Best practices for PVT technology

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Abstract

The PVT technology combines solar PV and solar thermal in the same PVT panel. In this way, both electricity and heat are produced by the PVT panel. Compared to the PV technology and the solar heating technology the PVT technology is in the early market stage with only few small and weak industries active.

Best practices for the PVT technology, which is still under rapid development, are summarized. Marketed systems with different PVT panel types, different PVT system types with different components for different applications are considered. The potential advantages for PVT systems and the needs for key actors in order to establish a successful sustainable future PVT market are given.

Finally, recommendations for a subsidy scheme for PVT systems are given, so that a PVT market can be developed in parallel with the successful PV market.

Keywords: PVT panels, PVT systems, applications, best practices

1. Introduction

Within the project PowerUp MyHouse partners from Turkey, Portugal, Sweden, Lithuania and Denmark cooperate on preparation of teaching materials on PVT systems. A part of the work has focus on best practices for the PVT technology. This paper summarizes the findings, with inputs from all participants.

The PVT technology combines solar PV and solar thermal in the same PVT panel. The panel consist both of PV cells and an absorber in good thermal contact with the PV cells. PVT panels can provide electricity, heating and cooling. The PVT technology offers a number of potential advantages: The efficiency of the PV part can be somewhat increased by cooling the PV panel by air or fluid circulation through the absorber. Compared to separate PV panels and solar collectors, materials for the panels can be saved by using PVT panels. Further, roof and façade areas are utilized in a better way with PVT panels than with separate PV panels and solar collectors. Additional, by integrating PVT modules into building roofs and facades, the use of building materials, can be reduced.

Further, the PVT panel encapsulation technology is the same as for PV panels. Consequently, since PVT panels during operation have a lower temperature than similar PV panels, the lifetime of PVT panels is expected to be higher than the lifetime of PV panels.

The PVT economy is still today difficult to calculate precisely, based on market prices and existing installations, as it is an early market where costs always are much higher than in a mass market. The potential economic advantages are though large, compared to separate PV or solar heating systems, as the same mounting structure, installation work and almost the same module design are used.

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There are also disadvantages for PVT system: It is still a new technology and for many applications the optimal designs of the PVT systems have not been elucidated. PVT panels are relatively expensive, since the panels are not mass produced. International standards for PVT panels and PVT systems are still not available. It is much more complicated, time consuming and expensive to test PVT panels than to test PV panels (normally only an instantaneous peak power flash test is used). The system designs are often relatively complicated making installation time consuming and complicated. Installers do not promote systems, which are difficult to install. PVT installer training is therefore very important. The technology is still by many key actors considered unproven.

The PVT market is still in the early stage. By the end of 2020, 1,275,431 m² PVT systems were in operation worldwide. During the last years from 2017 to 2020 an average yearly growth rate of the market of about 9% was observed, Weiss and Spörk-Dür (2021). Approximately half of the PVT area consist of air cooled PVT panels. The heated air is often used to heat the same buildings, where the PVT panels are in operation. The other half of the PVT systems are based on PVT panels with absorbers, where a solar collector fluid cools down the PV cells while circulated through the absorber.

2. PVT panels

Different PVT panel types are available. Figure 1 shows a typical flat plate PVT panel, a low concentrating LCPVT panel and a PVT panel cooled by air. The PVT panels can be uncovered or covered, equipped with a cover plate, typically a glass cover. Further, PVT solar collectors are either classified as liquid or air PVT's, characterized by its heat transfer fluid. Typical liquids are water or glycol/water mixtures.

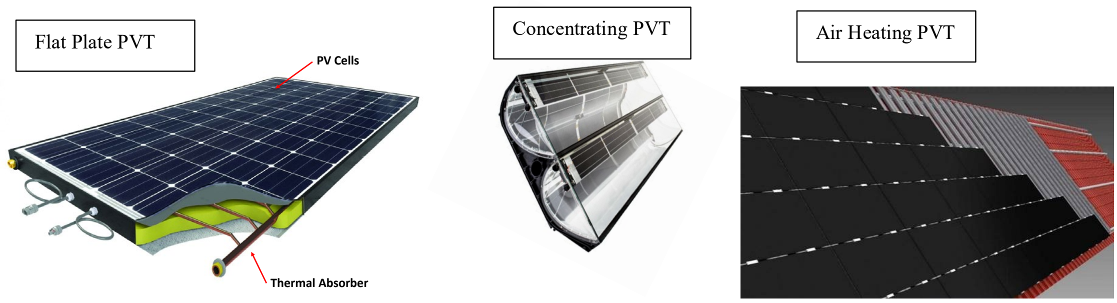

Fig. 1: Typical PVT panels, Perers et al. (2021).

Concentrating (CPVT) panels utilize small solar cell areas and normally produce high temperatures. The electrical efficiency of the solar cells is therefore low, due to the reduced PV cell efficiency, at increased cell temperature. However, based on the aperture or gross area of the panel, the electrical efficiencies of the PVT panels are high. Moreover, concentrating PVT collectors can be labelled by its concentration ratio in three different categories, such as with low, medium and high concentration factors. Typically, low concentration PVT collectors are used as a part of a stationary (fixed collector tilt angle) solar energy systems, while high concentration PVT collectors require a one-axis or two-axis tracking system.

PVT panels with cover plates produce higher temperatures than uncovered PVT panels. Consequently, the electrical efficiency of the covered PVT panels is lower than the electrical efficiency of the uncovered PVT panels.

In most cases, PVT air collectors have high heat losses compared to liquid based PVT panels and they are therefore less sensitive to overheating. Consequently, air PVT panels have relative high electrical efficiencies.

PVT liquid collectors are more complicated to install than air cooled PVT collectors, while the air handling system inside the house normally needs more space and materials

In most PVT panels monocrystalline PV cells are used due to their enhanced electrical efficiency and higher solar absorption compared to polycrystalline PV cells. Thin-film solar cell technologies (e.g. CIGS and CdTe), are typically characterized by their lower temperature coefficient, which makes them very attractive for PVT panels with high temperatures. In high concentrating PVT applications, multi-junction PV solar cells are typically used.

The electrical performance of a PVT panel is measured and given as an instantaneous peak power at a solar irradiance of 1000 W/m² and an ambient and PV cell temperature of 25°C. The electrical efficiency of a PVT panel is given as the ratio between the peak power and (PVT area x 1000 W/m²).

The reduction of the electrical efficiency of a PVT panel with increasing PV cell temperature is given by equation 1, which represents the traditional linear expression for the PV electrical efficiency η_{el}.

$$\eta_{el} = \eta_{0,el}\left(1 - \beta\left(T_c - T_{ref}\right)\right) \quad \text{(eq. 1)}$$

where

Tc is PV cell temperature, °C

Tref is reference temperature equal to 25°C, °C

β is the coefficient of temperature, $°C^{-1}$

η0,el is the electrical efficiency of the PVT panel at a temperature of 25°C, -

The thermal efficiency of a PVT panel can often in a simplified way be given by equation 2.

$$\eta = \eta_0 - a_1 \frac{T_m - T_a}{G} - a_2 \frac{(T_m - T_a)^2}{G} \quad \text{(eq. 2)}$$

where

η is the thermal efficiency of the PVT panel, -

η_0 is the peak thermal efficiency of the PVT panel, -

a_1 is the heat loss coefficient of the PVT panel at ambient temperature, W/(m²K)

a_2 is temperature dependence of heat loss coefficient of the PVT panel, W/(m²K²)

T_m is the mean solar collector fluid temperature in the PVT panel, °C

T_a is the ambient air temperature, °C

G is the solar irradiance on the PVT panel, W/m²

PVT panel efficiencies are determined by tests at test institutes. In order to evaluate the current state of commercially available PVT panels and their electrical and thermal performance, seven different PVT collectors (Solarus, Abora, Dual Sun, Solimpeks, EndeF, Fototherm and Solator) are selected and compared in Table 1. Figure 2 shows electrical efficiency of the PVT products at a reference temperature of 25°C. Figure 3 shows the thermal efficiency of the PVT products at a total solar irradiance on the PVT panels of 800 W/m² as a function of the difference between the mean solar collector fluid temperature of the PVT panel and the ambient air temperature. The thermal efficiency is measured with the PV part active, otherwise too high parameter values are derived from the test.

Tab. 1: Different PVT panels and their principal parameters, Perers et al. (2021)

Company	Panel Model	Technology	Country	Size [m²]		Price [€/m² gross]	PV Specifications			Thermal Specifications		
				Gross	Aperture		Cell Type	Power Peak [W]	Eff. [%]	η_0	a_1 [W/m².k]	a_2 [W/m².k²]
Solarus	Power Collector	C-PVT- Glazed	Netherlands	2.57	2.31	253	Mono	270	10	0.47	3.78	0.014
Abora	aH72	PVT-Glazed-Water-airgap	Spain	1.96	1.88	204	Mono	350	17.8	0.7	5.98	0
Dual Sun	Wave - 280	PVT-Unglazed-Water-N/A	France	1.66	1.58	452	Mono	280	17.2	0.578	11.4	0
Solimpeks	Volter Powertherm	PVT-Glazed-Water-airgap	Turkey	1.43	1.42	243	Mono	180	16	0.486	4.028	0.067
EndeF	Ecomesh	PVT-Glazed-Water-airgap	Spain	1.61	1.55	596	Mono	260	15.95	0.51	4.93	0.021
Fototherm	FT250Cs	PVT-Unglazed-Water-N/A	Italy	1.61	1.59	618	Mono	250	15.5	0.559	9.123	0
Solator	PVTHERMAU 300	PVT-Unglazed-Water-N/A	Austria	1.64	-	-	Mono	300	18.5	0.499	11.84	0

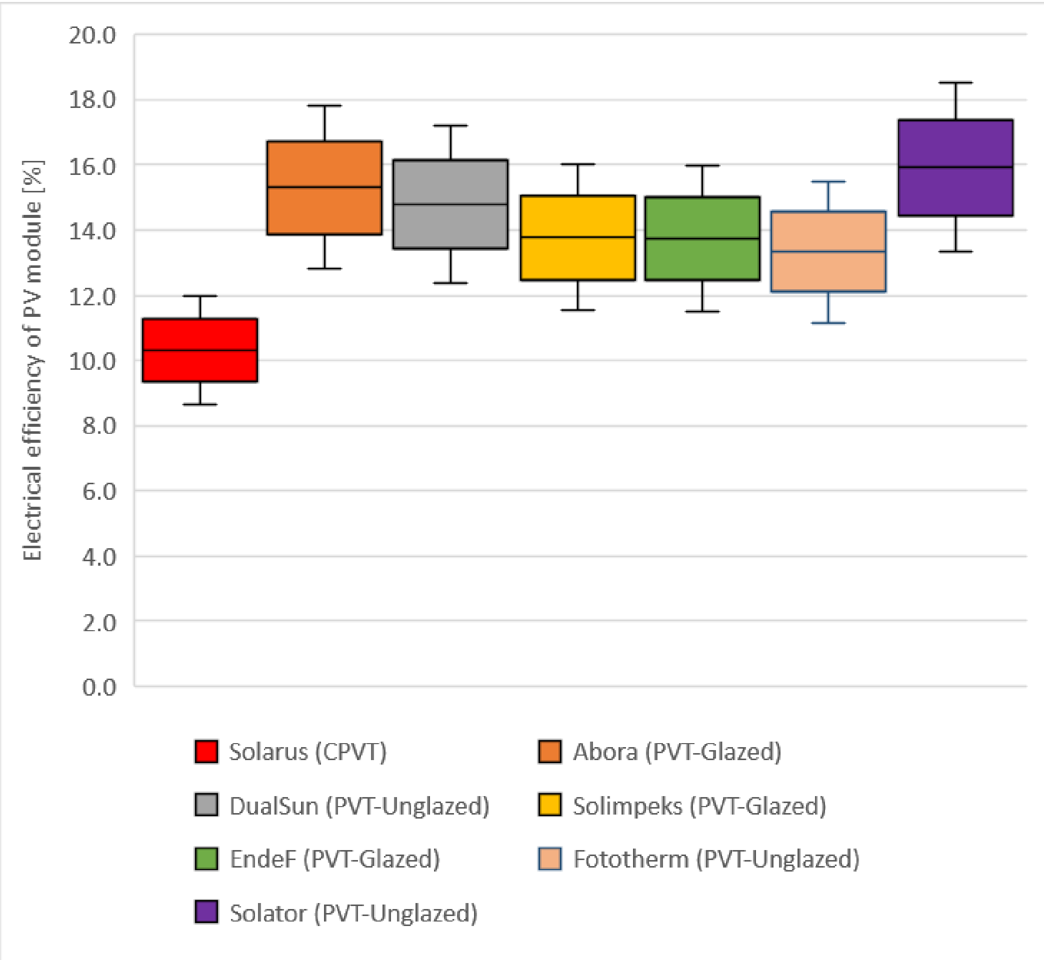

Fig. 2: Electrical efficiency of PVT panels, Perers et al. (2021).

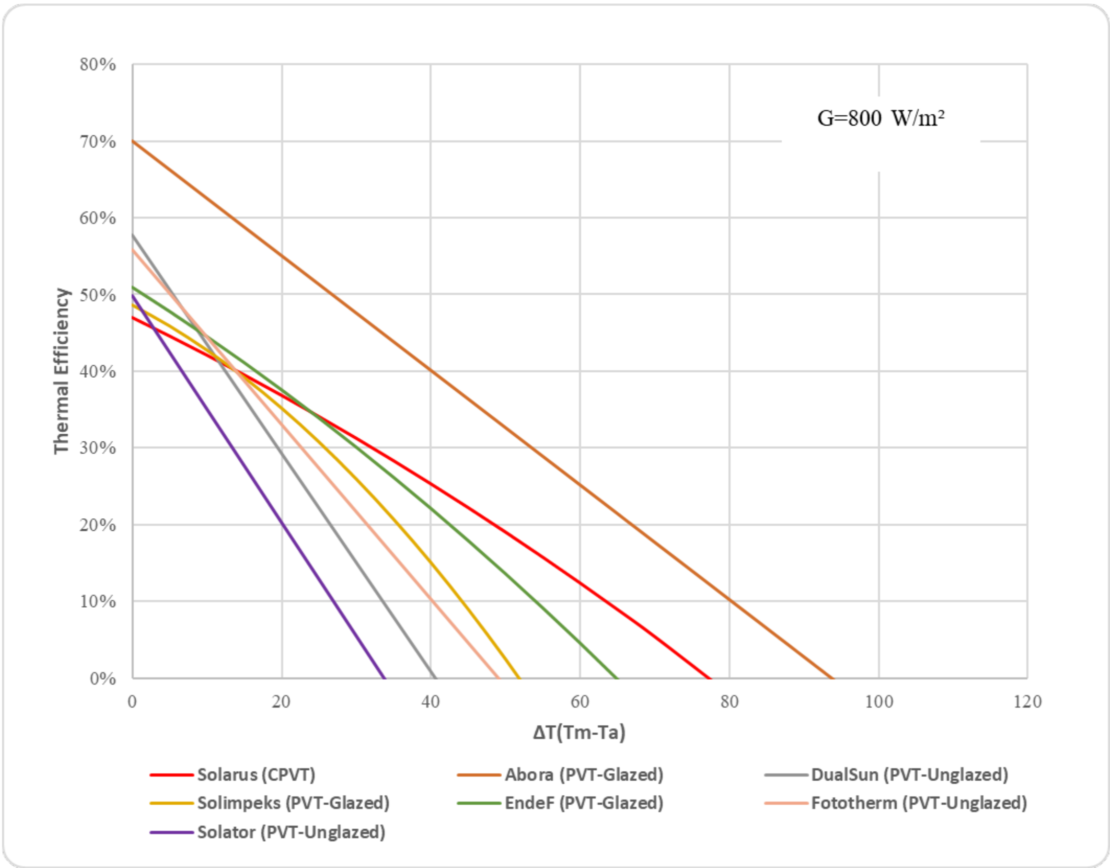

Fig. 3: Thermal efficiency of PVT panels, Perers et al. (2021).

From figures 2 and 3 it is seen that the electrical efficiencies of the marketed PVT panels vary between 10% and 16%, while the thermal efficiencies vary between 0% and 70%, strongly depending on the temperature level of the panel and the product in question.

3. Best practices for PVT systems

PVT systems can be used for many different applications and many different PVT system designs are possible. Figure 4 gives an overview of PVT panel technologies and PVT applications for different temperature levels.

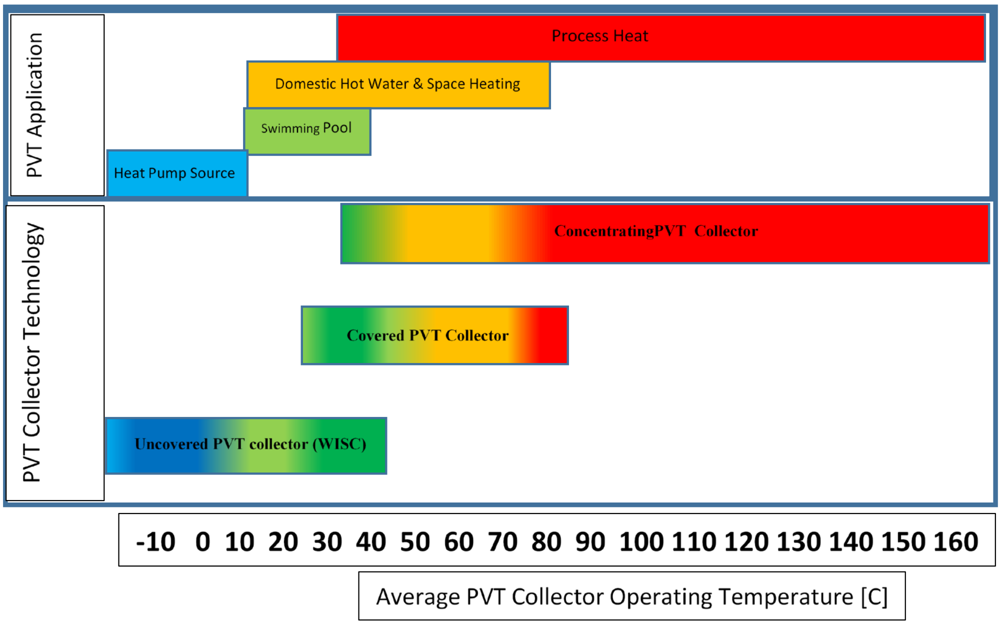

Fig. 4: PVT technology and applications for different temperature levels, Lämmle et al. (2020).

Approximately half of the presently installed PVT area of all PVT systems in operation consist of air cooled PVT panels. PVT air collectors are suitable for buildings where air is used for heating, see figure 5. In these relatively simple systems, the air flow rate, plays a key role in lowering the solar cell temperature and increasing the overall energy efficiency of the system. The thermal efficiency of the panels is typically situated in the range from 20% to 40%.

The other half of the PVT systems in operation, are based on PVT panels with thermal absorbers, where a solar collector fluid cools down the PV cells while circulated through the absorber. The solar collector fluid can in simple PVT systems be used for heating swimming pools.

PVT panels can be combined with a heat pump, which can achieve a high efficiency by utilizing the heat produced by the PVT panel. Preferably on the cold side of the heat pump. In these systems simple uncovered PVT panels are often used and the systems inclusive one or more thermal storages plus electrical batteries, can be controlled in a smart way, optimizing the interplay with the electrical grid.

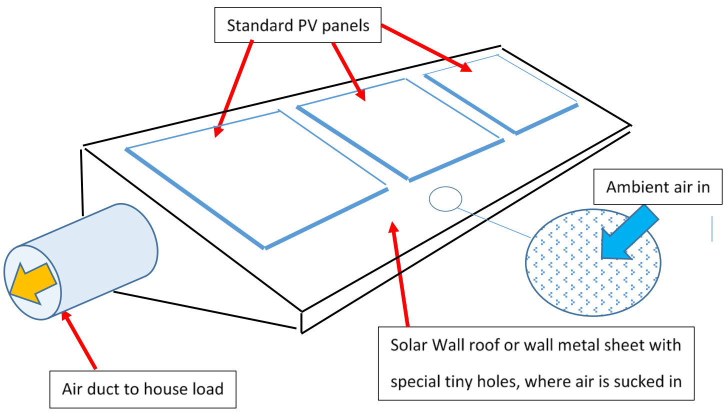

Fig. 5: Air cooled PVT panels, Perers et al. (2021).

PVT systems with liquid based PVT panels can also be used to cover domestic hot water consumption and/or space heating demand. Lämmle, Oliva, Hermann, Kramer and Kramer (2017) suggested four different systems, see the principle sketches in figure 6.

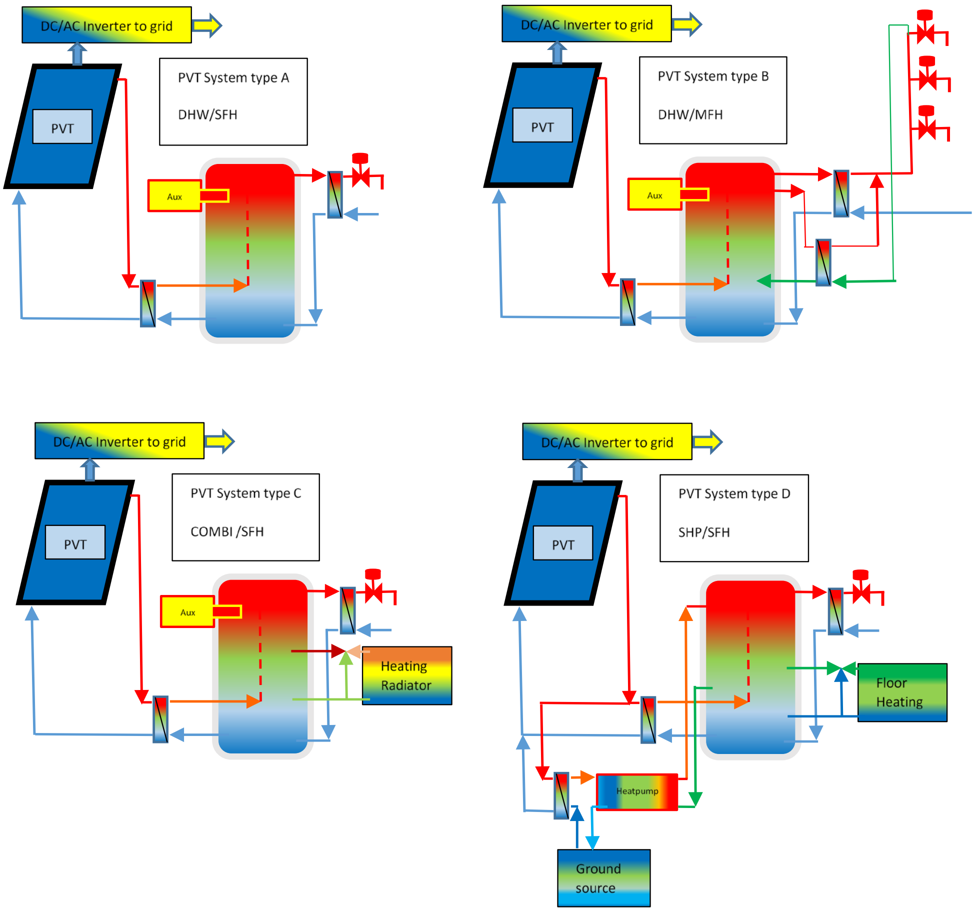

Fig. 6: System principles. (A) domestic hot water in a single-family house, system. (B) domestic hot water in a multi-family home. (C) combi system in a single family house. (D) solar heat pump system in series/regeneration configuration in a single-family house.

System (A) is a domestic hot water system in a single-family house. It is the classical system for solar collectors and is therefore considered a promising application with a potentially big market for PVT collectors. If the PVT system is not oversized compared to the load the operating temperatures can be quite low.

System (B) is a domestic hot water system in a multi-family house, MFH. The system is typically dimensioned in such a way that a relatively low solar fraction is reached. Therefore, the operating collector loop temperatures are relatively low.

System (C) is a combined domestic hot water and space heating system in a single-family house. It is a challenging application with high requirements for the thermal efficiency of the PVT collector, since the heat demand occurs mostly in winter, with low levels of solar radiation and low ambient temperatures. Here avoiding oversizing is very important. Floor heating, like in this example, gives lower operating temperatures for the PVT. Often also a heating demand exist in summer.

System (D) is a heat pump system in a single-family house, SFH. The PVT panel and the heat pump supply space heat and domestic hot water. A synergetic integration of PVT panels can be reached when the PVT panel is coupled to the heat pump, as cold side heat source, or for the regeneration of a ground heat exchanger, which potentially offers the lowest PVT collector temperatures.

The electrical system can also be coupled with an electrical power meter, power optimizers in each PVT panel, battery storage systems and smart controllers, optimizing the interplay with the electricity grid.

PVT systems can also be used for high temperature applications, for instance to cover process heat demands for industries. In such systems advanced concentrating tracking PVT panels can be used. However, these systems are not commonly used so far.

PVT panels can also be used for cooling, as the panel surfaces undercool below the ambient temperature during night up to 10 K, by radiation to a clear sky. This potential is not so much utilized yet but could be used for both air and liquid unglazed PVT panels.

On the cold side of a heat pump system, heat can be extracted also during night, from the PVT panels, especially in windy and cloudy periods.

4. Needs for key actors

The PVT market is small and PVT manufacturers and installers need to be supported in the coming years in order to further develop and utilize the potential of the technology. To secure a high quality of installed PVT systems, prefabricated and easy to install components, for PVT systems, must be developed by manufacturers. It is recommended to support manufacturers in their efforts to develop and demonstrate the reliability of such components, through national and international energy research projects.

Also development of suitable education materials on PVT systems, for installers, consultants and energy planners are needed. Dedicated easy to use design software, directly connected to test standard results, is also important. Further, to secure the quality and safety of the systems, requirements on well educated PVT system installers must be established. It is therefore recommended to establish requirements on certified PVT installers, so that only certified installers are allowed to install PVT systems.

It is also recommended to educate university students in the building and energy sectors on PVT systems, and to carry out information campaigns on the technology. In this way PVT systems will not be forgotten as a solution for future buildings.

In order to establish a sustainable PVT system market there are needs for improvements on all levels. The following needs can be mentioned:

General needs:

- Design Tools for PVT systems
- Decreased costs for PVT systems, compared to separate PV and solar heating systems
- Development of simple and easy to install PVT systems
- A complete test standard for PVT systems like for PV and solar heating systems
- Teaching on all levels, also architects and installers
- Demo systems with proven performance and reliability. ”Bankability” = Banks/Investors rely on the technology, to lend money.
- Proven building integration designs

Needs for key actors:

Researchers:

- Development of standards for PVT panels
- Development of standards for PVT systems
- Development of planning/optimization tools for PVT systems

Manufacturers:

- Development of improved PVT system types

- Development of prefabricated components for PVT systems: PVT panels, heat pumps, storages etc.

Project planners, consultants, decision makers, energy planners:

- Education on PVT systems
- Different PVT demonstration systems in different locations followed up during many years with the aim to document high reliability, high performance and long life time of PVT systems

Installers:

- Installer education on PVT systems

PVT systems are on the market in competition with PV systems. In order to achieve a successful PVT market in the future, it is additional needed that governments are supporting the technology by means of subsidy schemes. A proposal for a subsidy scheme is given in the next section.

5. Recommendations for PVT subsidy scheme

Experience from earlier subsidy schemes has shown that it is important not to introduce sudden changes in the subsidy conditions for the whole life time of the schemes. Since the PV market, especially for large ground based PV systems, is booming for the moment, there will soon be a surplus of solar electricity produced in summer days in the electrical grids. Assuming that the subsidies for PVT systems are related to the electricity delivered to the grid, this might result in sudden and surprising changes of the future subsidy rules. This is especially unfortunate for PVT systems, still being in the early market stage. To give PVT systems a fair chance compared to PV systems, which are already in a mass production and mass market stage, a special high subsidy level for PVT systems is suggested for the next 10 years. It is estimated that this can create a sustainable market for PVT systems along with a sustainable market for PV systems.

The following principles for a subsidy scheme are suggested:

- The subsidy is only payed as long as the system is working and according to how high the energy production is, in Euro per kWh. This also promotes a sustainable aftermarket for repair and upgrade of systems.
- The subsidy level is lowered year by year for new customers, according to the system cost development on the market.
- Early PVT adaptors/investors get a contract with a high enough fixed subsidy in Euro per kWh, stable over 10 years, to create a more predictable payback time, even when the reduction of systems costs and subsidy reductions, are fast for later customers.
- The kWh meter is located directly after the PVT inverter, to avoid economic uncertainties, due to local differences in self-consumption.
- If possible, also a meter on the thermal side can be used with a different lower subsidy level.
- These meter results can also be used to assure and compare system performance figures and help companies to improve the systems. This is in line with the emerging IoT 5G information technology.

6. Conclusions

The PVT technology is a promising new technology offering solutions to cover electricity, heating and cooling demand of buildings.

Today the PVT market is small, and the companies in the field are small and weak. The PVT market is sensitive to rapid changes in rules and support schemes.

Consequently, in order to utilize the potential of the technology on the market, there is a need for long term stable support on all levels: Support for development of prefabricated components and systems, support for education of key actors in the field, information campaigns on the technology, requirements on certified PVT installers and a favorable subsidy scheme for PVT systems.

7. Acknowledgments

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