A PVT SYSTEM and its competition for a one family house

Jean-Christophe Hadorn
Solar energies and strategies - 11 route du Crochet – CH 1035 BOURNENS - jchadorn@gmail.com

Summary

Over the past few years, PVT systems that combine solar thermal technology and solar PV have gained more attention. IEA SHC started in 2018 the Task 60 called "PVT systems" to better understand the applications of the technology. PVT solutions can be used in several ways Task 60 is currently investigating. Heating or cooling for residential, commercial, administrative or industrial buildings is the main application. In this paper we compare a PVT solution for a single house to other classical solutions chosen by swiss villa owners.

We show in this analysis that the PVT solution for a one family house remains expensive while bringing a high solar fraction and the least CO2 emissions. A better cost competitiveness could be reached if the electricity price was higher and if the investment cost could be lower or if the CO_2 emission penalty costs were much higher. The PVT solution can lead to higher heat pump performances and a high renewable energy fraction that could be even 100% with some electrical storage not considered in this study.

1. Recent Literature review

Recent studies on PVT solutions in real cases have been conducted noticeably by IEA SHC Task 60 participants.

Zenhäusern et al. [12] have monitored 3 similar apartment buildings in Switzerland equipped each with a different system (PV 132 m^2 21.1 kW, PVT 130 m^2 21.8 kW, PV 90 m^2 15.1 kW+ ST 40 m^2) on a 30 kW brine/water heat pump with 5 boreholes 170 m deep. The heat demand have been somewhat different but similar (44'603, 43'410, 50'521 kWh for heating, 17'865, 10'269, 9'389 kWh for DHW). The PV production was from August 2017 to July 2018: 17'002, 16'827, 11'521 kWh, and the heat production from the roof: 0, 16'335, 16'454 kWh). The annual system efficiency (SHP+ defined by IEA SHC Task 44) was found to be 3.3, 3.42 and 3.85 for each of the buildings. In terms of specific production, we find that PV in A produced 806 kWh/kW, PVT in B 772 kWh/kW electricity and 126 kWh/ m^2 of heat (total 898 kWh), PV in C 763 kWh/kW electricity and T 411 kWh/ m^2 of heat (total 1174 kWh). PVT is more productive per m^2 than PV but still less than a PV&T system (glazed solar collectors). The 3 buildings had a 80%, 81%, 82% of local renewable fraction so in the end very similar. The costs were not reported.

Matuska et al. [13] found in simulations that a glazed PVT system provides 33% higher heat and 35% higher electricity than a PV & ST with 50% of the surface of the roof of a multifamily building in the climate of Stockholm, Prag, Marseille or Milan. The glazing of the collector is certainly a key success factor for increasing total energy yield of a PVT area.

Peng Xu et al. [14] showed that a PVT field could increase the electrical return from 3.5% because of a reduced operating temperature thanks to a heat pump coupled to the PVT field, but also points out that PVT systems without subsidy do not compete with conventional systems in China.

Gagliano et al. [15] analyses in detail different configurations from 100% PV to 100% ST for a house in 3 climates: Catania, Split, Freiburg. They find that a 100% PV area produces in Catania 3'219 kWh/y and a 100% ST 2'416 kWh. The best separate combination is 80% PV + 20% ST for a total of 4'385 kWh, but the 100% PVT provided 4'795 kWh. Total cost analysis shows that the minimum investment is for PV (3800 €), it is 6000 € for the 100% ST area and 8'300 € for a PVT field. When the revenues are considered PV is largely the winner and the initial

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cost of PVT makes it difficult to compete. PVT is the best solution for maximizing the primary energy reduction and the yield per m^2.

Herrando et al. [17] analyses the economy of a PVT system without heat pump for a house (space heating and DHW) in 3 climates Zaragoza, London and Athens. The main cost of an installation is the PVT collectors (38% at 380€ per collector). They find that the payback time can be around 12 years in Zaragoza and 23 years in London.

2. Sizing a system

Let us consider a typical new low energy house of Geneva with an annual heat demand of 4’200 kWh/a and a domestic hot water demand of 3’400 kWh/a. This low demand and the balance between heating and DHW is very representative of a “Minergie” house demand, a popular energy label in Switzerland.

We will compare the following solutions for our typical house:

1. a gas boiler system, 6 kW
2. same with some 6 m^2 of solar thermal glazed collectors for DHW (mandatory in some regions of Switzerland) with a 500 l tank
3. a good air heat pump system connected to the grid, 6 kW ACOP 4,0 (optimistic in 2019)
4. a ground coupled heat pump with no limitation on borehole depth or spacing, 6 kW ACOP 4,5
5. a ground coupled heat pump with some solar thermal for DHW (very usual solution for CH), 6 kW ACOP 4,5 and 6 m^2 of solar glazed collectors charging a 500 l cylinder
6. same solution but with 12 m^2 of collectors but unglazed on a 1000 l cylinder with an injection of solar heat in the heating system
7. A 20 m^2 uncovered PVT roof (say air collectors but it could be water glycol collectors, unglazed) providing 3 kW PV, linked to a 6 kW air heat pump and no solar direct to load or to DHW, solar only injected at the evaporator side of the heat pump. Boosting the HP with a PVT heat exchanger could bring a higher COP that we consider with optimism at 5.0. We do not consider a positive effect on the PV production in a PVT collector since this is marginal as shown in literature review.
8. A PV only air heat pump with a 3 kW peak power, identical to the PVT previous case.
9. Same case as 8 but with a better feed in tariff (hypothetical), that could correspond to the selling of electricity to a neighbor or a community and not to the grid operator.

Table 1 defines all parameters of each case and gathers the dimensions of each configuration. Energy yields are then derived with typical ratios from literature and experience, not from detailed simulations: 1000 kWh/kW for PV and PVT, 300 kWh/ m^2 for WISC collectors in DHW mode, 450 for a solar DHW system with glazed FP collectors, and 700 for a PVT collector coupled to a heat pump. This value will have to be challenged within IEA SHC Task 60 in 2020 based on numerous examples being reported.

The heat demand of our low energy house in Geneva climate is 4’200 kWh/y and the DHW demand 3’400 kWh/y. In cases with a heat pump, its nominal power is always 6 kW.

For example, the case Nr 7 which is our PVT system, reads: 20 m^2 of PVT collectors, for a 3 kW peak PV and with a 500 l tank.

SPF (seasonal performance factor including auxiliary energy) and renewable energy fraction are calculated for each case in the bottom part of table 1, leading to the following statements:

the maximum renewable fraction is achieved with system 6 at 88% and 7 and 8 at 97% ! A solar DHW system with a gas boiler as auxiliary achieves only 35% but a good air heat pump 80% ! With a PV installation or PVT, self-consumption is assumed to be limited to 50% of the electricity demand which is rather favorable to PV, thanks to a heat pump diurnal demand in summer for DHW and winter for both DHW and space heating.

Table 1: heat demand, system definition and sizing

Minergie house 200 m² in Geneva		
Space heating demand	kWh/a	4 200
DHW demand	kWh/a	3 400
Total	kWh/a	7 600

System		Gas only	Solar DHW & gas boiler	Heat pump Air	Heat pump Ground	Solar DHW HP ground no integration	Solar SP+DHW HP ground integration	PVT air air HP with T direct	PV only air HP	PV only air HP feed in tarif
Solar										
Collector area	m2		6			6	12	20		
PV installed	kW							3	3	3
Store volume	l		500			500	1 000	500	500	500
Productivity T	kWh/m2 a		450			450	300	500		
Productivity PV	kWh/kW a							1 000	1 000	1 000
Heat to HP contrib max	kWh/a							5 200		
Heating contrib direct from solar	kWh/a		0			0	1 200	0		
DHW contrib direct from solar	kWh/a		2 700			2 700	2 400	2 400		
Total T direct from solar	kWh/a		2 700			2 700	3 600	2 400	0	0
Heat pump										
Type			-	air/water	ground/water	ground/water	ground/water	air/water	air/water	air/water
Power	kW			6	6	6	6	6	6	6
COP				4.0	4.5	4.5	4.5	5.0	4.0	4.0
Heating contrib	kWh/a		0	4 200	4 200	4 200	3 000	4 200	4 200	4 200
DHW contrib	kWh/a		0	3 400	3 400	700	1 000	1 000	3 400	3 400
Total from heat pump	kWh/a		0	7 600	7 600	4 900	4 000	5 200	7 600	7 600
Heating from source at evap	kWh/a		0	3 150	3 267	3 267	2 333	3 360		
DHW from source at evap	kWh/a		0	2 550	2 644	544	778	800		
Total from source	kWh/a		0	5 700	5 911	3 811	3 111	4 160	0	0
								OK		
Auxiliary										
Power	kW	6	6							
Annual efficiency	%	80%	80%							
Heating contrib	kWh/a	4 200	4 200							
DHW contrib	kWh/a	3 400	700							
Total auxiliary	kWh/a	7 600	4 900							
Electricity demand										
Electricity for solar T	kWh/a	0	72	0	0	72	144	240	0	0
Electricity for heat pump	kWh/a	-	-	1 900	1 689	1 089	889	1 040	1 900	1 900
Total electricity	kWh/a	0	72	1 900	1 689	1 161	1 033	1 280	1 900	1 900
PV electricity produced	kWh/a							3000	3000	3000
PV electricity self consumed	kWh/a							1280	1280	1280
PV electricity to grid	kWh/a							1720	1720	1720
Electricity from grid	kWh/a	0	72	1 900	1 689	1 161	1 033	0	620	620
Renewable energy performance										
SPF heating	%	0%	0%	75%	78%	78%	84%	80%	0%	0%
SPF DHW	%	0%	79%	75%	78%	95%	93%	94%	0%	0%
SPF heat overall	%	0%	36%	75%	78%	86%	88%	86%	0%	0%
Solar heat overall	%	0%	36%	0%	0%	36%	47%	86%	0%	0%
PV contribution to elec demand	%							100%	67%	67%
Renewable fraction	%	0%	35%	80%	82%	87%	88%	100%	93%	93%

Economic analysis

Assumptions for each investment cost have been made based on experience.

The following costs (material and installation ready to go) have been considered:

- Solar DHW circuit and tank, 6 m² of glazed flat plate collectors: 1’200 €/m² of collector
- Solar DHW solution 6 m² when with a HP: 800 €/ **m²** (installation at marginal cost and shared tank)
- Solar PVT circuit: 800 €/m². This value has a strong influence on the cost of energy from the PVT field. We considered an average value from several PVT systems we have seen. WISC (unglazed) PVT

collectors costs are around 350 €/m^2 but the material (pipes, pump, inverter, cables) and the installation make the remaining.

- PV modules completely installed are considered at 2 €/W a usual 2019 cost in Switzerland.
- A gas boiler ready to go is considered at 1 €/W, an air heat pump at 3 €/W, a ground coupled heat pump at 4 €/W. Those are observed (lower) costs of such systems in Switzerland.

Over 20 years a constant annuity is taken at 6.4% thus with an average interest rate of 2 %.

Gas cost is taken at: 6 € cts/kWh which is low for over the future 20 years. An average cost of electricity of 20 € cts/kWh (night/day, typical swiss tariff in 2019) is taken and the feed in tariff is assumed to be 7 € cts /kWh for case 7 and 8 (this is the 2019 tariff in Switzerland, here taken over the 20 years to come, which might be optimistic if we refer to the past changes observed over time in several countries) and as a parametric study in an optimistic case as 15 € cts/kWh for case 9 (which is case 8 but with this more favourable tariff).

Maintenance and insurance costs are considered around 300 €/year depending on the case.

3. Results

Table 2: cost of heat calculated for all cases

System		Gas only	Solar DHW & gas boiler	Heat pump Air	Heat pump Ground	Solar DHW HP ground no integration	Solar SP+DHW HP ground integration	PVT air HP no solar T direct	PV only air HP	PV only air HP feed in tarif
Cost										
Solar collectors	€		7 200			4 800	9 600	16 000	6 000	6 000
Auxiliary	€	6 000	6 000							
Heat pump	€			18 000	24 000	24 000	24 000	18 000	18 000	18 000
Total initial cost	€	6 000	13 200	18 000	24 000	28 800	33 600	34 000	24 000	24 000
Annuity	%/a	6.4%	6.4%	6.4%	6.4%	6.4%	6.4%	6.4%	6.4%	6.4%
Financial cost	€/a	383	842	1 148	1 531	1 837	2 143	2 169	1 531	1 531
Fuel	kWh/a	9 500	6 125							
Fuel cost	€ cts/kWh	6.0	6.0							
Cost of fuel	€/a	570	368							
Average price of elect. to grid	€ cts/kWh							7.0	7.0	15.0
Average cost of elect. From grid	€ cts/kWh	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Electricity cost	€/a	0	14	380	338	232	207	0	124	124
Solar	€/a		60			60	120	230	30	30
Auxiliary	€/a	200	200							
Heat pump	€/a			200	200	200	200	200	200	200
Total maintenance + insur.	€/a	200	260	200	200	260	320	430	230	230
Total annual cost wo sales	€/a	1 153	1 484	1 728	2 069	2 329	2 670	2 599	1 885	1 885
Total electricity sold	€/a							-120	-120	-258
Total net expenses	€/a							2 478	1 764	1 627
Cost of kWh heat	€ cts/a	15.2	19.5	22.7	27.2	30.6	35.1	32.6	23.2	21.4

The cost of kWh of heat is calculated for each case in €. Results for a gas only system (case 1) shows a 15.7 € cts/kWh cost in line with the swiss usual cost. Then case 2 solar and gas at 20.8, then the air heat pump (case 3) with 24.4 cts/kWh which is also a classical in Switzerland. Then we find case 4 the ground coupled heat pump which is a choice of swiss villa owners for 20 years with 29.5 cts/kWh. The solar for DHW and space heating with a heat pump as auxiliary is the most expensive solution, the PV + air HP is attractive at 25.1 cts/kWh, and
our PVT solution with an air heat pump (case 7) is quite expensive, the better COP of the heat pump being not enough to compensate on operational for the high fixed costs. This is typical for a low energy house where operational costs are low.
Case 9 shows that a better feed in tariff of 15 cts/kWh could bring the cost of a PV + air HP solution close to that of an air heat pump only. Selling to a neighbour who pays 20 is a good option if allowed!

4. CO_2 emission reduction

When it comes to CO_2 emissions, the reduction provided by the PVT solution is the greatest, from 1957 kg CO2/y for the gas only solution to 0 kg for the PVT solution in our assumptions where no electricity from the grid is necessary according to our calculations (there might be years when the grid is necessary for peak).

At even a 100 €/t for penalty, the CO_2 avoided cost is much too small to compensate the higher initial costs.

Table 3: CO_2 emissions for all cases

System		Gas only	Solar DHW & gas boiler	Heat pump Air	Heat pump Ground	Solar DHW HP ground no integration	Solar SP+DHW HP ground integration	PVT air HP no solar T direct	PV only air HP	PV only air HP feed in tarif
CO2 emissions										
from solar operations	kg/a									
from gas	kg/a	1 957	1 262							
for grid elec UCPTE	kg/a	0	58	1 520	1 351	929	826	0	496	496
Total CO2	kg/a	1 957	1 319	1 520	1 351	929	826	0	496	496
in %		100%	67%	78%	69%	47%	42%	0%	25%	25%
Value of CO2 at 100 €/t	€/a	196	132	152	135	93	83	0	50	50
Specitic emission values										
gas	0.206	kg CO2/kWh								
UCPTE electricity	0.800	kg CO2/kWh								

5. Conclusions

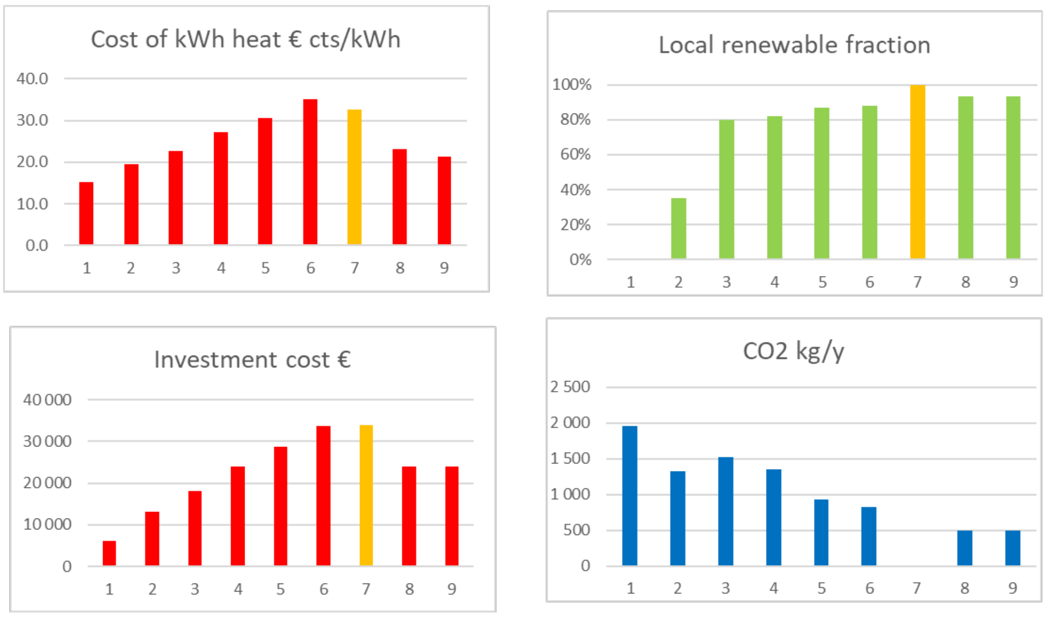

Figure 1: Comparison of all 9 configurations along 4 main criteria

For low energy houses, PVT needs to have a low initial cost when economics is the criteria. System optimisation might also bring the system cost down. The size of the load might also influence this conclusion.

For environmental and renewable fraction criteria it is probably the best choice, but a LCA global analysis should be performed to better assess the comparison with a PV only air heat pump solution.

CO_2 emission reduction and virtue of local renewable fraction should be better encouraged in order to enhance the interest in PVT solutions at current cost in low energy houses.

More simulations and field experience are needed to confirm these preliminary conclusions. Task 60 of IEA SHC which we operate (2018-2020) will bring more important results and optimised solutions to PVT applications.

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