Glazed photovoltaic-thermal component for building envelope structures

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Abstract
The paper presents ongoing development of glazed solar PV-T collector integrated into façade element for curtain walling structure. Glazed PV-T collector generally increases the use of available envelope area for energy generation (heat and power). An analysis for a residential building retrofit has shown the advantage of the glazed PV-T component application.

Keywords: solar energy, PV-T collector, curtain walling façade, building integration, solar heat, solar power

1. Introduction
Utilization of solar energy being a scarce energy source needs large south-facing collecting surfaces. Rational use of building envelopes for collection of the solar energy and conversion to required energy carrier results in development of elements integrating the building structures and active solar devices. Use of roofs could be limited by other technology installations (ventilation systems, elevator rooms, GSM transmitters, etc.), façade are sensitive to shading by other buildings or trees. It is always a question in the design stage of solar energy systems in buildings what ratio between the solar thermal collectors (for heat generation) and PV modules (for power generation) should be applied and which kind of solar technology will be used.

Considerable advance comes in constructional building integration of solar collectors meaning a replacement of building envelope construction by the solar collector. To certain extent, such level of integration facilitates also the architectural integration and seems to be a challenging issue crucible for future development and spreading of solar technologies. The integration of solar collectors into building envelope instead of separate installation represents a transition from the concept of envelope considered as an energy loss to envelope being an energy source (energy active envelope) which actually means a step further to solar energy active buildings.

Large innovation potential exists not only in coupling the function of the building envelope with the solar energy collector but also in multi-functional construction elements combining several purposes (heat and electricity generation, daylighting) in single unit. Further development of such novel concepts, experimental evaluation of their complex performance and synergy effects and consecutive commercialization should lead to pre-designed solar construction elements which are essentially required for widespread application and use of solar energy in buildings. The presented concept of solar hybrid photovoltaic-thermal (PV-T) collector combines the power and heat generation in one component with higher efficiency of solar radiation conversion to usable energy.

2. Solar photovoltaic-thermal collector
Research activities in the field of solar photovoltaic-thermal (PV-T) collectors have increased in last decade. Combination of heat and power generation from the same receiving surface in one collector unit is very
attractive alternative to conventional solar energy components. There is already a number of commercial products available on the market as unglazed PV-T collectors based on standard PV laminates from ethylene-vinyl-acetate (EVA) compound used in PV modules. A significant drawback of the unglazed technology is a high heat loss and low heat output at real operation conditions (ambient temperature, wind convection) which lead mainly to low-temperature applications combined with heat pumps.

Gla zed PV-T collectors represent an alternative with significantly higher thermal output but lower electric energy generation because of the additional glazing blocks part of solar radiation which could be converted to electricity. Anyway, the total energy production balance is higher than in the case of combination of conventional technologies (PV modules and solar thermal collectors) and also than the unglazed PVT collectors [1]. On the other side, the concept of glazed PV-T collectors restricts the use of conventional EVA compound as encapsulation material of PV cells. Glazed PV-T collectors at stagnation conditions, i.e case with no heat removal from the collector, reach maximum absorber temperatures in the range of 120 to 180 °C, while application of EVA is limited to operation temperatures up to 90 °C [2, 3]. It has been experimentally proved that the long-term thermal load at higher temperature levels results in decomposition of EVA to acetic acid which causes the corrosion of PV cells contacts, delamination and also degradation of the encapsulation layer transparency [4, 5].

More suitable candidates for application as PV encapsulant for the glazed PV-T collectors are silicone polymers (polysiloxanes). Polysiloxane gel offers several important advantages like a large range of operation temperatures (from -60 to +250 °C), high transparency for solar radiation (even higher compared to EVA in solar wavelength region), compensation of thermal dilatation stresses due to low modulus of elasticity (permanent gel), high physical adhesion to semiconductors, glass and most other materials without use of sub-layers and good heat transfer from PV to heat exchanger due to higher thermal conductivity [5]. Polysiloxane laminate thus opens the application potential especially for glazed PV-T collectors development.

2.1 Detailed mathematical model of glazed PV-T collector

In order to optimize the design and construction of the glazed solar PV-T collector, a detailed mathematical model has been developed [6] and implemented into the TRNSYS environment for energy systems simulations [7]. The reason of implementation into the TRNSYS was the need for a model, which includes the sufficient amount of detailed construction parameters of the collector which can be parametrically changed to monitor the influence on the total system energy output. The detailed model of glazed PV-T collector allows to define construction parameters of PV-T collector configuration: geometry, electric properties of PV cells, thermo-physical and optical properties of materials used in PV-T collector (insulation, absorber, glazing), etc. Inputs of the model are climatic and operation conditions related with the relevant energy system, e.g. hot water application in given climate zone. Main outputs of the model are useable thermal and electric power, absorber temperature and collector fluid outlet temperature.

Implementation of detailed PV-T collector model in the system simulation environment allows to show the impact of given design change in annual perspective of energy generation [8]. This approach results in cost-benefit analysis which compares the production costs for a given change in PV-T collector design and achieved annual cost savings in relevant system. The glazed solar PV-T collector model can optimize a single collector components to be manufactured and applied on the roofs s well as the specific application of PV-T component to be integrated into building envelope structure.

2.2 PVT collector for building integration

The concept of glazed liquid PV-T collector is based on sandwich structure with monocrystalline PV cells encapsulated in the polysiloxane gel layer between double-glazing (see Figure 1) and copper sheet with soldered pipe register (conventional solar thermal absorber technology) [9]. Several prototypes of PV-T collector were developed and fabricated with the new PV cells encapsulation technology at UCEEB CVUT in Bustehrad. The identical concept will be used also in the new construction of energy active curtain walling façade developed in collaboration with SKANSKA LOP company. The façade element consists of transparent part (windows with triple glazing) and opaque part (glazed PV-T collector, insulation layer) in the position of the window sill and floor construction, see Figure 2. The element size 3 x 3 m is adapted for given building structure further analysed in the text. Number of PV-T collector parameters is influenced by the integration into envelope unit for façade.
Double-glazing consists from low-iron solar glazings 6 mm thick with a gap 16 mm filled with argon. The glazing attached to absorber has a coating with low emittance 30 % with high transparency for solar radiation 86 %. The PV part of the collector has 60 cells at size 125 x 125 mm in three parallel strings. The PV cell nominal efficiency is 17 % under STC (standard test conditions, i. e. reference temperature 25 °C and solar irradiance 1000 W/m²). There are 18 risers in the copper pipe register, distance between the risers is 50 mm. Each pipe register has only two upper hydraulic connections Cu 22x1 mm. Gross area of PV-T collector unit in the façade element is 1.5 m², aperture area is 1.4 m². In total, 67 % of aperture area is covered by PV cells.

Figure 1: Glazed PV-T collector component ready for building envelope integration

Figure 2: Layout of the façade element with glazed PV-T collector

Thermal and electric performance of the developed glazed PV-T collector has been analysed for a fabricated sample. Thermal performance was tested according to ISO EN 9806 (both, for pure thermal mode and the hybrid mode) at indoor climate with sun simulator (see Figure 3). Electric performance was measured in hybrid mode at conditions of maximum power point tracking (MPPT). The detailed model of the glazed PV-T collector has been verified and further used for determination of characteristics of the designed glazed PV-T component finally integrated into building envelope structure with insulation thickness 160 mm and vertical position (change in natural convection in argon gap). Derived performance characteristics are shown in Figure 4. Electric peak power of the glazed PV-T unit is 148 W_p at standard testing conditions (25 °C, 1000 W/m²), thermal peak power is 930 W_p with simultaneous electricity generation.
3. Analysis of the building application

Curtain walling façade is a typical envelope technology for office buildings. The presented application example focuses on the residential sector, especially the retrofit of the building stock from 70’s. Figure 5 shows a block of flats in Prague which could serve as an application pilot of deep retrofit. Roof of the building is occupied by technology systems and there is very limited space for solar collectors installation. Another possibility is to apply the presented prefabricated curtain walling system with PV-T units to the south façade area. Incorporation of open loggias into compact building envelope structure could result in lower specific space heating demand of the building (less thermal bridges, compact shape of building and an increase of
occupied building volume), larger utilization of building floor area and easier retrofit of the facade by prefabricated curtain walling elements. The aim of the analysis is to show, how the multifunctional building integrated unit – glazed PVT collector – could increase the energy usage of the available south façade area.

Figure 5: Considered residential building for the analysis

3.1 Solar PV-T system simulation

The considered residential building has 90 flats occupied with 230 occupants. Gross floor size of the building is 54 m x 13 m with height 36 m (12 floors). The total floor area of the building is 8424 m², south façade area is 1944 m². There are 9 vertical sections of the façade with 6 m wide module. Façade elements of 3 x 3 m could be applied in the layout depicted in Fig. 2. Because of green vegetation in the front of south façade is present, only upper 6 floors are reasonably available for energy active facade to avoid future significant shading. Thus, in total 324 m² of glazed PVT collectors integrated into prefabricated elements could be used.

The possible hydraulic layout of the solar PVT collector system is shown in Figure 6. The PVT collectors of each two façade elements for one building façade module are connected in series. The façade collector area of each building floor is divided into two collector fields: 5 façade modules on the left side with 10 energy active façade elements, 4 façade modules on the right side with 8 energy active façade elements, see Fig. 6. Piping is led in the space within the window sill. Horizontal distribution pipes for each floor field is Cu 22x1 mm. Vertical distribution pipes connecting the individual collector fields at each floor has a dimension DN50.

Energy demand for water heating in the building is considered 11500 l/day at 55 °C based on assumed 50 l/per.day, i.e. around 220 MWh/a without distribution heat losses included. Hot water load profile (hourly basis) with one significant peak in the morning and large peak load in the evening has been used in simulation. Electricity demand of the building depends on the equipment and appliances used in of the flats. It is considered average electricity demand per flat 2000 kWh/flat.a, i.e. around 180 MWh/a for the analysis. It is obvious that the heat demand for hot water is comparable with the electricity demand. Electricity was used to cover the building electricity demand. Typical electricity load profile (hourly basis) for more than 100 users has been used in simulation.
Figure 6: Hydraulic layout of glazed PV-T collectors in facade

The simulation analysis was performed in TRNSYS. Besides the solar PV-T system, also the alternative combining solar thermal and photovoltaic system has been analysed to make a clear comparison with conventional solar heat and power systems. An alternative solar energy system considered façade integrated solar thermal collectors with gross area 162 m$^2$ (50 %) and façade integrated PV modules with gross area 162 m$^2$ (50 %). Both solar thermal collectors and PV modules has been considered as façade integrated components adapted for the gross area 1.5 m$^2$.

3.2 Results

Monthly results of solar PV-T system simulation, the usable thermal and electric energy, are shown in the graph in Figure 7. The annual thermal output of the PV-T collectors used for domestic hot water preparation is 80.2 MWh/a covering 36 % of the energy demand. Annual electric output used for coverage of electric load in the building is 21.6 MWh/a with a solar fraction 12 %. Only 1 % of the electricity production is to be exported into public grid. The comparison with the conventional alternative is presented in Table 1.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Usable heat gains [MWh/a]</th>
<th>Electricity generation [MWh/a]</th>
<th>Total energy gain [MWh/a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>glazed PV-T</td>
<td>80.2</td>
<td>21.6</td>
<td>101.8</td>
</tr>
<tr>
<td>50 % PT – 50 % PV</td>
<td>59.5</td>
<td>15.6</td>
<td>75.1</td>
</tr>
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Table 1: Results of solar systems annual simulation.

Despite the fact that energy gains per installed area are higher for the conventional technologies (higher thermal efficiency, higher electric efficiency), the total energy savings both for heat and electricity are significantly higher for solar PV-T system. The heat production is about 35 % higher, electricity production is about 39 % higher.
4. Conclusion

The glazed photovoltaic-thermal component for building envelope integration is under development to increase the potential of energy use from available façade area in the buildings. Energy active curtain walling concept combines the usable heat generation for hot water preparation and power generation to cover base load in the buildings.

Simulation analysis has been made with a detailed model of glazed solar PV-T collector experimentally verified with testing of prototypes. The result from simulation of hot water system and electric load in the given residential building shown a large potential for achieving the higher coverage of building demand than in case of separate conventional technologies.

5. References


for TRNSYS”, Czech Technical University, 2015.

[7] TRNSYS 17, "TRaNsient SYstem Simulation program", Solar Energy Laboratory, University of


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