. All PV modules of CPVT system generates battery $\Sigma P_f = (4\cdot P_{f1} + 2\cdot P_{f2} - P_H)$ W*h energy. Most of the solar energy through the surface of solar cells goes over into useful heat within heat carrier at conversion efficiency of ϑ, i.e. part of it immediately dissipated into the environment by convection and radiation. As a result, useful heat of heat transfer fluids at the outlet photo module channel is equal $Q_f \approx 3{,}5\cdot P_f\cdot\vartheta$, and from all PV modules $\Sigma Q_f = 3{,}5\cdot\vartheta\cdot n\cdot(P_{i1} + P_{i2})$.

The total heat transfer fluid thermal energy of low temperature PV module circuits dumped in the linear heat exchanger, at the counterflow mode with high-temperature coolant circuit of collector. A portion of heat is lost through the outer insulation of the heat exchanger which is having a heat efficiency $\vartheta_T \approx 0{,}9$. On the collector input channel comes thermal energy from the high-temperature coolant quantity: $3{,}5\cdot\vartheta\cdot n\cdot(P_{i1} + P_{i2})\cdot\vartheta_T$.

Selective coating TINOx [20] increases the coefficient of absorption of solar energy to 94%. By using the calculated value of the standard solar insolation E = 1000 W · h / m2, we obtain an expression for the determination of the thermal energy received by heat transfer fluids flowing along the walls of collectors:

$$Q_k = 0.94 * E * \tau_1 * 2 * S_k * C_{opk} * \vartheta_1 \qquad (4)$$

As a result, total thermal energy produced by CPVT system and transported to the boiler heat supply system amounts to: Q Q ≈ $(4 \cdot Q_{f1} + 2 \cdot Q_{f2}) \cdot \vartheta_T + 2Q_k$.

The optimum heat transfer fluids flow rate is determined on the basis of a differential equation of stationary heat exchange in flat channels based on previously obtained expression [21]:

$$G * C_p * (T_2 - T_1) = S_f * C_{opf} * E * [(1 - \eta) - (1 - \vartheta] \qquad (5)$$

where G - the coolant flow rate, kg/s; Cp - heat capacity of the coolant, J/kg·K; T1 and T2 - temperature of coolant at the entrance and exit of the channel; η- solar cells electrical efficiency; C_{opf} - optical concentration factor; $(1 - \vartheta) \approx 0{,}23$ - share of heat losses by convection and radiation from the surface area S_f.

A potential for heat exchange from solar cells output by heat transfer liquid is determined from the inequality:

$$S_f \cdot C_{opf} \cdot E \cdot [(1 - \eta) - 0{,}23] \leq S_f \cdot \left[\frac{(t - t_ж)}{R_1} + \frac{(t - t_0)}{R_2}\right] \qquad (6)$$

where R1 and R2 - thermal resistance to heat flow, directed from solar cells with a temperature t to the heat carrier with a temperature $t_{ж}$ and to the environment with temperature $t_{0,}$ respectively equal $R_1 = \frac{\delta_n}{\lambda_n} + \frac{\delta_{o,}}{\lambda_o} + \frac{\delta_{Al}}{\lambda_{Al}} + \frac{1}{\alpha_{ж}}$ u $R_2 = \frac{\delta_c}{\lambda_c} + \frac{1}{\alpha_в}$; $\delta_{n,}$ $\delta_{o,}$ δ_{Al}, δ_c - respectively, the thickness of the heat conducting paste layer, oxide film on the surface and the channel wall; $\alpha_ж$, $\alpha_в$ - the average length of the channel for the fluid heat transfer coefficient and the ambient air; $\lambda_п$, $\lambda_{o,}$ λ_{Al}, λ_c - respectively the thermal conductivity of paste, oxide film, aluminum and EVA films.

During the snowfalls in winter some types of collectors (especially vacuum) cease to function for a long time. In our design, this problem is solved by the thermal radiation from the surface of PV modules, collectors and a heat exchanger which maintains positive temperature of mirrors and promotes the melting of the snow on their surface, as shown at Fig.5.

FIGURE 5. Snow melting on the surfaces of carrier platform mirrors.

One of the characteristics of the of the design quality is the coefficient of construction materials usage in the manufacture of solar systems (km), which is equal to the ratio of the aperture area to the carrying platform area. Technological space occupied by the metal frames profiles and supporting structures of carrying platform, will be denoted by ΣSn. Then we obtain: km ≈ 4·Sf · cos αi + Σ(Sza + Sba) / (Σ (Sz + Sb) + ΣSn) ≈ 0,82. For instance, in the Swedish system Matarenki Light carrier platform utilization rate is km ≈ 0,75 [22], and for IBM SUNFLOWER system which uses a large number of circular mirror reflectors and amount of non-working gaps km ≈ 0,59 [23].

SYSTEM COST ANALYSIS

The final step is to estimate the cost of working elements production of the CPVT system using domestic and foreign components, as well as the calculation of operating costs, taking into account service maintenance.

The obtained expressions (1) - (6) and the experimental graphs of the solar cells peak power at different concentrations of the sun (Fig.4) make it possible to carry out model calculations of the projected annual production of industrial CPVT system prototypes with a length of cooled PV modules L ≈ 0,125· n/2 ≈ 2,14 m and the size of the light field at the offset receivers Δ ≈ 6,5 mm.

From (1) working area of PV modules Sf ≈ 0,55 m^2; working area of thermal collector Sk ≈ Sc = Sf/2; mirrors Sba ≈ Sf/2 = 0,28 m^2 and Sb = √2· Sk ≈ 0,39 m^2. For N = 12 concentrator mirrors of planar PV modules mean value of the cosine coscpαi = (Σcos αi)/12 ≈ 0,95, aperture area of concentrators ≈ 48·Sz ·coscp αi ≈ 12,8 m^2 and geometric concentration of Cgf = (N · Sz · coscp αi)/Sf ≈ 5,7. With the same number of mirrors Ni = 4 areas concentrators for collectors and flat PV modules below them are Σ Sb ≈ 16Sb ≈ 6,24 m2, and the aperture area 16· Sba ≈ 4,45 m2. For Ni = 4 mirrors Cgk ≈ Ni·Sb·coscp φi / Sk ≈ 3,8. For Kdif ≈ 0,25 and taking into account ψ/π ≈ (π /6)/π obtain the value of the last multiplier in (3) ≈ 0,89. Determined the optical concentration of planar PV modules Sopf Copf ≈ 5,7·0,95·0,96·0,89 ≈ 4,6, and for collectors Copk ≈ 3,1, according to the graph at Fig.4, we find the corresponding projected peak power of a Maxeon solar cell Pi ≈ 12,8W and ≈ 9W. By cooled solar cell on flat and planar PV modules will be generated electricity respectively Pf1 ≈ 435W·h and Pf2 ≈ 306 W·h. Uncooled solar cells from four planar PV modules generates energy per hour ≈ 4·n·2,5·1 ≈ 340 W·h, a portion of which (4·n·2,5·1 - PH) ≈ 180 W·h enters to the energy storage system. The total aperture of mirrors for all PV modules is equal 17,24 m^2 and collector 4.45 m^2. The calculated insolation for receivers on the carrying platform we obtain by dividing the amount of insolation on a horizontal plane to the cosine of the latitude angle. For example, Kapchagai city estimated average annual insolation is equal 1560/cos 430 ≈ 2200 kW·h/m^2.

TABLE 1. Results of calculations for various latitudes, when D ≈ 0,96, K_{ref} = 0,95, N = 12, N_i = 4, n =34, E = 1000 W·h/m^2.

Parameter	**Kapchagai, 43^0 Solar insolation at the horizon. plane 2200 kW·h/m2per year**	**Madrid, 40^0 Solar insolation at the horizon. plane 1622 kW·h/m2per year**	**Ashgabat, 37^0 Solar insolation at the horizon. plane 1500 kW·h/m2per year**
K_{dif}	0,25	0,21	0,17
C_{opf}/C_{opk}	4,6/3,0	4,7/3,3	4,8/3,5
Σ P_f, kW·h	2,533	2,57	2,70
ΣQ_f, kW·h	5,57	6,30	6,62
2Q_k , kW·h	2,40	2,48	2,53
Q, kW·h	7,97	8,78	9,15
ΣP_f/4ΣS_{af} , kW·h/m^2	0,147	0,15	0,21
2Q_k/ ΣS_{ba} , kW·h/m^2	0,53	0,56	0,57
P, kW·h/year	2,53·2200 = 5560	2,57·2317 =5955	8100
Q, kW·h/year	7,97·2200 =17530	8,78·2317 =20343	28365
$P_{уд}$, kW·h/m^2/year	0,147·2200 = 323	0,15·2317 =348	630
$Q_{уд}$, kW·h/m^2/year	0,53·2200= 1160	0,56·2317=1290	1710

Figure 6 shows the results of calculations annual performance of solar systems on electricity (blue rectangles) and heat for different latitudes.

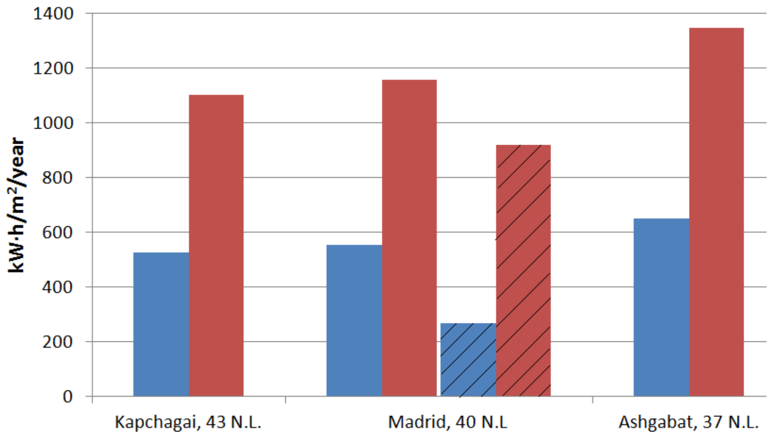


FIGURE 6. Annual performance of CPVT systems

For comparison, there are presented data of [7.17] on the latitude of Madrid (hatched rectangles). The specific productivity of our plants is much higher, which is due to the fact that in planar arrays of PV modules work paired of solar cells - uncooled from direct and scattered light and cooled with the concentration of the sun. In addition materials are used with high optical reflectance coefficients and transmission coefficients of protective glasses in linear radiation receivers.

In [23,24] reviewed a method of calculating the cost of CPVT systems and their payback time. We use it to determine the cost of electricity and heat of our CPVT systems. Earnings from production assume 20%. Figure 7 shows the structure of capital expenditure at manufacturing a small batch of systems - 300 pieces per year, taking into account the currently existing prices for components and materials. Determined retail price CPVT systems around $C_p \approx \$7100$. Thus obtained value of installed electric and heat capacity: $C_p / (\Sigma P_f + Q) \approx \$0,65$/Watt.

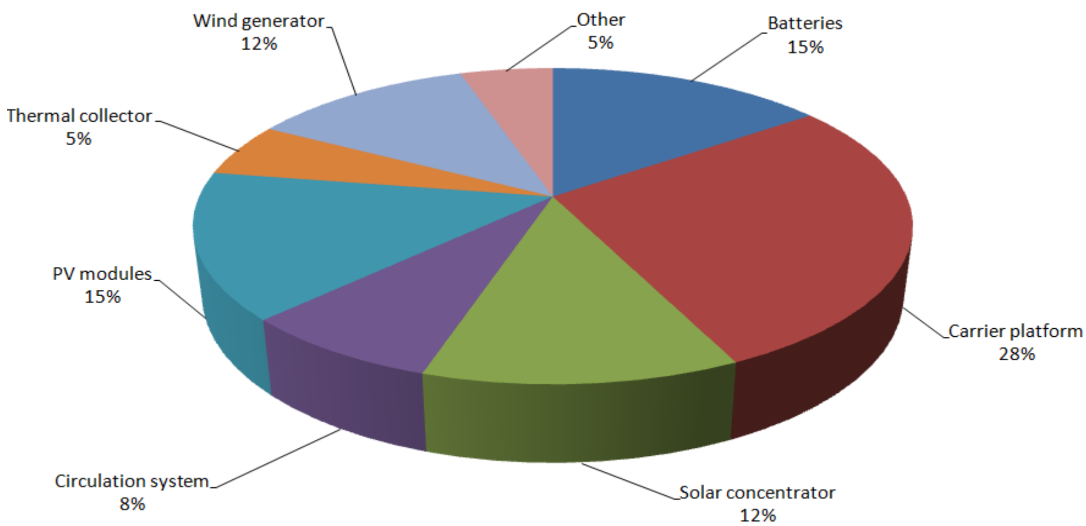


FIGURE 7. Structure of the capital cost of CPVT systems manufacturing.

To determine the cost price of separate electricity and heat were taken into account capital costs for materials and components responsible for the production of electricity or heat. In this case, we obtain the cost of installed electric capacity ≈ \$1.94/W and heat capacity ≈0,27 \$/W. In the city of Kapchagay 2690 hour/year, annual production capacity of electric energy is $\approx 2{,}53 \cdot 2690 = 6805$ kW·h/year and heat ≈ 22300 kW·h/year. At the cost of a network electricity and heat at the beginning of 2016 CPVT installation pays off after about six- seven years. During this period will be replaced circulation pumps and tracker which slightly increases the capitalization, and the cost of electricity will be $\$4900/(6805 \cdot 7\ \text{kW·h}) \approx \$0{,}103/\text{kW·h}$ and heat - $\$2200/(22300 \cdot 7\ \text{kW·h}) \approx \$0{,}014/\text{kW·h}$. Should be noted that such systems are designed for remote from the networks tourist centers and farms, where the energy of imported fuel costs significantly exceeds the cost of the energy suplies, and where our systems will pay off in four - five years.

RESULTS AND DISCUSSION

High performance of CPVT systems with new design is due, above all, the use of silicon of solar cells, working with solar concentration, which generating a large amount of heat and intense heat transfer by liquid coolant. The global photovoltaic industry is ready to put on the market today any number of such solar cells with relatively low cost. The second important factor is the use not only direct solar irradiance but diffuse irradiation either, in comparison with analogues. What is important is the way of solar cells placed on the carrier platform. Per square meter of uncooling surface of conventional photo module with a thick protective glass (D ≈ 0,9) can be placed no more than 1m2/0.0161 m2 = 62 pieces of solar cells Maxeon type, capable to generate electric power ≈ 175 W·h. Without solar concentration cooling solar cells does not make sense, so generated thermal energy is dissipated into the environment. With the same aperture area and heat-generating solar cells operation mode with intensive cooling by heat transfer can be obtained ≈ 150 W·h of electricity and ≈ 450 W·h of thermal energy.

The results of engineering calculations of CPVT systems developed in accordance with the provided design rules, are in agreement with experimental results. According Based on research findings designed industrial prototype of CPVT system with two concentrator sections, peak electric power of more than 2.5 kW and 9 kW peak heat power.

REFERENCES

1. "Maxeon solar cells technology improvement." available at www.sunpower.com.
2. T.T. Chow, "A review on photovoltaic/thermal hybrid solar technology." Applied Energy, 2010, pp. 365–379
3. A.Krois, S.Hamberger, M.Spinnler, et al., "Development of a Seawater-Proof Hybrid Photovoltaic/Thermal (PV/T) Solar Collector." Proceedings of the International Conference on alternative Energy in developing Countries and Emerging Economies, 2013, pp. 93-103
4. L.Kostic, T.Pavlovic, Z.Pavlovic, "Influence of Physical Characteristics of Flat Aluminum oncentrators on Energy Efficiency of PV/Thermal Collector." Proceedings of the Tenth Annual Conference of the Materials Research Society of Serbia, September 2008, pp.827-833
5. G.Mittelman, A.Kribus, A.Dayan, "Solar cooling with concentrating photovoltaic/thermal (CPVT) systems/Energy Conversion and Management." Vol.48, 2007, pp. 2481-2490
6. D.R. Meneses, P.Horley, J.Hernandez, et al., "Photovoltaic solar cells performance at elevated temperatures." Solar Energy, Vol.78, 2005, pp. 243-250.
7. L.R.Bernardo, B.Perers., H.Hakansson, B.Karlsson, "Performanse evaluation of concentrating photovoltaic/thermal systems: A case study from Sweden.", Solar Energy, Vol.85 2011, pp.109-124
8. P.A.Nesterenkov, A.G. Nesterenkov, "Hybrid Solar Collector.", Proceedings of the 2nd International conference on energy materials, solar cells and solar energy applications, 22 – 24 august 2013 University of MALAYA Kuala Lumpur, Malaysia pp.283 -286 / ISBN 978-967-1206706
9. L. A.Nesterenkova, A.G.Nesterenkov, P. A.Nesterenkov, "Method of modeling of the heat transfer of pv modules and solar collectors to the environment.", International Journal of Mathematics and Physics. Al-Farabi Kazakh National University, Vol.5, 2014. pp. 64-68. ISSN 2218-7987
10. N.Duo, Z. Dongyu, H. Jiangzhou, "Development of the Reflected concentrator for photovoltaic System.", Proceedings of the 15th international Photovoltaic Science & Engineering Conference (PVSEC-15) Shanghai China, 2005, pp. 436-437.
11. V.S. Antoshenko, A.G. Nesterenkov et al.,"Calculation of combined heat photovoltaic system with concentrated solar radiation.", Energy and Fuel Resources of Kazakhstan, Vol.2, 2010, pp.27-31
12. J.A.Duffie, W.A.Beckman, "Solar Engineering of Thermal Processes." edited by John Wiley and Son Inc., Hoboken, New Jersey, 3rd edition, 2006.
13. Atmospheric Science Data Center, available at https://eosweb.larc.nasa.gov/ (08.02.2016)
14. W.A. Butuzov, A.A. Lichagin, "Solar hot water: calculations, design of solar collectors, and the economic feasibility of energy.", available at http://www.rosteplo.ru/Tech_stat/stat_shablon.php?id=254
15. "Reflective aluminum Miro Sun", available at www.alanod.com. (08.03.2016)

16. H.Price, E.Liipfert, D.Kearney, et al., ”Advances in Parabolic Trough Solar Power Technology/ Journal of Solar Energy Engineering.”, ASME, vol.124, 2002, pp.163-174
17. L. C. Chea, H. Håkansson, B. Karlsson, “Performance evaluation of new two axes tracking pv-thermal concentrator.”, Journal of Civil Engineering and Architecture, Vol.7, 2013, pp. 1485-1493, ISSN 1934-7359
18. www.pilkington.com/solarenergy
19. A.G. Nesterenkov, P.A. Nesterenkov, L.A. Nesterenkova, “Hybrid c-PVT system” Proceedings of the VI International Symposium "Combustion and plasma chemistry" and International scientific-technical conference "Energy Efficiency -2015", Almaty 2015, pp.115-120.
20. “TINOX aluminum coatings”, available at www.almecogroup.com (20.01.2016)
21. A.G. Nesterenkov, P.A. Nesterenkov, L.A. Nesterenkova, “Principles of hybrid solar systems.”, Automation Bulletin, Vol.4, 2014, pp.10-13
22. “Matarenki Light. Technical Information” available at www.gsesweden.com/ (15.11.2015)
23. “Calculating of CPVT systems costs” available at www.forbesmarshall.com/solar_cogeneration.aspx (20.01.2016)
24. J.S.Coventry, K.Lovegrove, “Development of an Approach to Compare the ‘Value’ of Electrical and Thermal Output from a Domestic PV/Thermal System.”, Solar Energy, Vol.75, 2003, pp. 63–72