# Energy Performance Figures of Combined Solar PVT Heat Pump System

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**Abstract**
*Energy performance analysis of solar heat pump system coupled with hybrid solar photovoltaic-thermal collectors is presented in the paper. Investigated variants of PVT heat pump system are compared with state of art solar heat pump system from the point of possible electricity use reduction. Only PVT technology based on low emissive PV absorber offers a significant electricity savings when compared to reference systems.*

***Keywords – PVT collector; heat pump system; seasonal performance factor***

## 1. Introduction

Use of the electrically driven heat pumps is considered as a measure for energy use reduction in buildings with a significant advantage of easy integration into smart grids of future. On the other side, today electricity production is primary energy intensive and efficient use of the heat pump technology assumes the high seasonal performance factors (*SPF*). Although the EU Directive on renewables has set out a minimum *SPF* value 2.9, values more than 4.0 have to be met to achieve notably lower emission production and primary energy use level when compared with direct combustion of the fossil fuels.

While heat pumps for the low temperature space heating achieve *SPF* above 4.0, *SPF* for domestic hot water (DHW) preparation above 3.0 is possible only with reduced hot water temperature bellow 45 °C. Combination of solar thermal systems with heat pumps is an approach to eliminate the DHW preparation by the heat pump especially in summer season. State of art systems use the parallel approach, i.e. both solar collectors and heat pump deliver the heat into one store for the heat load. Then, the heat pump is an auxilliary energy source for the combined solar thermal system. Second approach is to combine the heat pump system with a PV system. The actual electricity need for heat pump system from external network is reduced by the direct use of electricity produced by PV within such combined PV and heat pump system.

Hybrid photovoltaic-thermal (PVT) solar collectors represent one step further. Combination of photovoltaic and thermal collector in the single device has a potential to increase energy (heat & electricity) production from given building envelope and provide higher self-sufficiency in local networks. Potential use of PVT collectors in the advanced solar heat pump systems has been analysed from the point of energetic savings and the results are presented in the paper.

## 2. Hybrid PVT collectors

Hybrid solar photovoltaic and thermal collectors (solar PVT collectors) can provide both heat and electricity, while heat production is several times higher than electricity. Through the solar electricity and heat cogeneration, the total energy output per unit collector area can be higher than the outputs of standard PV module and thermal collector placed and operated separately with the equal total area.

Solar PVT liquid collectors offer a large potential for applications thanks to better usability of heat (heat pumps, DHW, pool water, space heating, etc.) than PVT air collectors. Today, the market of PVT liquid collectors is limited to unglazed types due to problems with standard EVA lamination of PV modules which can decompose at temperatures above 80 °C to acetic acid (delamination, coloration, degradation of PV cells by acid) and thus it could not withstand usual stagnation temperatures in glazed collectors [1]. Moreover, the use of unglazed PVT collectors with thermal efficiency significantly dependent on ambient conditions (wind, temperature) is restricted to low tempeature applications (water preheating, primary circuits of heat pumps).

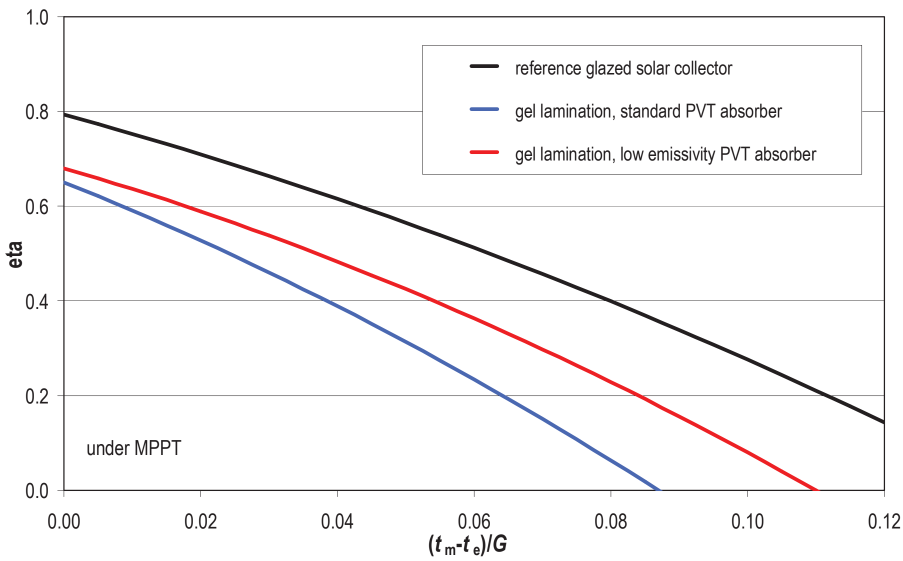


Fig. 1 Efficiency characteristics for different concepts of solar PVT collectors compared with standard glazed solar thermal collector (reference)

The field of standard DHW and space heating applications with glazed PVT collectors is opened by introducing new silicone (polysiloxane) gel lamination, highly transparent and flexible material which is inert in a wide range of temperatures up to 250 °C [2]. Moreover, there is a possibility to use PV absorber laminated to a glazing highly transparent in the visible region (to maintain good PV efficiency) but with a low IR emissivity coating to reduce radiative heat loss and improve thermal properties of the PVT collector.

## 3. Combined solar heat pump system analysis

Possibilities of the improvement for the state of the art of solar heat pump (SHP) systems in seasonal performance are investigated in the frame of the MacSheep project [3]. The main task is to develop the costs-competitive SHP system with 25 % less electric energy use than for the state of art systems. This ambitious target should be achieved by introduction of new materials, technology and ICT breakthroughs. One of the investigated breakthroughs is a replacement of conventional solar thermal collectors by glazed PVT collectors which will supply also the electricity for the heat pump. The effect of the combination of PVT and heat pump has been investigated by system simulation to reveal the potential of reduction in SHP system electricity use.

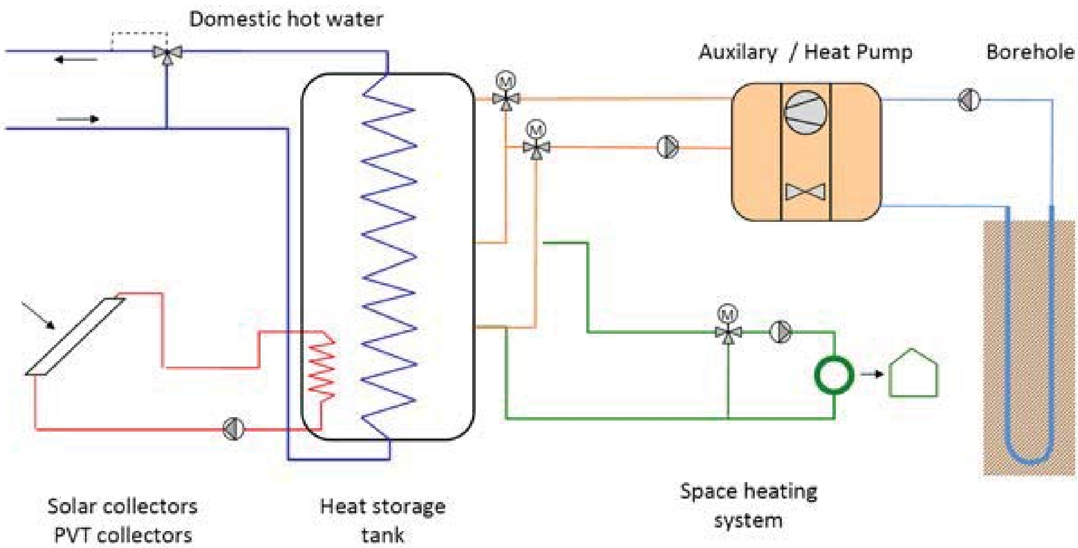


Fig. 2 Reference solar heat pump system scheme

The system simulations have been done for a building defined in frame of T44A38 [4] as the single family house SFH45. Building has a space heating demand 60 kWh/m$^2$.a in Zurich climate and hot water load of 73 m$^3$/a at 45 °C. Low temperature system 35/30 °C has been considered for space heating. Evaluated electricity consumption of the system comprises of electricity for the heat pump, back-up heater, circulation pumps and controls, including the penalty function if the thermal comfort for space heating or DHW is not achieved.

To analyse the benefits of the hybrid PVT collectors application for the solar heat pump systems, the state of art solar heat pump system has been defined as a reference variant (REF). The state of art system comprises of the main store (800 l), single glazed flat-plate collectors (10 $m^2$) and ground source heat pump with a borehole 75 m long (see Fig. 2). The main store has an integrated internal heat exchanger for DHW preparation. Solar loop heat exchanger is placed in the lower part of the store. Heat pump has been designed as monovalent heat source with 5 kW nominal heat output. Total electricity demand of the reference SHP system is 2.63 MWh with *SPF* equal to 4.17 in the Zurich climate.

There are several variants of the system investigated and compared (see Tab. 1). Reference solar collectors are replaced by PVT collectors in two different designs: nonselective glazed PVT collectors with a new gel lamination resistant to temperatures above 200 °C (PVT/NG) and a new theoretically proposed design with low-e coating on PV absorber to introduce the selective glazed PVT collector (PVT/SG). The hybrid PVT collector variants are under development now to increase the performance and to reduce the costs. Considered thermal performance characteristics for different concepts of solar glazed PVT collectors are compared with standard glazed solar thermal collector (reference) in Fig. 1. Characteristics for PVT collectors are presented in maximum power point tracking mode (MPPT). A variant of reference SHP system combined with PV only system (10 $m^2$, pc modules, 2.25 $kW_p$) has been also investigated for comparison.

Table 1. Investigated variants of the solar heat pump system

| Variant | Description |
|---|---|
| REF | reference parallel solar and heat pump system with 10 $m^2$ of standard solar thermal collectors |
| REF/PV | reference system combined with PV only system (10 $m^2$ of polycrystalline modules) |
| PVT/NG | system with reference collectors replaced by given area of glazed nonselective PVT collectors |
| PVT/SG | system with reference collectors replaced by given area of glazed selective PVT collectors |

## 4. Results and discussion

Use of PVT collectors for both heat and electricity supply for the solar heat pump system has been evaluated from energetic point of view. Simulation analysis of the combined solar heat pump system in described variants has been done in TRNSYS. System electricity savings $\Delta W_{el}$ (in percents), total PV production of electricity $E_{PV}$ and the fraction of it used for system demand coverage $f_{PV}$ have been evaluated. The electricity produced by PV is taken into account to reduce the electricity demand of the solar heat pump system only if there is a match between PV production and SHP system consumption (direct use of PV electricity). Solar thermal heat gains $Q_{ss,u}$ used from collectors has been monitored for comparison.

Tab. 2 shows the results of the energy performance analysis which indicate several important figures. Use of nonselective PVT collectors can't compete with the reference case REF with standard solar thermal collectors at same installed area. Worse thermal performance of the PVT collector is not outbalanced by PV electricity use in SHP system.

Table 2. Results of system simulations in given variants (with given PVT collector area)

| Variant | $\Delta W_{el}$ [%] | $SPF$ [-] | $E_{PV}$ [MWh/a] | $f_{PV}$ [%] | $Q_{ss,u}$ [MWh/a] |
|---|---|---|---|---|---|
| REF | - | 4.17 | - | - | 3.56 |
| REF/PV | -8.0 | 4.53 | 1.38 | 15.2 | 3.56 |
| PVT/NG5 | 11.4 | 3.75 | 0.56 | 26.3 | 1.73 |
| PVT/NG10 | 1.5 | 4.12 | 1.10 | 19.0 | 2.52 |
| PVT/NG15 | -4.2 | 4.36 | 1.62 | 16.1 | 2.97 |
| PVT/NG20 | -9.1 | 4.59 | 2.13 | 14.2 | 3.29 |
| PVT/SG5 | 8.0 | 3.87 | 0.53 | 27.1 | 2.03 |
| PVT/SG10 | -2.7 | 4.30 | 1.01 | 19.8 | 3.01 |
| PVT/SG15 | -8.7 | 4.58 | 1.46 | 16.9 | 3.54 |
| PVT/SG20 | -13.3 | 4.81 | 1.89 | 15.2 | 3.92 |

PVT collectors with selective PV absorber achieve up to 3 % electricity savings for the given SHP system when compared both with REF case (replacement of standard collectors with identical 10 m$^2$ area).

Combination of PV only only system with the reference SHP system (REF/PV variant) achieves high electricity savings 8 % due to high thermal output of standard solar collectors together with high PV electricity production for direct use by SHP system.

SHP system with glazed PVT collectors performs better than the advanced REF/PV system if the same total area is used (20 m$^2$). Selective PVT collectors achieve significantly higher electricity savings (13 %) than nonselective ones (9 %).

It is evident that the target of the MacSheep project – total 25 % electricity savings – couldn't be achieved only by one measure at solar collector side (here, use of glazed PVT collectors). Moreover, a precise cost-benefit analysis must be done in order to show the competitiveness for integration of PVT collectors into SHP system. Real costs for the glazed PVT collectors are not well known due to the development being in the progress. Presented energy performance analysis has been done to show the potential of PVT collectors in SHP system and to point out which kind of collector could be successful for the electricity savings achievement. Results show that glazed PVT collectors with low-e coating at PV absorber are the only reasonable path to be further developed as PVT collector component. SHP system with nonselective PVT collectors don’t bring considerable advantage when compared with reference SHP system with or without PV only system.

## 5. Conclusion

Energy performance analysis of solar heat pump system combined with solar glazed PVT collectors has been done to reveal the potential for system electricity savings. Results have shown that the replacement of standard solar collectors could bring electricity savings only if the glazed PVT collectors with low-e PV absorber have been used. Electricity use of SHP system with glazed PVT collectors ranges 3 to 5 % lower than for reference cases (REF, REF/PV).

## 6. Acknowledgment

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## 7. References

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