ABSTRACT

The combined photovoltaic/thermal (PVT) systems are actively developed all over the world. A short review of publications, devoted to PVT approach, is presented. The main trends are analyzed. The Russian experience in solar PVT concentrator systems and glazing technology is depicted.

1. INTRODUCTION

Great amount of publications devoted to combined PV/thermal systems in the last several years, the analysis of new architectural approaches of solar energy use shows a tendency of using solar energy when different technology are combined in integrated systems. It leads to more efficient way of solar energy conversion and combining of several consuming qualities. These systems are very suitable for integrating into buildings because of importance to use simultaneously photoactive and thermal parts of solar radiation. The better results can be achieved in concentrating PV/thermal systems.

In Russia cogeneration approach was actively initiated at the All-Russian Research Institute for Electrification of Agriculture (VIESH) from 1990s (some ideas and results were published even earlier). The previous papers described how it is possible to decrease the production cost of PV/thermal concentrator module to the level of 1 – 2 $/W cost in case of mass production [10, 11].

2. SHORT REVIEW OF COMBINED PVT SYSTEMS

The new abbreviation “PVT” appeared and became popular among the solar energy specialists to shorten simultaneously photovoltaic and thermal approach for conversion of solar energy. According to historical tradition the PV (photovoltaic) and the T (thermal) are the different technologies for the solar energy utilization. Even in new books we can see traditional chapters [1] with questions as “Photovoltaic or thermal concentration?” [2] We prefer question: “How effectively manage using of both Solar Photovoltaic and Solar Thermal?”

In classical book [3] authors included a chapter devoted to PV, explaining “this chapter is an anomaly in that the process it treats are not primarily thermal in nature”. They showed the wisdom to put into classical topic quantum by nature converters, remarking that radiation calculations developed for thermal processes are directly applicable to PV converters.

The rhetorical question “photovoltaic or thermal?” from the point of view a total efficiency of solar system and evolution of technical systems has only one answer – the PVT: joining two classical solar energy approaches we have logical step in evolution of technical systems. Now new combined PVT technologies appear at a rapid rate.

Solar systems have additional advantages when they are integrating into buildings. Cladding walls, roofs with help of PV gives new opportunities for renovations,
substitution of old elements of buildings, combining old
functions (protection) with new ones (generation).

Let us first look at the best achievements in PV.
Spectrolab, Inc. has achieved unprecedented conversion
efficiency for a terrestrial concentrator solar cell [4].
This example shows us the limiting efficiencies of PV cells.
Using concentrated sunlight, these photovoltaic cells can
convert 36.9 percent of the sun’s energy to electricity, a
technology capability that could dramatically reduce the
cost of electricity generated from solar energy. Let us
emphasize here that the costs of the multijunction solar
cells are still much higher than ones with a single p-n
junction. What way of increasing solar system consuming
qualities is cost-effective: increasing efficiency using very
high level PV technology or extracting simultaneously
electricity and heat? Some projects devoted to only
concentrator PV (see, for example, [5] and corresponding
references). Many last publications devoted to the PVT systems
describe concentrator systems with stationary
collectors (see, for example, [5] and corresponding
references).

Number of papers describing of the PVT conversion is
increasing exponentially. We give here only some
references we can do in short paper. Some publications
are devoted to the computational models of PV/T
collectors (see, for example, [5] and corresponding
references).

Many last publications devoted to the PVT systems
describe concentrator systems with stationary
concentrators but probably first practical non-tracking
concentrators were outlined at [6, 7].

Theoretical analysis of the hybrid PV/T collectors with
integrated Compound Parabolic Concentrator (CPC)
troughs has presented in [8, 9]. It has been shown that
system coupled with the CPC always performs better in
terms of both the thermal and electric output. Parametric
studies show that the thermal and electric output of the
PV/T system increases with increasing of the collector
length, air mass flow rate and packing fraction (cell
density), and decreases with increasing of the duct depth.

Energy research Centre of the Netherlands (ECN) in
cooperation with Shell Solar, AGPO/ZEN and Eindhoven
University of Technology develops the PVT panel that
can produce electricity as well as heat [10]. The research
has started in 1994 with the PhD project at the Eindhoven
University of Technology. At the moment, the fourth
improved prototype is undergoing some tests at the ECN
site. The development of the first prototype was mainly
intended as a “proof of principle” and as an investigation
of the main bottle-necks. The second prototype was the
optimization of thermal properties, resulting in efficiency
of 67% at zero reduced temperature, while producing
electricity with efficiency of 8.3%. This panel can
therefore convert 75% of solar radiation into useful
energy. The development of the PVT panels is still
ongoing, but the future for this panel is looking bright and
it is expected that they will be commercially available in
the near future. A photovoltaic/thermal (PVT) panel is a
combination of photovoltaic cells with a solar thermal
collector, generating solar electricity and solar heat
simultaneously. The PVT panels generate more energy
per unit surface area than a combination of separate PV
panels and solar thermal collectors, and share the aesthetic
advantage of PV. After several years of research, the PVT
panels have been turned into a product that is now ready
for market introduction. One of the most promising
system concepts, consisting of 25 m² of PVT panels and a
ground coupled heat pump, has been simulated in
TRNSYS, and has been found to be able to fully cover
both the building related electricity and the heat
consumption, while keeping the long-term average ground
temperature constant. The cost and payback time of these
systems have been determined; it has been found that the
payback time of these systems is approximately two-
thirds of the payback time of an identical system but with
21 m² of PV panels and 4 m² of solar thermal collectors.
The activity of this international group [10] is very
important for gaining international cooperation (including
Australia, Denmark, Germany, Israel, Italy, The
Netherlands, Norway, Spain, Sweden, and Switzerland).

Finally, by looking at the expected growth in the PV and
solar thermal collector market, the market potential for
PVT panels has been found to be very large. The main
tendencies of integrating different methods of solar
energy use are reflected in Fig.1.

![Diagram](image-url)  
Fig.1: Main trends of integrating solar energy technology
in buildings
3. SOME RUSSIAN DEVELOPMENTS

Conceptual direction for development of the solar PVT stationary concentrator systems led to several practical versions of different forms, reflector design and receivers [11, 12]. There are numerous publications (papers and patents) in Russian language. One of the main reasons for this direction is desire to avoid technical and exploitation problems of tracking system. Also the tracking system consumes energy. By integrated into buildings, solar systems have also advantages such as avoiding land expenses.

Last versions of concentrators based on non-imagine reflectors with faceted mirrors and PV module where bifacial solar cells immersed in heat-carrier liquid. Faceted mirror reflectors were chosen because glass mirrors with special coatings have more durable and tolerant to external influences covers than aluminum mirrors with plastic base and dielectric cover. They have also some advantages connecting with more uniform illumination of receiver. Of course they have some decreasing coefficient of concentration. The photo of faceted concentrating system is shown below (Fig.2).

 Doubles sections of the faceted concentrators with the PV and thermal receivers were created recently in framework of Ph. D. project by P. Litvinov (Fig. 3) [13]. The results of modelling and experiments are presented in [13] and his thesis. The previous results show that using glass panels technology the output parameters can be improved (please see next section).

About 70% of Russian territory, with a population of more than 10 million people, does not have a centralized energy supply. Out of 70 electrical systems 44 have power shortages, which lead to breaks in the energy supply. About 30% of individual farms and 20% of collective small farms are not connected to the electric grid. So, market for non expensive, simple in exploitation, without moving parts solar systems, which can be easily integrated into farm buildings, is quite big. The PVT systems represent a serious alternative to traditional energy sources even today, not just in the distant future.

According to [14], present PV market analysis shows that rural electrification accounts for approximately half of the world PV module shipments. Integrating trends in developing solar systems can facilitate wider distribution of solar energy technology.

Fig. 3: Face view of double section faceted solar concentrator

4. GLASS PANES TECHNOLOGY

Glass technology is one of the primary components of integrating solar systems into buildings. For building applications, the glass panes technology, which has been used before in electronic industry, was developed in Russia for solar applications. Soldered vacuum and gas field glass panes consist of two or three glass layers. They have better heat-insulating properties than the regular ones. To increase thermal resistance, the air layer between the glass panes is replaced with an inert gas with a large molecular mass or vacuum. The deposited IR-coating also reduces the IR emittance of the glass.

This considerably improves the performance characteristics for solar power engineering (Table 1). For comparing, the resistance to heat transfer of a brick wall 2.5 bricks in depth equals 1- 2 m² °C/W. Comparing gas-fill glass panels to panels separated by a vacuum, one has very small depth practically equal to the depth of a used glass. So, at the width of a sheet of a glass in 2.5 mm, triple layer of the glass panels with vacuum between the glass layers has depth in 7.6 mm, and the gas-filled in 31.5 mm. The gap in the vacuum glass panels between the layers of glass is set with the help of extra small ceramic
gaskets arranged on the surface of a glass with a step about 20 mm.

**TABLE 1: PARAMETRES OF GLAZING WITH DIFFERENT DESIGN**

<table>
<thead>
<tr>
<th>Type of glass window</th>
<th>Thickness of the gap, mm</th>
<th>$R$, m$^2$°C/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single layer of a glass</td>
<td>-</td>
<td>0.17</td>
</tr>
<tr>
<td>Double layer of glass panel</td>
<td>10 - 16</td>
<td>0.37</td>
</tr>
<tr>
<td>Double layer of glass panel with argon fill</td>
<td>10 - 16</td>
<td>0.39</td>
</tr>
<tr>
<td>Double layer of glass panel with IR coating</td>
<td>10-14</td>
<td>0.56 – 0.58</td>
</tr>
<tr>
<td>Double layer of glass panel with argon fill and with IR coating</td>
<td>10 - 14</td>
<td>0.71 – 0.72</td>
</tr>
<tr>
<td>Triple layer of glass pane</td>
<td>6 - 12</td>
<td>0.47 – 0.57</td>
</tr>
<tr>
<td>Triple layer of glass panel with argon</td>
<td>6 - 12</td>
<td>0.53 – 0.62</td>
</tr>
<tr>
<td>Triple layer of glass panel with IR coating</td>
<td>6 - 12</td>
<td>0.67 – 1.08</td>
</tr>
<tr>
<td>Triple layer of glass panel with argon</td>
<td>6 - 12</td>
<td>0.90 – 1.43</td>
</tr>
<tr>
<td>Double layer of glass pane with vacuum between the glass layers</td>
<td>0.05</td>
<td>0.44</td>
</tr>
<tr>
<td>Triple layer of glass panel with vacuum between the glass layers</td>
<td>0.05</td>
<td>0.57</td>
</tr>
<tr>
<td>Double layer with vacuum between the glass layers and with IR coating</td>
<td>0.05</td>
<td>1.2</td>
</tr>
<tr>
<td>Triple layer of glass panel with vacuum between the glass layers and with IR coating</td>
<td>0.05</td>
<td>2.0</td>
</tr>
</tbody>
</table>

The application of soldered glass panels allows considerably lower thermal losses through the glass surfaces. It can form the basis for creating energy efficient buildings and improve stability and characteristics of such items of solar power engineering, as solar cookers, thermal collectors for water or air heating (Fig. 4), solar modules, optical concentrators and combinations of these devices.

The heat losses in the thermal collector with the soldered vacuum glass panels (see photo below) are decreased by 1.5 - 2 times.

The elaborated technologies can sufficiently facilitate integrating solar energy systems in buildings.

**CONCLUSION**

The elaborated technologies can sufficiently facilitate integrating solar energy systems in buildings. The modeling and experiments show prospects of described technologies for integrating in buildings. The possible applications one can see at Fig. 5-8.

![Fig. 5: Symmetrical PV/T system at house](image)

![Fig. 6: Solar PV/T wall.](image)
Fig. 7: Balcony PV/T system.

Fig. 8: Solar concentrator for day lighting (with the North side window).

ACKNOWLEDGMENTS

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REFERENCES


4. Internet site of Spectrolab, Inc.


10. ECN site with excellent access to publications of this group


