Field test results of an innovative PV/T collector for indoor swimming pools

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Abstract

Hybrid solar PV/T has the potential to become a major player in the renewable energy sector, but one of the most important barriers is the inexistence of a proven track record in terms of reliability and performance. In order to address this issue, a study was conducted to monitor in-field energy performances of two indoor swimming pool installations near Perpignan (France) equipped with an innovative unglazed PV/T collector (1.64m², 250Wp, 912Wth).

With 300m² of PV/T collectors for a 1100m^3 indoor swimming pool and 6000L/day of hot water needs, an annual thermal production of 120MWh and an annual photovoltaic production of 64MWh were achieved. Performances were higher than simulated with the TRNSYS study.

Keywords: Photovoltaic thermal (PV/T) collector; Field test; Energy performance

1. PV/T characteristics

A review of PV/T technologies has been done by Zhang et al. (2012) and Good et al. (2015). The PV/T module in the study is based on the unglazed flat-plate liquid design described in these reviews. It has 60 monocrystalline cells for a nominal power of 250Wp. The photovoltaic characteristics are given in table 1.1. The thermal characteristics (table 1.2) were determined by tests conducted at the TÜV Rheinland laboratory following the Solar Keymark certification rules (ISO 9806 : 2013).

Tab. 1: Electrical and thermal characteristics

Electrical characteristics	
Dimensions	1677×990×40 mm^3
Number of cells	60
Type of cells	Monocrystalline (6 inches)
Nominal power (P_{mpp})	250 Wp
PV module efficiency (η_{PV})	15.40% (Tolerance : ±3%)
Power loss /°C (βp)	-0.44% / °C

Thermal characteristics	
Heat transfer fluid (HTF)	Water/glycol mix
Absorber surface area	1.58 m²
Conversion factor (η_0)	57.8%
Heat loss coeffiient (b_1)	12.08 W/K/m²
Wind dependency of collector efficiency (b_U)	0.028 s/m
Wind dependency of heat loss coefficient (b_2)	1.842 W.s/K/m^3

2. Presentation of the two field tests

Indoor swimming pool systems coupled with PV/T collectors have already been studied by simulation by Buonomano et al. (2015), but few experimental works have confirmed the expected performances with real installations, as has been done in this study.

For the two indoor swimming pools in the study, the PV/T modules are connected to heat exchangers and are used to preheat the water for the showers and to heat the pools. As an auxiliary heat source, a heat pump is connected in series to the solar heat exchanger to heat up the water instantly when needed. In the case that the system does not

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provide enough heat, the system is completed if necessary with a natural gas boiler. In order to monitor the system, a calorimeter is placed just before the solar heat exchangers.

Data were recorded every 5 minutes. A diagram of the system and the monitoring is given in Figure 1.

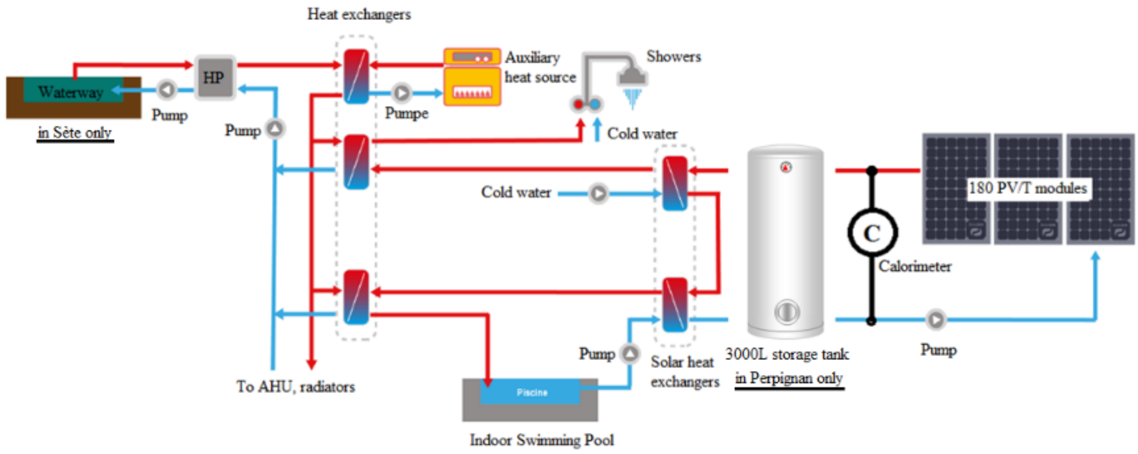

Fig. 1: Simplified hydraulic scheme and monitoring system put in place

In order to verify the in-situ reliability and performance for indoor swimming pools of the innovative hybrid solar PV/T module, two installations were monitored near Perpignan in the South of France (Lat/ Long. 42.6976 / 2.8954). In Perpignan according to Meteonorm, the maximum ambient daily temperature in the day is on average 19.6°C and the maximum daily irradiation in the day is on average 576W/m² over the year.

In Sete (Figure 2) as in Perpignan (Figure 3), 180 PV/T modules were installed as a solar canopy.

Fig. 2: picture of the PV/T canopy for the municipal swimming pool of Sète (France)

Fig. 3: picture of the PV/T canopy for the municipal swimming pool of Perpignan (France)

Key parameters of the two solar installations are provided in Table 2.

Tab. 2: parameter of the 2 installations

	Sète	Perpignan
Swimming pool dimensions	720 m² for 1100 m³ = 1 056 MWh/an	730 m² for 1095 m³ = 1 016 MWh/an
Pool temperature setup	28 °C	
Shower needs	~ 6000L/day = ~ 125 MWh/an	
Number of unglazed PV/T	180 (300 m²)	
Integration type	Solar canopy	
Orientation (0° = South)	South-East (-20°)	South (0°)
Slope	10 °	30 °

The solar energy goes to hot water preheating if the temperature of the panels is 6°C higher than the bottom of the sanitary tank or to the pool if it is higher than 30°C. The panels and the technical room, where the heat exchangers and the calorimeter are located, are separated by a distance of 70m. The pipes are buried over this distance.

3. TRNSYS study

A TRNSYS model has been performed, the diagram is given in Figure 4.

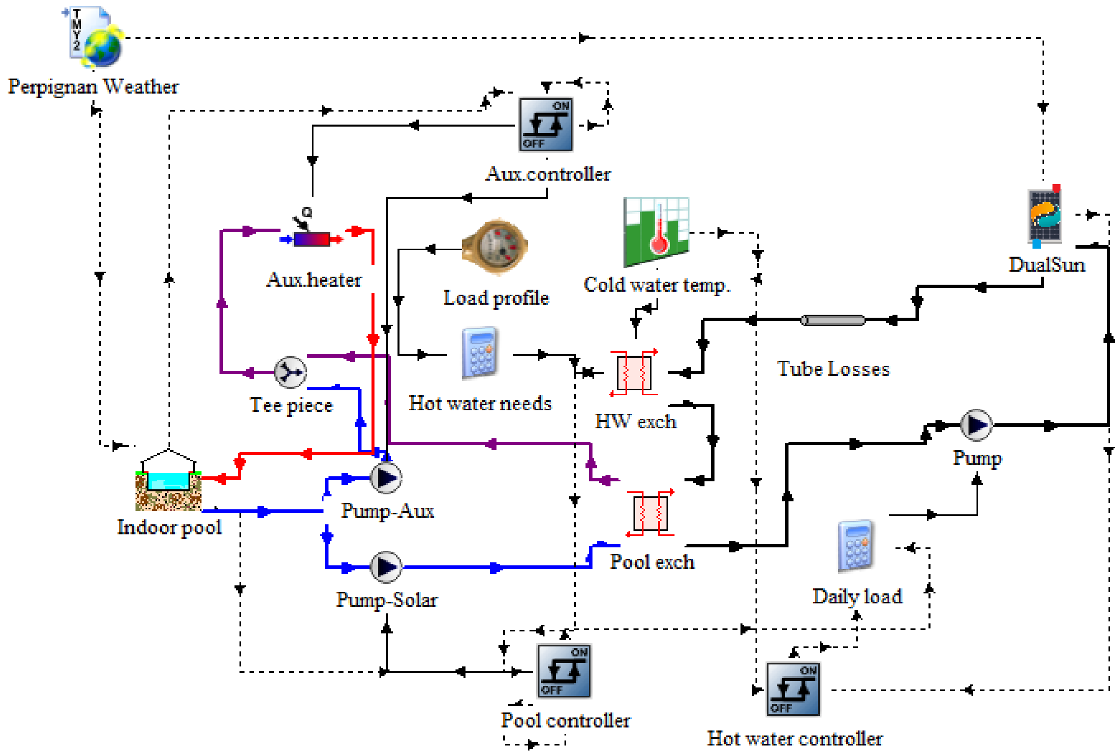

Fig. 4: TRNSYS diagram of the installation

The photovoltaic simulation does not take into account the cooling of the cells, and the storage of the heat for the showers in Perpignan is not included in the model.

The loss coefficient in the 70m buried pipe was taken at 24 W/(m².K).

The hot water profile was built from the scenario for sport facilities in the French thermal regulation method (RT 2012), and the typical day profile is given in Figure 5.

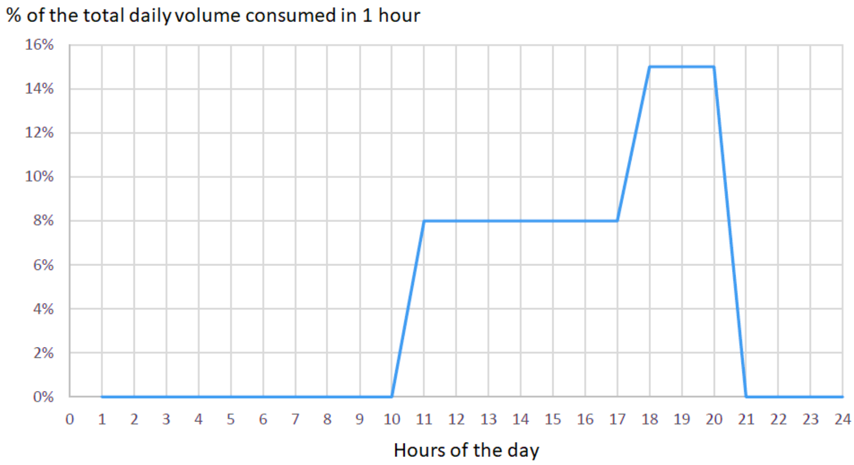

Fig. 5: Hot water need profile in the simulation

The hot water needs are estimated at 1.2GWh/yr, wich seemed very accurate with the 1,27GWh/yr (127 782 m^3 gas volume) consumed in Sète for a year before the solar installation. Recently a monthly detail of the previous gas consumption revealed some significative difference between the monthly distribution of the simulated consumption and the real one before the solar installation as seen in Table 3.

Tab. 3: Real and simulated global heat needs

Month	TRNSYS Heat needs (kWh)	Gas consumption (before solar) (m3)	Energy consumption (before solar) (kWh, η=90%)
January	139 937	16 911	167 727
February	120 905	16 770	166 321
March	117 706	15 725	155 961
April	101 207	13 218	131 099
May	88 562	9 463	93 853
June	65 746	7 491	74 294
July	60 373	5 460	54 150
August	58 353	4 001	39 684
September	72 506	5 091	50 493
October	101 365	7 121	70 628
November	118 812	12 617	125 137
December	135 364	13 914	137 996
Total /yr	**1 180 835**	**127 782**	**1 267 343**

At Sète, the production of the solar module to 81MWh/yr for the thermal part (6.9% of the heat needs) and 56MWh/yr for the electrical part (Table 4). At Perpignan were the slope and the orientation of the modules are more favorable, 97MWh/yr for the thermal part (8.5% of the heat needs) and 60MWh/yr for the electrical part (Table 5).

Tab. 4: TRNSYS model results for Sète

Month	Hot water needs (kWh)	Solar for hot water (kWh)	Pool needs (kWh)	Solar for pool (kWh)	PV electricity (kWh)
January	11 583	1 014	128 354	0	2 538
February	10 392	1 379	110 513	142	2 892
March	11 198	2 319	106 507	1 875	4 674
April	10 479	2 587	90 728	3 470	5 516
May	10 468	3 137	78 094	6 859	6 595
June	9 708	3 382	56 038	10 259	6 945
July	9 706	3 565	50 667	13 213	7 262
August	9 598	3 129	48 755	11 322	6 446
September	9 501	2 371	63 005	6 208	5 033
October	10 254	1 587	91 111	1 624	3 485
November	10 431	1 058	108 381	110	2 392
December	11 279	744	124 085	0	2 048
Total kWh/yr	**124 596**	**26 271**	**1 056 239**	**55 083**	**55 826**

Tab. 5: TRNSYS model results for Perpignan

Month	Hot water needs (kWh)	Solar for hot water (kWh)	Pool needs (kWh)	Solar for pool (kWh)	PV electricity (kWh)
January	11 583	1 772	123 747	432	3 441
February	10 392	2 019	104 845	1 014	3 798
March	11 198	2 748	106 154	3 206	5 454
April	10 479	2 775	90 286	4 587	5 644
May	10 468	3 103	76 208	6 342	5 831
June	9 708	3 336	54 972	9 641	6 203
July	9 706	3 696	44 745	13 078	6 663
August	9 598	3 345	44 316	12 616	6 408
September	9 501	2 719	60 786	9 015	5 645
October	10 254	2 188	85 017	4 250	4 592
November	10 431	1 648	104 041	1 569	3 608
December	11 279	1 584	120 807	394	3 247
Total kWh/yr	**124 596**	**30 932**	**1 015 924**	**66 144**	**60 535**

4. Field test results

The measured results of the PV/T panels are very close to the simulated results for the first year.

At Sète (Table 6), the thermal solar production is 2% higher than simulated, which confirms the accuracy of the model. At Perpignan (Table 7), the production is 23% higher, which proves the good impact of the storage for hot water to improve the solar share covering these needs.

The photovoltaic production measured are respectively 5,9% and 5,6% higher at Sète and at Perpignan, which is to attribute to the cooling of the cells that improves the performances.

Tab. 6: Comparison measurement and model for Sète

	Solar for heat (kWh)		Solar PV electricity (kWh)	
Month	**TRNSYS**	**MEASURED**	**TRNSYS**	**MEASURED**
Jan-17	1 014	1 000	2 538	3 280
Feb-17	1 521	1 000	2 892	1 828
Mar-17	4 194	4 000	4 674	4 904
Apr-17	6 057	8 000	5 516	6 452
May-17	9 996	8 000	6 595	6 575
Jun-17	13 641	12 000	6 945	4 361
Jul-17	16 778	16 000	7 262	6 669
Aug-16	14 451	15 000	6 446	8 604
Sep-16	8 580	8 000	5 033	6 386
Oct-16	3 211	7 000	3 485	4 514
Nov-16	1 168	2 000	2 392	3 239
Dec-16	744	100	2 048	2 301
Total kWh/yr	**81 354**	**82 100**	**55 826**	**59 113**

Tab. 7: Comparison measurement and model for Perpignan

	Solar for heat (kWh)		Solar PV electricity (kWh)	
Month	**TRNSYS**	**MEASURED**	**TRNSYS**	**MEASURED**
Jan-17	2 204	2 600	3 441	2 603
Feb-17	3 033	4 000	3 798	3 387
Mar-17	5 954	9 100	5 454	4 060
Apr-17	7 361	10 250	5 644	6 179
May-17	9 445	10 250	5 831	8 147
Jun-17	12 977	11 490	6 203	7 461
Jul-17	16 774	16 080	6 663	7 836
Aug-16	15 961	18 100	6 408	8 058
Sep-16	11 734	15 800	5 645	5 736
Oct-16	6 439	10 000	4 592	4 223
Nov-16	3 217	8 900	3 608	3 813
Dec-16	1 978	3 300	3 247	2 439
Total kWh/yr	**97 077**	**119 870**	**60 535**	**63 942**

The cost of these installations was around 250 k€ (no subsidies taken into account), around 100 k€ for the PV side and 150 k€ for the thermal solar side. If we assume a solar production of 20 years, which seems reasonable, the solar electrical price was around 9c€/kWh and the solar thermal price around 6c€/kWh for the swimming pool at Perpignan (in the South of France). It seems very promising for this innovation, and as the cost reduction potential exists still, the competitivity even with gas may be achieved in the few years.

5. Conclusion

The 300m² PV/T panels provide 30% of the energy for the 6000L/day shower needs and 20% of the heating needs for the 1100m^3 indoor swimming pool during 4 months of the year *(June – September).*
The measured thermal results of the PV/T panels are very close in this first year, and to add a storage seem to better of 20% the share of solar energy in hot water needs. The positive effect of the cooling of the cells can be estimated around 5.5 and 6% in this type of installation.

With a global cost of energy over 20 years of 7c€/kWh, this promising innovation may be competitive even with natural gas in a few years.

6. References

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