Thermal performance analysis of 28 PVT solar domestic hot water installations in Western Europe

Laetitia Brottier[1,2] and Rachid Bennacer[2,3]

[1] DualSun, Marseille (France)

[2] MT /ENS-Cachan/CNRS/Université Paris Saclay, Cachan (France)

[3] EPMI, Cergy-Pontoise, France

Abstract

Hybrid solar PVT has the potential to become a major player in the renewable energy sector, but one of the major barriers is the limited reliable information due to the lack of reliable number of monitored PVT hybrid systems with proven thermal performance results. In order to address this issue, a statistical study was realized to analyze in-field performances of twenty-eight hybrid solar domestic hot water installations equipped with innovative non-overglazed PV-T collectors in Western Europe (France, Switzerland and Portugal).

The results show that PVT technology , moreover PV production, is very pertinent for domestic hot water preheating, with a monthly average of the daily maximal temperature (Tmean) of the panels above 45°C during 5 months in the year. The results also demonstrate the robustness of the non-overglazed PVT collector, as the highest stagnation temperature was always measured below 74.5°C, which is very safe in terms of risk of overheating and effect on PV performance.

Keywords: Photovoltaic thermal (PVT), PVT Solar Domestic Hot Water (SDHW), European PVT database

1. Introduction

PVT is not a new technology, as Kern and Russell published a report for the MIT already in 1978. Hybrid collectors have been optimized over the years, and even in 2003 Zondag et al. gave a large review of possible designs for collectors. Since the 2000s commercial collectors have been launched, some manufacturers had underestimated the technological difficulties. In the 2010s, the commercial products have become more reliable and at the end of 2013, the norm ISO 9806 proposed a procedure to test the hybrid collector reliability and performances. More recent reviews of PV/T technologies has been done by Zhang et al. (2012), Wu et al. (2016) or Das et al. (2018).

As the cost of photovoltaics has dropped significantly, PVT technologies have also become more cost-competitive. But Dupeyrat et al. noted in 2014 that very few field studies with a global system approach of PVT technology exist. This study provides data for PVT collectors in a pre-heating domestic hot water (PVT-SDHW) configuration.

The used PVT module for the field data collection is based on the DualSun module and presented on Figure 1, for more details see Brottier et al., 2014. PV/T module in the study is based on an **WISC** (wind and infrared sensitive collector) flat-plate liquid design with dimensions of 1677×990×40mm^3, it has 60 monocrystalline cells and a nominal power of 250Wp (power loss -0.44%/°C). The thermal characteristics (η_0=57.8%; b_U =0.028 s/m; b_1=12.08 W/K/m²; b_2=1.842 W.s/K/m3) were determined by tests conducted at the TÜV Rheinland laboratory following the Solar Keymark certification rules (ISO 9806 : 2013).

We will first present the twenty-eight installations with PVT modules for domestic hot water system, from where the data were collected. Then the study will continue with the statistical analysis of the field temperatures.

doi:10.18086/swc.2019.05.01 Available at http://proceedings.ises.org

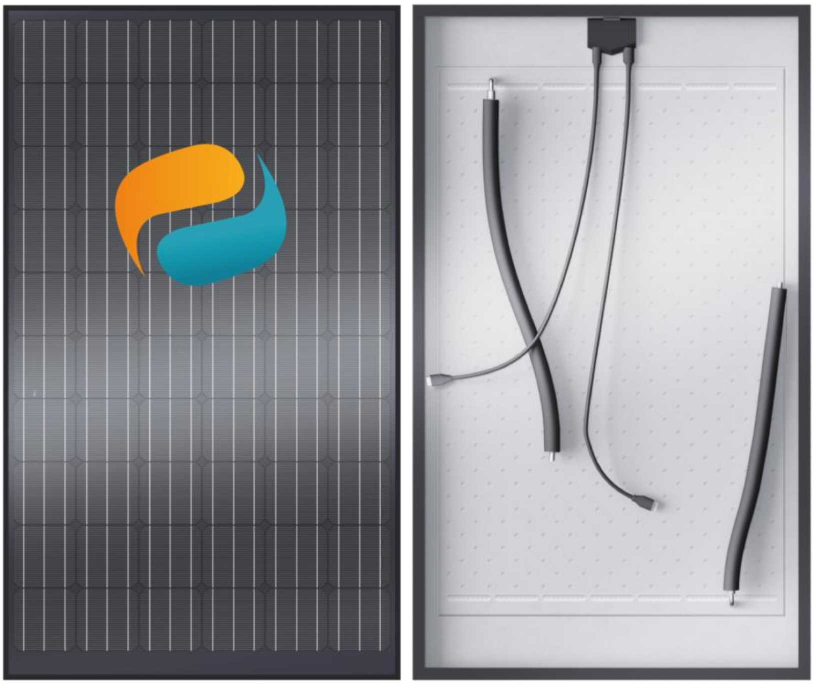
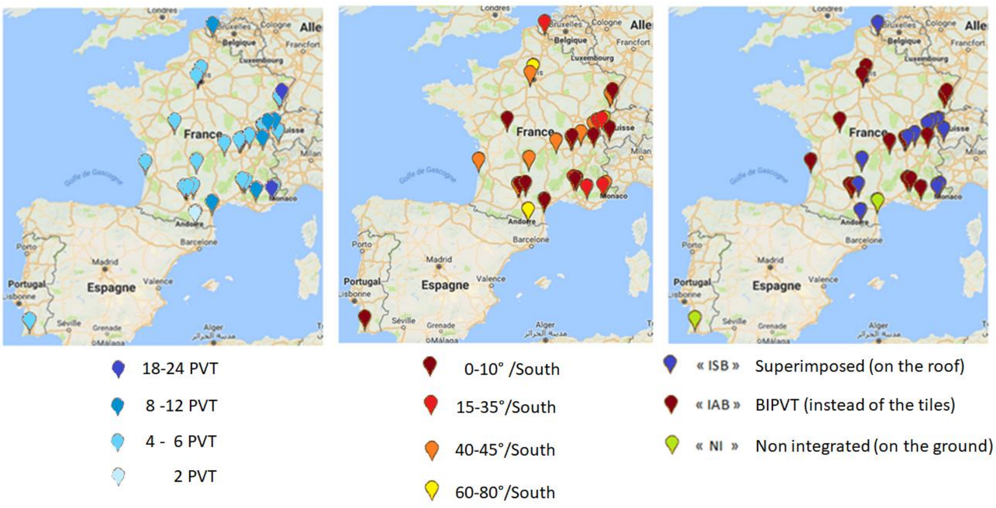


Fig. 1: Picture of the DualSun PVT module

2. Presentation of the 28 PVT SDHW installations

Twenty-eight installations with PVT modules across France, Portugal and Switzerland (Figure 1) were installed and monitored. The majority of the installations are composed of 4 to 6 PVT modules (Figure 1.a). All but two installations are mainly south facing (0-45°/South) (Figure 1.b). Half of the installations are building-integrated (BIPVT) - with the modules replacing roof tiles, and the other installations are mainly on roof - with an air gap between the tiles and the modules (Figure 1.c).



-a- -b- -c-

Fig. 1: Number of PVT (a), orientation to the South of the PVT (b), integration type (c) for the 28 PVT installations

All of the installations are PVT solar domestic hot water (SDHW) systems, and 5 of 28 installations (including the largest installation) also combine pool heating. With a **SDHW** PVT system, the hybrid PVT solar panels are used as a pre-heating solution for sanitary water, and simultaneously produce photovoltaic electricity for self-consumption in the house or injected into the grid for a feed-in tariff. Heat from the solar panels is transferred to the hot water tank via a heat exchanger with circulating glycol water (which flows into the modules) and the sanitary water (Figure 2) in the tank. The system's pump is stopped as soon as the difference between the temperature of the modules and the bottom of the tank is only 2 ° C.

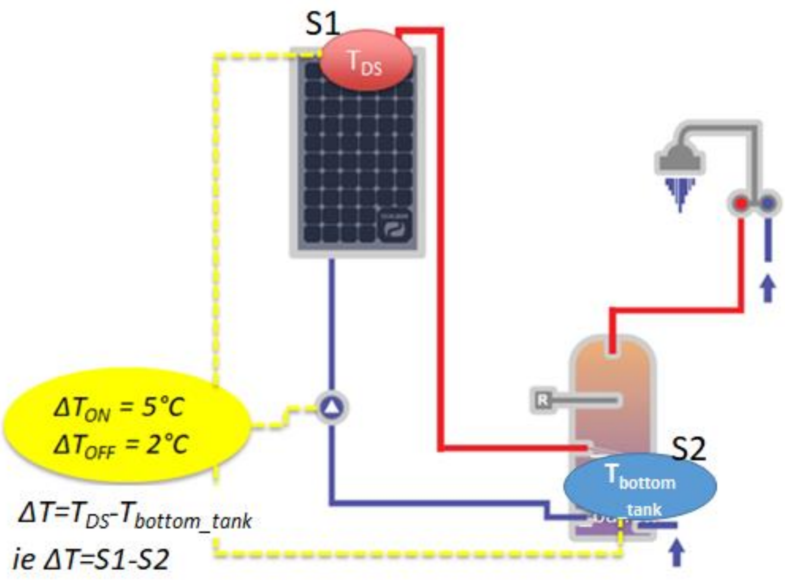


Fig. 2: Hydraulic diagram of the PVT SDHW system

An electrical (electrical resistance, heat pump) or thermal (gas, oil, wood ...) backup heater complements the heating. This backup heater is installed at the top of the tank (internal) for half of the installations, or at the output after the storage (external) for the other, so as to deliver a set temperature (Figure 3).

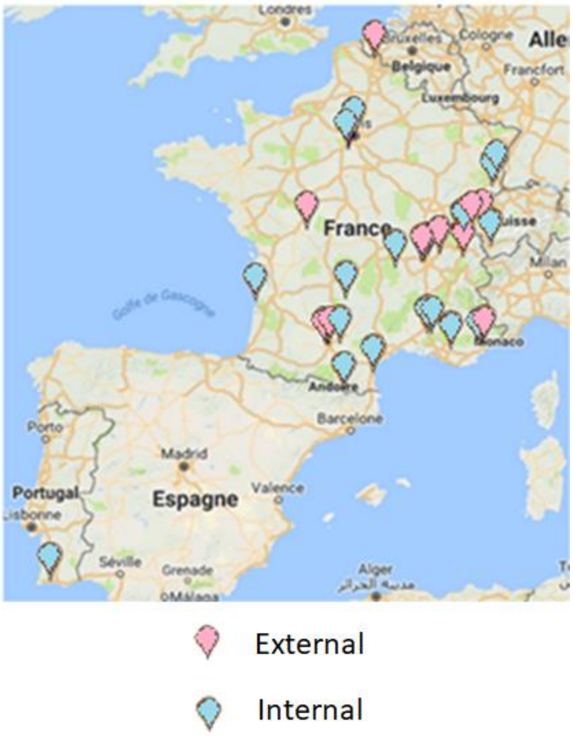


Fig. 3: Position of the additional heater for the 28 installations

All of the 28 installations had at least one temperature probe to measure of the bottom of the tank temperature (S2) and one temperature probe to measure the PVT collectors field output temperature (S1). The temperature probes are of type PT1000 (precision 0.3 °C). The solar controller processes the data of the probes and activates accordingly other equipments like the pump. This controller, usually a BXPlus, also collects the data and the datalogger (DL2) routes them to the server of the private vbus.net platform, which stores them and makes them available on the Internet. For the photovoltaic part, inverters that convert DC to AC (Enlighten, SMA, SolarEdge) also often collect electrical data, their accuracy is better than 5%.

As we can see with a data sets taken from 03 to 08 July 2017 from the Ambérieu-en-Bugey installation in Figure 4, the produced electricity illustrates the solar availability and we can see the as expected the regularity of the periodic electricity production (sunlight in time and intensity). When the temperature difference between the bottom of the tank and the PVT collectors field output is sufficient, the solar pump is activate. The panel temperature increases and heat the water as long as the pump is circulating. The solar thermal part is pre-heating the tank, the temperature at the bottom of the tank follows the PVT collectors field output temperature as illustrated by the changes from 03 to 08 July 2017. Finally when the difference between the two temperatures is no longer sufficient, the pump stops. The bottom of the tank then loses temperature due to thermal losses of the tank or hot water consumption.

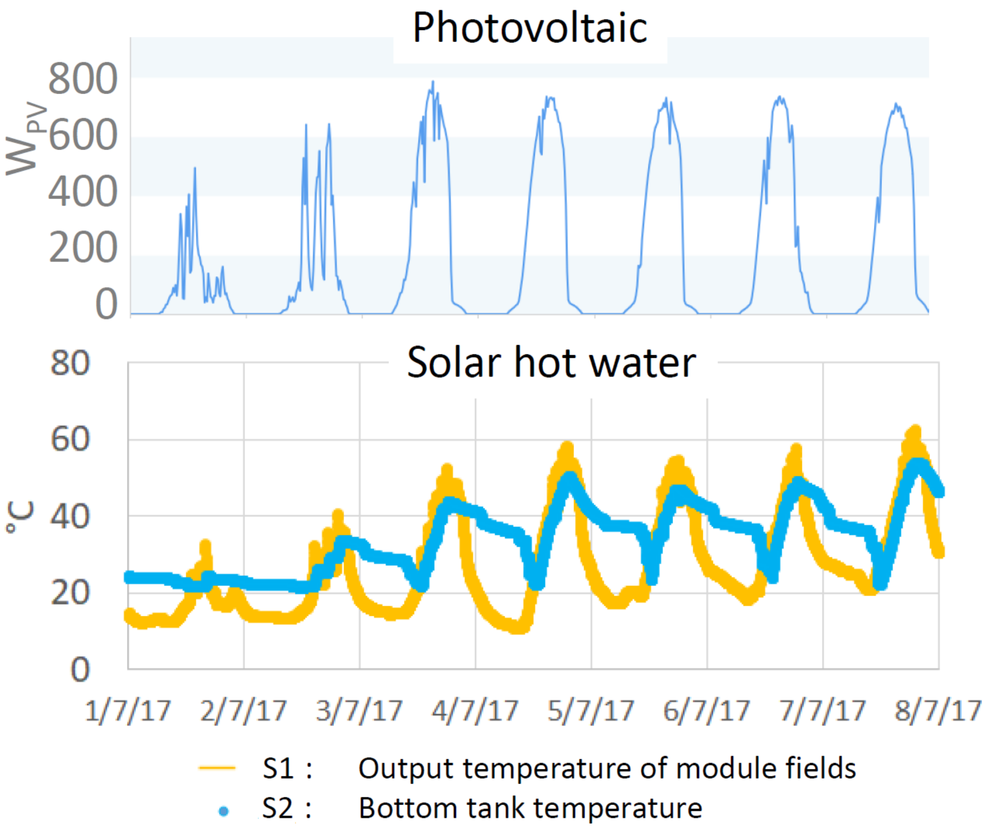


Fig. 4: Functioning of the PVT: PV production (top) and thermal solar energy transfer to the bottom sanitary tank (bottom); from the Ambérieu-en-Bugey installation

3. Temperature statistics and analyze

It has been checked that the photovoltaic production shows a good statistical coherence with 1% difference to predictions obtained by PVGis in average over the twenty-eight installations and a small standard deviation of 7%. The discrepancy is due first the bias (shadowing, albedo...), to the difference between the real and the statistical weather, to the cooling of the cells (effect supposed negligible in this application), and to the uncertainty of the measurement (5%).

To analyse the thermal part, we plot the outlet temperature (S1 sensor) during July on Figure 8. Such evolution illustrate clearly the large amplitude on the panel temperature from almost 10°C to 60°C. The different collectors field output temperature will first considered averaged in order to avoid the previously underlined errors and variability of the external conditions (radiation, wind and outer temperature). Several parameters have been defined and plotted on the following figure (Figure 8):

- The monthly maxima of the PVT collectors field output temperature T_{max}^{month} (red symbol), noted Tmax for simplicity
- The daily maxima of the PVT collectors field output temperature T_{max}^{daily} represented with the orange points linked with the orange full line

- The monthly average of the daily maxima of the PVT collectors field outlet temperature $\overline{T_{max}^{daily}}|_{month}$ noted Tmean for simplicity and represented with horizontal dashed line on the figure 8.

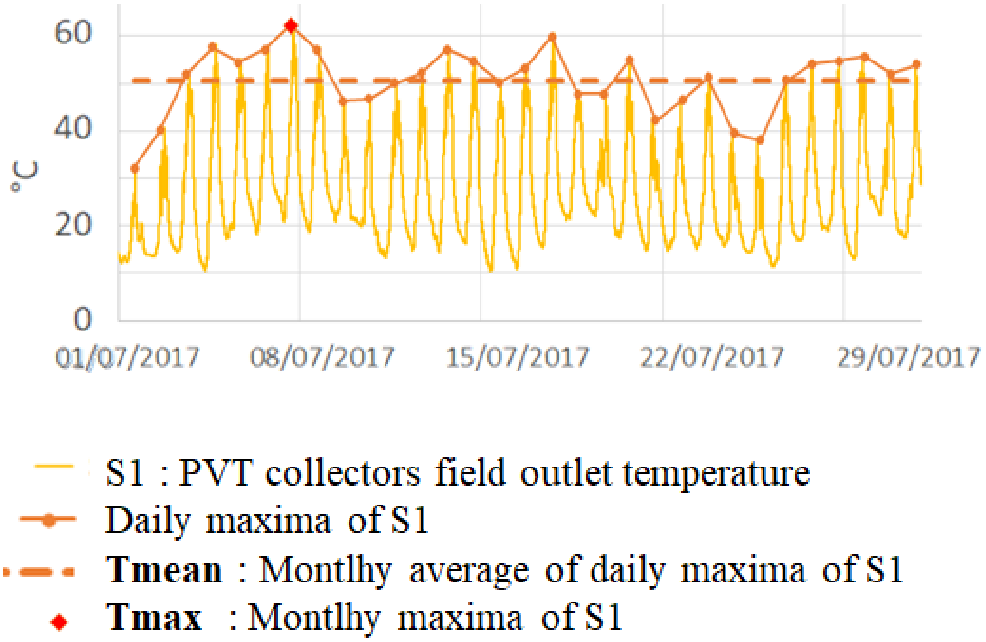


Fig. 5 : Definition of Tmean and Tmax

The maximum temperature of the PVT collectors field measured on the twenty-eight installations is 74.2°C (stagnation), it is under the 85°C, so this **SDHW** thermal system will not affect the PV robustness in the time. Another conclusion with this maximum temperature measured in the field is that **WISC** PVT modules do not need high pressure in the system. Indeed the glycol water fluid is always below its boiling point, already at atmospheric pressure. Furthermore with low temperature and low pressure, the piping can be done with polymer material, and it will reduce the system price comparing to copper or stainless steel pipes usually used in solar heating installations. Thus this low temperature is good news for the PV robustness and the potential of price reducing for the system.

The maximum temperature is low enough for robustness, it will be checked now if the mean temperature is high enough to warm the water for domestic hot water application.

As seen in Figure 4, in a normal functioning way, the bottom of the tank should be pre-heated by the thermal part of the PVT. The pump is turned off when the temperature at the modules output is only 2°C higher than the bottom tank temperature. So the maximum bottom tank temperature is expected to reach, at 2°C near, the maximum module output temperature each sunny day (each time the pump is turn on because the module output is 5°C higher than the bottom tank temperature). For that reason, the daily maxima of the PVT collectors field outlet temperature is interesting to considered. The monthly average of these daily maxima (Tmean) gives an indication of the capability of the collectors field to provide a given hot water temperature.

More precisely, the average over the twenty-eight installation of the monthly averages of the daily maxima of the PVT collectors field outlet temperature is given in Figure 6. The standard deviation over these twenty-eight installations is only 5.2°C, so we have a strong idea of the potential temperature of PVT in Western Europe.

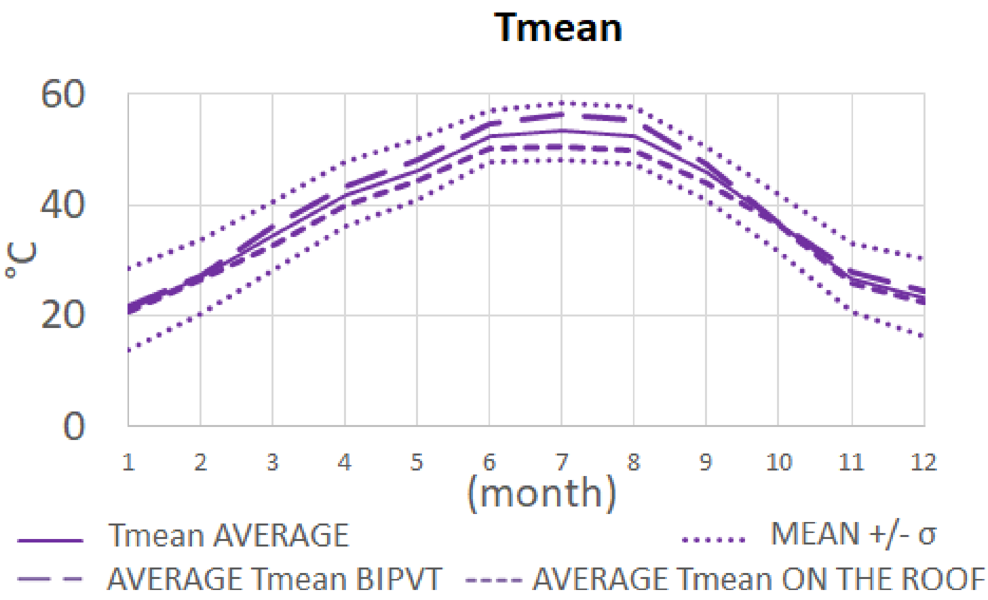


Fig. 6 : Definition of Tmean and Tmax

The Tmean is on average above 45°C during 5 months in the year, demonstrating that PVT technology is really suitable for domestic hot water preheating. So with a set temperature of 45°C (and we will see this temperature is a reference for some configurations), PVT hot water systems can imagine be autonomous and permit to stop the additional heater up to 5 months. On the other hand, the Tmean is on average under 55°C all the year, so if the set temperature is 55°C, it is quasi sure the system will use the additional heater, even in summer time. Most of the time, it is not a problem, as the additional heater is precisely here to complement the heating, but for wood booster, it could be interested to stop the boiler for summer time, in that case, it has to be checked that a temperature set at 45°C is possible or to integrated an additional electrical booster.

Anyway, it is certainly worth to pre-heat to lower the thermal energy demand and make savings as it has been studied in Brottier et al., 2015.

To be noticed also, the Tmean average is 5.7°C higher for the BIPVT installations than for the on-roof installations in summer time (Figure 6), as in BIPVT systems, the collectors are much more insulated thanks to the roof insulation just behind the modules. It was verified that there is no major difference in irradiation between these two groups (<2% in the month of July 2015).

The average difference between the monthly average of the maximum daily temperature of the bottom of the tank and Tmean was 6°C in summer and 3°C in winter with a very low standard deviation (<3.7°C), which is really coherent with the +5/+2°C hysteresis in the solar pump regulation. This low deviation means that this difference is a good indicator of the good functioning of the installations.

4. Conclusion

Thank to 28 PVT-SDHW installations in Western Europe, a database of PVT performance has been established. The results shows that the PVT is really suitable for domestic hot water preheating, with a monthly average of the daily maxima of the PVT collectors field output temperature (Tmean) above 45°C during 5 months in the year. It demonstrates also the robustness of the non-overglazed PVT as the highest stagnation temperature was measured at 74.2°C, which is really safe in terms of risk of overheating and effect on PV performance.

5. References

Brottier, L., Hugo, J.M., Bennacer, R., 2014. An innovative PV-T collector: CFD and experimental results. Eurosun 2014. https://www.researchgate.net/publication/266399536_An_innovative_PV-T_collector_CFD_and_experimental_results

Brottier, L., Naudin, S., Veeser, V., Terrom, G., Bennacer, R., 2016. Field Test Results of an Innovative PV/T Collector for Solar Domestic Hot Water. Energy Procedia, 91, 276-283.

https://doi.org/10.1016/j.egypro.2016.06.219.

Dupeyrat, P., Menezo, C., Fortuin, S., 2014. Study of the thermal and electrical performances of PVT solar hot water system. Energy and Buildings. 68, 751–755. http://dx.doi.org/10.1016/j.enbuild.2012.09.032.

Das, D., Kalita, P., Roy, O., 2018, Flat plate hybrid photovoltaic- thermal (PV/T) system: A review on design and development. Renewable and Sustainable Energy Reviews. 84, 111–130. http://dx.doi.org/10.1016/j.rser.2018.01.002.

Kern, E.C., Russell, M.C., 1978, Combined photovoltaic and thermal hybrid collector systems. In: 13th IEEE, Washington.

Wu, J., Zhang, X., Shen, J., Wu, Y., Connelly, K., Yang, T. Tang, L., Xiao, L., Wei, L., Jiang, K., Chen, C., Xue, P., Wang, H., 2017, A review of thermal absorbers and their integration methods for the combined solar photovoltaic/thermal (PV/T) modules. Renewable and Sustainable Energy Reviews. 75, 839-854. http://dx.doi.org/10.1016/j.rser.2016.11.063.

Zhang, X., Zhao, X., Smith, S. , Xu, J, Yu, X. Review of R&D progress and practical application of the solar photovoltaic/thermal (PV/T) technologies. Renewable and Sustainable Energy Reviews; Vol 16, Issue 1, 2012, p. 599–617. http://dx.doi.org/10.1016/j.rser.2011.08.026.

Zondag, H.A., de Vries, D.W, van Helden, W.G.J, van Zolingen, R.J.C., van Steenhoven, A.A., 2003, The yield of different combined PV-thermal collector designs. Solar Energy. 74, 253–269. http://dx.doi.org/10.1016/S0038-092X(03)00121-X.