PVT Benchmark

Corry de Keizer

Jeffrey Bottse

Minne de Jong

seac

Partner in solar energy solutions

PVT benchmark

An overview of PVT modules on the European market and the barriers and opportunities for the Dutch Market.

Authors: Corry de Keizer, Jeffrey Bottse, Minne de Jong

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Management Summary

The market for Photovoltaic-Thermal (PVT) systems and the number of PVT module suppliers is growing. This report presents a market survey of PVT modules and a classification of PVT heat pump systems. Furthermore, a list of barriers and opportunities will be presented as perceived by a wide range of stakeholders in the Netherlands.

In the built environment, the main energy use consists of electricity and heat. Regular PV systems convert approximately 15-20 % of the incoming radiation to electricity, while ca. 75% is converted into waste heat. In hybrid Photovoltaic-Thermal (PVT) systems, a part of this energy is transferred to a liquid or air, and harvested as (useful) heat. In this way, multi-functional PVT roofs can play an important role in the supply of local renewable energy, both in the form of electricity and heat. A promising option to reach near zero energy residential buildings is the combination of PVT collectors with a heat pump.

In our market investigation we found 54 different PVT module types that are currently being sold. 11 of these originate from the Netherlands. The largest share of these, roughly three out of four, are uncovered flat plate PVT collectors. The other types of PVT collectors in the market survey are covered PVT collectors, PVT collectors with vacuum tubes and PVT-air collectors. Uncovered PVT collectors supply lower temperature heat in comparison with traditional covered solar thermal collectors. Therefore, systems with uncovered PVT collectors are often used in combination with heat pumps or for pool heating.

Opportunities and barriers were identified by interviews with 28 stakeholders in combination with a literature review. The stakeholders ranged from PVT, PV, solar thermal and heat pump producers to government parties, experts, installers and project developers. The main opportunities that were identified are a higher combined thermal and electrical yield per square meter. Furthermore, a combination with heat pumps and the possibility to achieve a (near) zero energy building with these technologies was seen as an opportunity. Also the more unified appearance offers opportunities to reach a better aesthetic roof. Several barriers were identified. The largest is the complexity of the system design, the optimization of the system and installation. Furthermore, the high upfront costs and the lack of standardization were mentioned as barriers.

1 Introduction

The market for Photovoltaic-Thermal (PVT) systems and the number of PVT module suppliers is growing. This report presents a market survey of PVT modules and a classification of PVT heat pump systems. Furthermore, a list of barriers and opportunities will be presented as perceived by a wide range of stakeholders in the Netherlands.

In the built environment, the main energy use consists of electricity and heat. Regular PV systems convert approximately 15-20 % of the incoming radiation to electricity, while ca. 75% is converted into waste heat. In hybrid Photovoltaic-Thermal (PVT) systems, a part of this energy is transferred to a liquid or air, and harvested as (useful) heat. This way, multi-functional PVT roofs can play an important role in the supply of local renewable energy, both in the form of electricity and heat. A promising option to reach near zero energy residential buildings is the combination of PVT collectors with a heat pump.

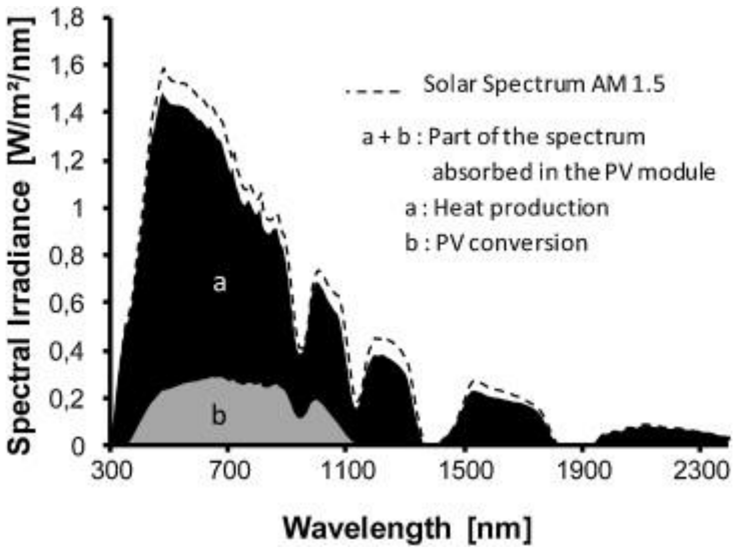


Figure 1.1 Spectral absorption, heat production and reflection for a typical crystalline silicon PV cell [1]

This benchmark report takes a look at the PVT market in Europe with a special focus on the Netherlands. We will answer the following research questions:

- Which PVT collector producers are active on the market? What type of PVT collector do they produce?
- What are the current market prices for PVT collectors?
- What PVT-heat pump combinations are available on the market?
- What are the opportunities and barriers for PVT products in the Netherlands

This benchmark was carried out as part of the PVT inSHaPe (PVT integrated Solar Heat Pump systems) project, which is carried out in the framework of the TKI Urban Energy and is supported by Netherlands Enterprise Agency (RVO).

2 PVT modules

2.1 Module classification

A PVT collector is a solar energy device that uses PV as a thermal absorber and produces both electrical and thermal energy [2]. A wide variety of PVT module configurations exist. Several previous market surveys have been published and include a classification [2] [3]. The attention for PVT systems and the number of suppliers is steadily growing. During the work on this benchmark, two further studies on the PVT market were published by researchers in Switzerland [4] and the UK [5].

There are a lot of parameters that can vary and characterize a PVT module. These include e.g. [2] [3]:

- Type of PV laminate: crystalline silicon, CIGS, CdTe, III-V etc.
- Type of collector: flat plate liquid, flat plate air, concentrator, vacuum tube
- Type of heat transfer medium: air, water or water-glycol mixture
- Type of absorber: sheet and tube, a free-flow and a dual channel, roll bond.
- Type of insulation: covered, uncovered with or without thermal insulation
- Building integrated or not building integrated
- Method for attaching the PV module to the absorber

A visual overview is shown in Figure 2.1.

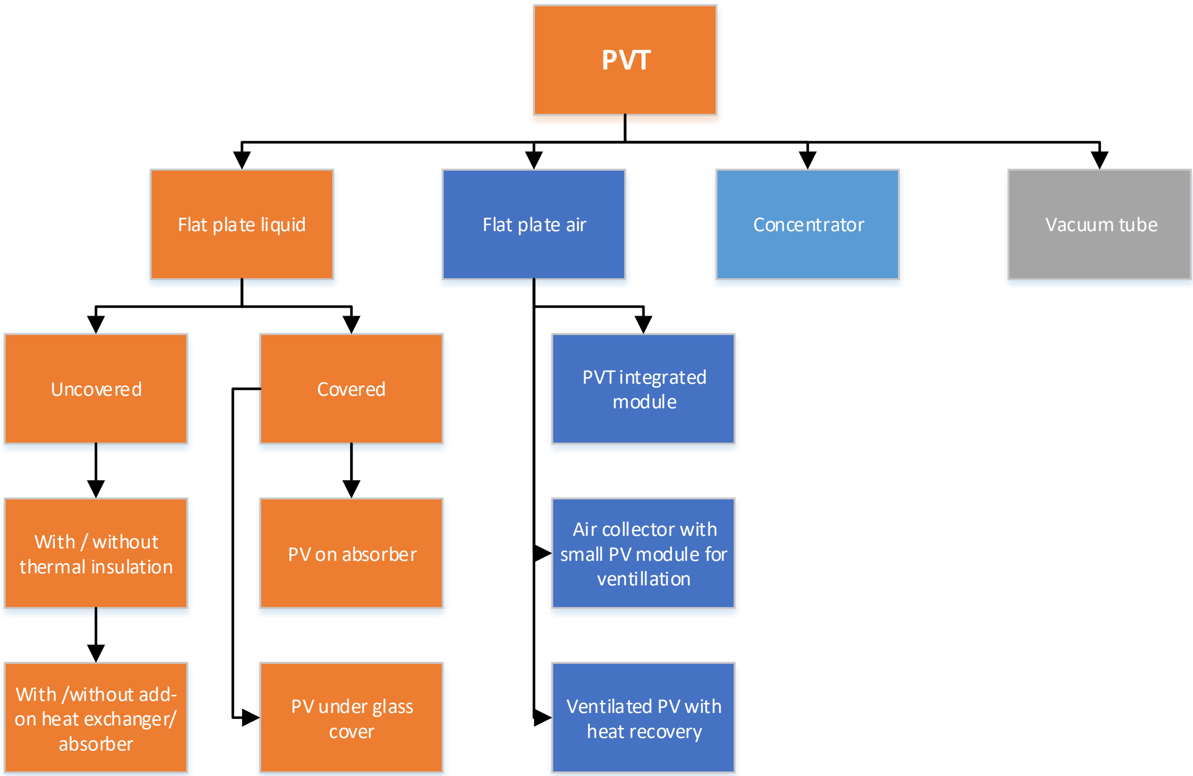


Figure 2.1: PVT Module Classification (adapted from [3])

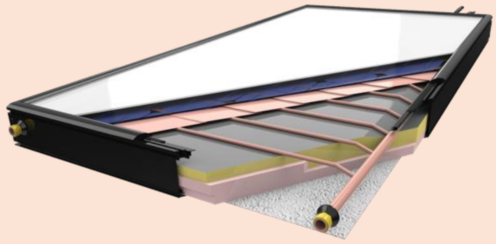
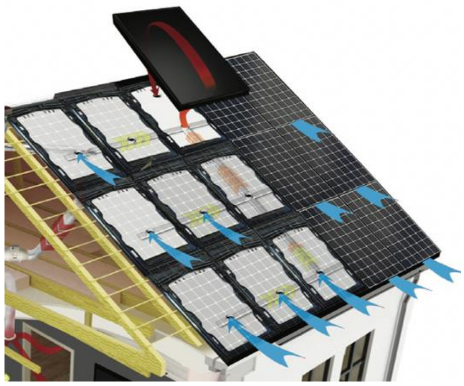
In this benchmark we use the classification as defined in the PVT Norm Project [3]. The categories are:

- 1a Flat plate water uncovered without thermal insulation
- 1b Flat plate water uncovered without thermal insulation, thermal absorber as separate unit under PV module(s)
- 2a Flat plate water uncovered with thermal insulation
- 2b Flat plate water uncovered with thermal insulation thermal absorber as separate unit under PV module(s)
- 3 Flat plate water covered, PV cells placed on absorber
- 4 Flat plate water covered, PV cells placed directly under glass cover
- L1 Flat plate air (heating and electricity in one component)
- L2 Air collector + (small) PV module only used for ventilation power
- L3 Ventilated PV module with heat recovery system for ventilation system
- Conc Concentrating sunlight to a smaller receptive area
- Vac Vacuum tubes above a PV laminate or vacuum tubes containing PV cells

The module classification is further illustrated in Table 2.1 that elaborates on the most occurring PVT module categories and presents examples of recently introduced PVT modules, fitting the most occurring categories.

Table 2.1: Examples of PVT Modules

Category	Explanation	Example
1a: Uncovered flat plate without thermal insulation	One PVT module option is to laminate a (standard) PV module or PV cells on an absorber without adding thermal insulation. The advantage of this module type is that also ambient heat can be harvested. Thus, during cloudy days or even nights with higher ambient than fluid temperatures, the module can produces heat from both sides for low temperature applications. The main disadvantage is that these modules have high heat losses, due to heat dissipating from the back. Examples are *DualSun, FDE Solar, MeyerBurger, Millennium Electric, Solator, Solvis* and *Triple Solar*	 Figure 2.2 1a Triple Solar PVT Module [6]
1b: Uncovered flat plate without thermal insulation, separate heat exchanger	This category refers to absorbers / heat exchangers adjusted to fit behind different types of commercial PV modules. This category is growing, allowing any PV module to be "hybridized" into a PVT module [5]. Some of these modules fit within one PV module, others fit under a series of PV modules. This concept introduces flexibility in the choice of PV module and introduces the retrofitting of readily installed PV modules on roofs into PVT modules. Examples are *Building Energy, CGA Technologies, Geo Holland, SundrumSolar* and the *VolThera* module.	 Figure 2.3 1b VolThera Module [7]

2a: Uncovered flat plate with thermal insulation	The second main category refers to uncovered PVT modules with thermal insulation. The key advantage is reduced heat losses during periods with high irradiance. Furthermore, higher temperatures can be generated, thus sufficient thermal storage needs to be included in the system to prevent stagnation and overheating of the PV cells. Examples are *3F Solar, DualSun, Fototherm, 2Power* and *Solimpeks, SolarTech Int. B.V.*	 Figure 2.4: 2a DualSun Spring [8]
3/4: Covered flat plate	Category 3 and 4 represent covered modules, introducing an air gap between the outer glass layer and the PV cells / absorber. The PV cells are placed on the absorber in the third category and directly below the glazing in the fourth category. These modules can generate higher temperatures, useful for domestic hot water applications. However, the PV cells operate at higher temperatures, resulting in lower electrical efficiencies. Examples are *EndeF Engineering, Solimpeks* and *Hörman-Barkas.*	 Figure 2.5: 3 PowerTherm [9]
L1/2/3: Air-based PVT	Where all other categories involved liquids as heat transfer medium, the L1/2/3 categories contain air. L1 refers to flat plate modules with air as a medium, L2 to air collectors with only several PV cells purely for powering the ventilation and L3 refers to ventilated PV modules with a heat recovery system. The latter is often used and is mainly convenient for building-integrated modules and facades. This way, PV modules are cooled and hot air can be used for heating the dwelling. Examples are *Conserval Engineering, GSE Integration, IRFTS, SCX Solar* and *Systolic.*	 Figure 2.6: L3 Easy Roof Boost'R [10]
Concentrated PVT	Concentrating sunlight can increase the electrical yield of the PV cell and temperature of the thermal fluid, while reducing the cell area / module size area ratio. In other words, the collector area is much larger than the PV and absorber area, possibly reducing total module costs. Concentrators reach higher temperatures and are suitable for heating water. Furthermore, they often track the sun throughout the day. However, for the PV cells increase in temperature and scalability is often a limiting factor. Examples are *Solarus, Suncore, Suncycle* and *Absolicon.*	 Figure 2.7: Solarus PowerCollector [11]

Vacuum tubes with PV	PVT collectors with vacuum tubes form the final category. Where vacuum tubes containing brine are often installed for solar thermal applications, two companies have hybridized them to PVT. *HONE* created a kind of PVT module by placing vacuum tubes over a PV module, increasing the yield per unit of area. *Naked Energy* places PV cells inside the vacuum tubes.	 Figure 2.8 HONE [12]

2.2 Electrical and thermal efficiency

Currently, a specific norm for testing PVT modules is not available. The PV module can be tested according to norm IEC 61215 and IEC 61730. Solar thermal collectors can be certified according to ISO 9806. Because the thermal and electrical yields are interdependent and also e.g. safety aspects change if the PVT module is assembled, it is important to develop norms. Developments to create a new norm have started, see e.g. [3] [4].

The electrical efficiency is determined at standard test conditions (STC, 1000 W/m^2 irradiance and 25°C module temperature). The module efficiency depends on module temperature and irradiance. The efficiency for uncovered PVT collectors is often in the same range as standard ventilated PV modules. It depends on the application and the temperature level of the fluid, at low fluid temperatures the efficiency can also be higher. For covered collectors the efficiency is slightly lower due to the additional glass layer that increases reflection. Also for covered collectors higher PV temperatures occur and lead to lower PV efficiencies.

The thermal efficiency can be determined according to ISO 9806. ISO 9806 acknowledges different methods for determining the uncovered and covered thermal yields, which include the steady state and the quasi-dynamic method. Those all include the zero-loss efficiency (η_0) at which the efficiency is determined when the fluid temperature is the same as the ambient temperature. For covered collectors linear and quadratic losses due to higher / lower fluid temperatures are taken into account. For uncovered collectors wind dependencies and the effect of long-wave radiation are also quantified. [13]

The collector curves for different types of several good quality PVT collectors are shown in Figure 2.9. The following formula is used for the thermal yield of uncovered PVT collector:

$$\frac{\dot{Q}_{th}}{A} = G''\eta_0\,(1 - b_u\,u) - (b_1 + b_2\,u)\,(T_m - T_a)\ [\text{W/m}^2]$$

where

- η_0 – zero loss efficiency
- b_u – wind speed dependence of the zero loss efficiency $[s/m]$
- b_1 – heat loss coefficient $[W/m^2K]$
- b_2 – wind speed dependence of the heat loss coefficient $[Ws/m^3K]$
- u – wind speed $[m/s]$
- T_m – mean collector temperature $[°C]$
- T_a – ambient temperature $[°C]$

- G'' - net incoming irradiance and calculated by correcting the in plane irradiance G for long-wave irradiance E_L: $G'' = G + \frac{\varepsilon}{\alpha}(E_L - \sigma T_a^4)$ where G is the in-plane irradiance, ε/α is defined in the norm to be equal to 0.85 and σ is the Stefan-Boltzmann constant.

Covered PVT collectors are less sensitive to wind and long wave irradiance losses. The following formula is used to calculate the heat flow for covered PVT collectors:

$$\frac{\dot{Q}_{th}}{A} = G \cdot \eta_0 - a_1 (T_m - T_a) - a_2 (T_m - T_a)^2 \text{ [W/m}^2\text{]}$$

where

- a_1 – heat loss coefficient $[W/m^2K]$
- a_2 – quadratic heat loss coefficient $[W/m^2K^2]$

The following typical values for PVT collector efficiencies are used for Figure 2.9 .

- Covered PVT collector:
  η_0 = 0.5, a_1 = 5 W/m^{2}K and a_2 = 0.02 W/m^{2}K^2
- Uncovered PVT collector with back insulation:
  η_0 = 0.6, b_u = 0.05 s/m, b_1 = 9 W/m^{2}K, b_2 = 1.5 W/m^{3}K
- Uncovered PVT collector no back insulation:
  η_0 = 0.58, b_u = 0.05 s/m, b_1 = 12.5 W/m^{2}K, b_2 = 1.5 W/m^{3}K

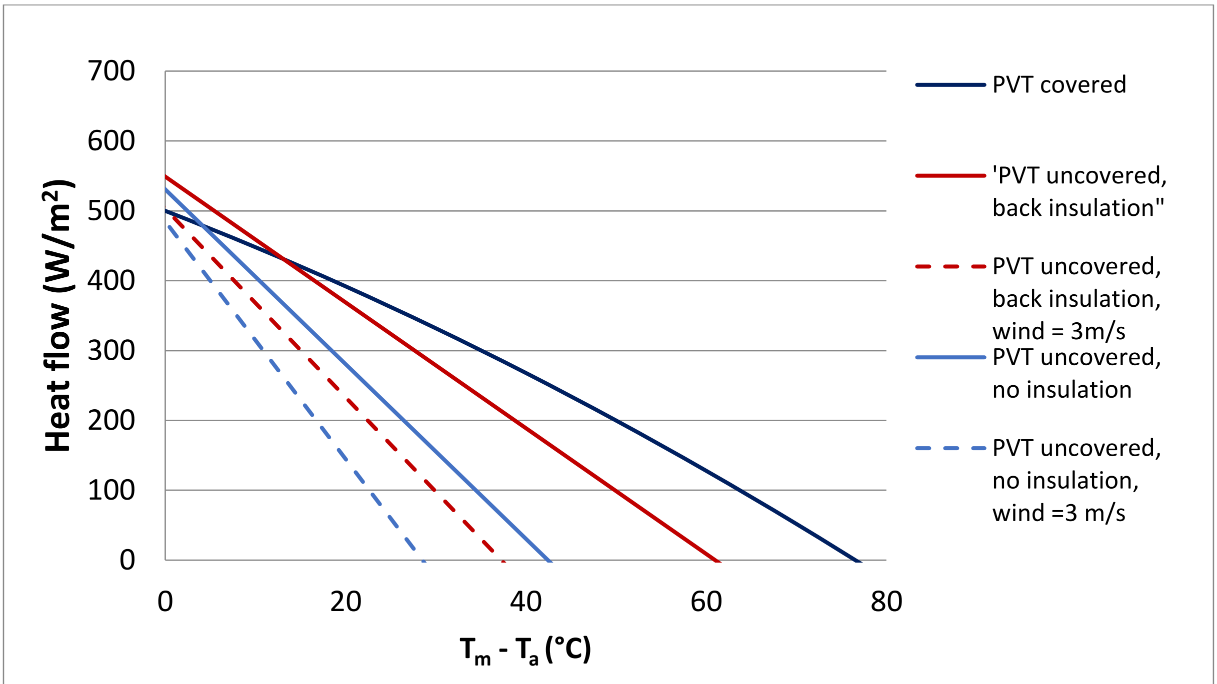


Figure 2.9 Typical PVT collector heat flows for covered and uncovered PVT collectors with PV in MPP at G = 1000 W/m^2, ($E_L - \sigma T_a^4$) = -100 W/m^2, ε/α = 0.85 and therefore G'' = 915 W/m^2. Efficiencies are derived from [4]

At lower temperatures uncovered PVT collectors are more efficient and also function as a heat exchanger with the ambient.

2.3 PVT product database

A market analysis on PVT products that are currently available was carried out. The modules have been categorized in the classification above, as well as in availability statuses (available, in development and (production and sales have) stopped). A PVT company can produce different type of PVT modules. Out of the 92 different PVT modules found, 54 modules are currently sold, out of which 11 originate from the Netherlands. Furthermore, 6 products are in development and 32 are taken out of production. A short disclaimer, we do not guarantee completeness.

The classification in Figure 2.10 shows a large share of uncovered flat plate liquid collectors. These account for 72% of the total PVT module availability. In the Netherlands, the uncovered flat plate liquid modules even represent 82% of all modules. Uncovered flat plate collectors perform well for applications that require a low temperature, like regeneration of a ground-source heat pump or in general with heat pumps. Furthermore, for covered PVT products there is a large tradeoff between the desired higher temperature for thermal applications and the desired low temperature for PV cells. Also stagnation can lead to very high PV temperatures.

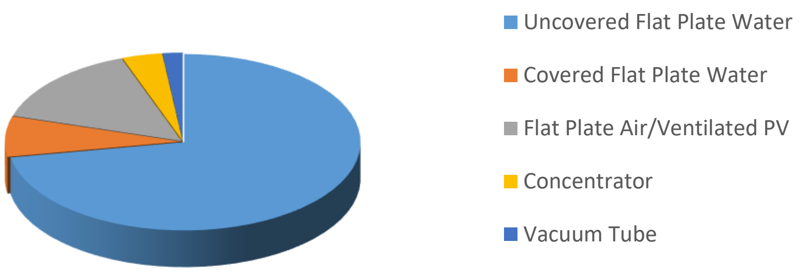


Figure 2.10 Classification of available PVT products

Most available modules found are produced by companies situated in Europe (46). The origin of PVT modules is shown in Figure 4.15. Besides the modules originating from Europe, a total of eight PVT modules originate from China (1), Australia (1), Israel (3), the USA (1) and Canada (2).

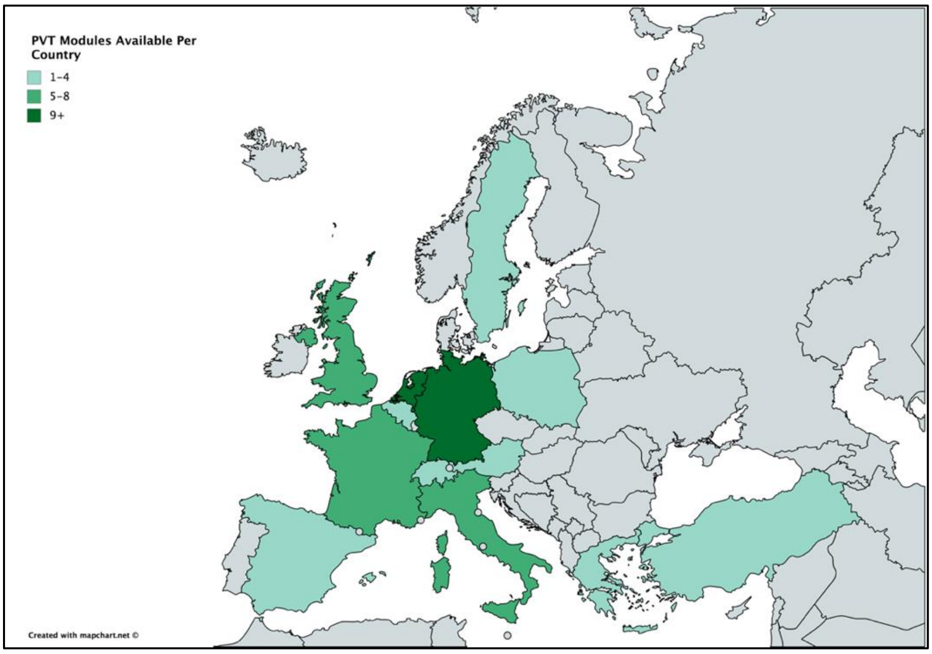


Figure 2.11 Geographical Overview of PVT Module Origins

The electrical parameters and module dimensions mostly match PV modules, the thermal parameters do not match the parameters of uncovered solar thermal collectors. Out of 39 available uncovered flat plate modules, 18 have certifications for the electrical properties of the module (IEC61215/IEC61730). Furthermore, 16 modules are certified with the *Solar Keymark*, after being tested to the EN12975 standard, for the thermal part of the module. This means that about 40% of the PVT modules has been certified as a solar thermal system in Europe. Within the Netherlands, no PVT module has any certifications.

A list of available PVT products is given below. If there are different variations that only vary in size or in rated power, it is noted as one collector with a range of rated power.

Legend of PVT product database

Picture *Source: Supplier website*	**Name PVT product** Rated power PV in Wp, this can be a range or different Wp's for sizes Gross area in m² PV type and supplier **PVT classification number** Company (country) Website company

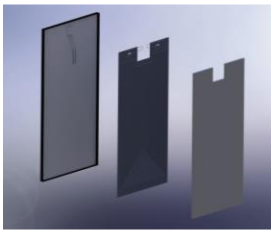
2Power HM 260
260 Wp
1.6 m²
mono cSi
Type 2a
PA-ID Process (DE)
http://www.2power-hybrid.com/de/

Absolicon X10 PVT
In development
550 Wp
6.6 m²
Type Conc
Absolicon (SE)
http://www.absolicon.com/

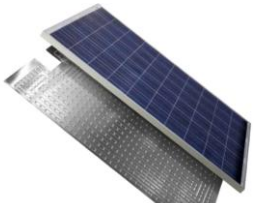
3F Solar One Hybrid-kollektor
265 Wp
1.6 m²
mono cSi
Type 2a
3F Solar (AT)
http://www.3f-solar.at/

Alius Solar Volthera
260 - 275 Wp
1.6 m²
Poly/mono cSi (JA Solar)
Type 1b
Alius Solar (NL)
https://aliusenergy.nl/

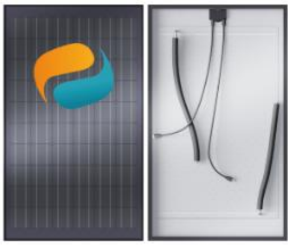
3S HYBRID 240-900
285 Wp
1.6 m²
mono cSi
Type 1a
MeyerBurger (CH)
http://energysystems.meyerburger.com/en/products/hybrid/



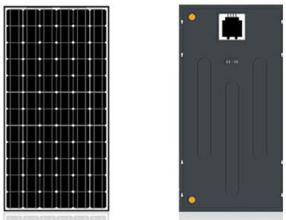
Building Energy Hybride PV/T 2-in-1
250 Wp
1.6 m²
Poly/mono cSi
Type 1b/2b
Building Energy (BE)
http://buildingenergy.be/



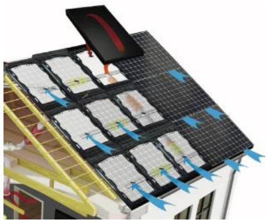
CGA Technologies Hybrid Solar Thermal
1.6 m²/ flexible
Roll bond absorber
Type 1b
CGA Technologies (IT)
http://www.cgaspa.it/



DualSun Wave
250 Wp
1.6 m²
mono cSi
Type 1a
DualSun (FR)
https://dualsun.fr/



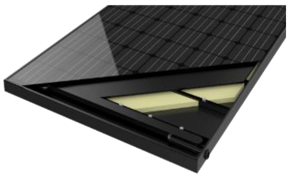
CHN200-72-PVT
200 -210 Wp
1.3 m²
mono cSi
Type 1a
Chinaland Solar Energy (CN)
www.chnlandsolar.com



EASY ROOF Boost'R
PV independent
1.6 m²
Type L3
IRFTS (FR)
www.irfts.com

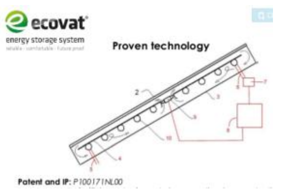
Dimark Modular Energy Roof System
245 Wp
1.5 m²
Mono/poly cSi
Type 2a
Dimark Solar (NL)
www.dimarksolar.nl

Eclipse Solar Roof Tile
76 Wp
0.6 m²
mono cSi
Type 2a
Tractile (AU)
www.tractile.com

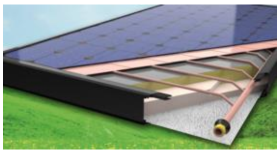


DualSun Spring
280 Wp
1.7 m²
mono cSi
Type 2a
DualSun (FR)
https://dualsun.fr/

Ecomesh
255 Wp
1.6 m²
poly cSi
Type 3
EndeF Engineering (ES)
http://endef.com/



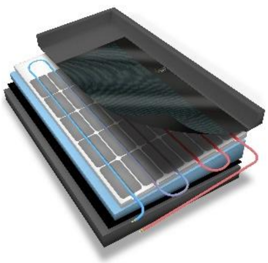
Ecovat PVT Paneel
? Wp
2 m^2
?
Type 1a
Ecovat (NL)
http://www.ecovat.eu/



FDE Hybrid
250 Wp
1.4 m^2
poly cSi
Type 2a
FDE Solar (IT)
www.fdesolar.com/

Energiedak - Multi Energy Panel
Ca. 165 Wp/m^2
Flexible 1-1.6 m^2
All PV panels and technologies
Type 2b
Solartech BV
www.energiedak.nl

Flint Energy Roof
Type 2b
Flint Engineering (UK)
www.flintengineering.com
in development

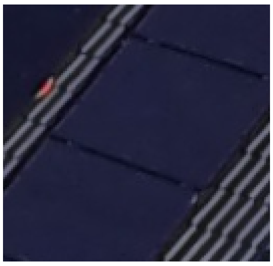


Energiedak Plus
Up to 150 Wp/m^2
flexible m^2
Flexible foil (CIGS)
Type 2a
SolarTech Int. B.V.
www.energiedak.nl

Fototherm FT250CS
250-265 Wp
1.6 m^2
poly cSi
Type 2a
Fototherm (IT) & Aleo
www.fototherm.com

ENSOL E-PVT 2.0
300 Wp
1.9 m^2
poly cSi
Type 1a
Ensol (PL)
www.ensol.pl

Fototherm FT285AL
290-300 Wp
1.6 m^2
mono cSi
Type 2a
Fototherm (IT) & Aleo
www.fototherm.com



GEO Holland - Triple Power Panel
250-270 Wp
1.6 m^2
poly-cSi
Type 1b
GEO Holland (NL)
www.geoholland.nl

MAS (Modular Anti-Seismic Solar)
215 Wp
1.8 m^2
poly cSi
Type 2a
Roof MAS (IT)
www.roofmas.com
in development

GSE Air System V3.0
285 Wp
1.6 m^2
cSi
Type L3
GSE Integration (FR)
www.gseintegration.com

MSS MIL-PVT-195W-MO3
195 Wp
1.3 m^2
mono-cSi
Type 1a
Millennium Electric (IL)
http://www.millenniumsolar.com/

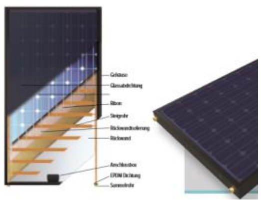
HONE 501 Thermal/ Electric
100 Wp
1.7 m^2
Type Vac
HONE (UK)
http://www.hone.world/en/products.html

MSS MIL-PVT-340W-MO3
340 Wp
2.7 m^2
mono-cSi
Type 1a
Millennium Electric (IL)
http://www.millenniumsolar.com/

ISIEtherm WRS 200-ST48F
200 – 250 Wp
1.3 m^2
poly cSi
Type 2b
Nieberle Solar (DE)
www.isie-therm.com

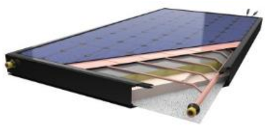
Naked Energy Virtu
Si
Type Vac
Naked Energy (UK)
www.nakedenergy.co.uk
in development

Optisolar PVT – Thermodule 2.0
Flexible sizing / PV types
Type 1b
Optisolar PVT (NL)
www.optisolarpvt.nl



PowerTherm 180
180 Wp
1.5 m^2
mono cSi
Type 3
Solimpeks (TR)
www.solimpeks.com/

Power Kombi Module 96 M
250-285 Wp
1.7 m²
mono-cSi
Type 1a
Power Kombi Module (DE)
www.powerkombimodule.com

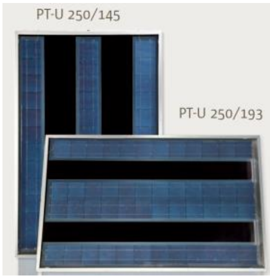


PowerVolt 200
200 Wp
1.4 m²
mono cSi
Type 2a
Solimpeks (TR)
www.solimpeks.com/

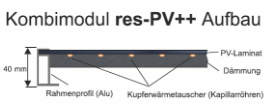
Power Profit 105/270
235 Wp
1.6 m²
mono cSi
Type 1a
R&R Systems (NL)
www.energieverdieners.nl

PSS PIK® Combi Solar Collector
245 Wp
1.7 m²
mono-cSi
Type 1a
Poly Solar Solutions (CH) http://www.pss-ag.com/de/

PowerHybrid 240
240 Wp
1.3 m²
Heterojunction (mono cSi + thinfilm aSi)
Type 2a
Minimise Group (UK)
www.minimisegroup.com/



PT-U-250/145 or 193
145 Wp / 193 Wp
2.4 (gross)
1.3 (apert) m² / 1.1 m²
poly cSi
Type 4 (side by side)
Hörmann-Barkas Metallbau (DE)
http://hoermann-solarhybrid.de/

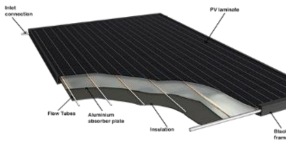


RES-PV++250
250-300 Wp
1.6 m²
Poly/mono cSi
Type 2a
RES Energie
http://www.2power-hybrid.com/de/

Solarus Power Collector
250 Wp
2.5 m²
cSi
Type Conc
Solarus (NL/SE)
http://solarus.com/

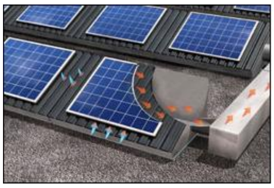
ScanSun XL 250
6-11 Wp
0.5 – 1.2 m²
Type L2
ScanSun (DE)
www.scansun.info

Solarwall PV/T
100 Wp/m²
Type L3
Conserval Engineering (CA)
www.solarwall.com



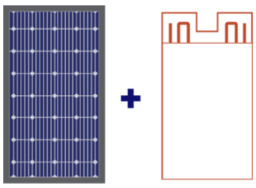
Solar Angel DG-01
250 Wp
1.6 m^2
poly cSi
Type 2a
Solar Angel (UK)
www.solarangel.com

Solator PV + Therm Aufdach
280-300 Wp
1.6 m^2
mono cSi
Type 1a
Solator (C. Bosch) (DE)
http://www.solator.cc



Solarduct PV/T
100 Wp/m^2
Type L3
Conserval Engineering (CA)
www.solarwall.com

Solator PV + Therm Indach (BIPVT)
190 Wp
1.2 m^2
mono cSi
Type 1a
Solator (C. Bosch) (DE)
http://www.solator.cc



Solar Energy Booster
variable Wp
1.6 m^2
cSi
Type 1b
Solar Energy Booster (NL)
www.solarenergybooster.nl

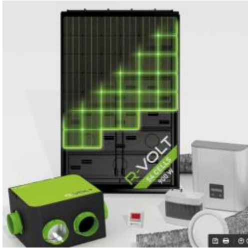
Soloroof Heat recovery
For all BIPV types ventilated PV
Type L3
SCX Solar (NL)
www.scx-solar.eu

SunDrum Hybrid PV Panel
Flexible sizing / PV types
Type 1b
Sundrumsolar (USA)
www.sundrumsolar.com

Solvis Hybrid SV60PVT
250-260 Wp
1.6 m^2
poly-cSi
Type 1a
SOLVIS (HR)
www.solvis.hr

SunCycle Urban System (SUS)
1000 Wp
5.5 m^2 (4 m^2 aperture)
Triple junction
Type Conc
Suncycle (NL)
www.suncycle.nl

Sunbag
Wp
m²
cSi
Type 2b
Geo Clima Design (DE)
www.geoclimadesign.com

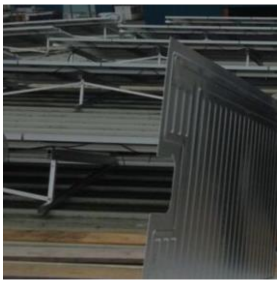


Systovi R-Volt
250 Wp
1.5 m²
Mono-cSi BIPV
Type L3
SYSTOVI (FR)
www.systovi.com

SunCore Z10
1500 Wp
12 m²
Multi-junction
Type Conc
Suncore (USA)
http://suncoreus.com/

Triple Solar PVT
285 / 340 / 570 Wp
1.7 / 2.1 / 3.4 m²
mono-cSi all black (Bisol)
Type 1a
Triple Solar (NL)
www.triplesolar.eu

Twin Energy Solar Panel (TESP)
250-280 Wp
1.6 m²
mono cSi
Type 1a
SunErg (IT)
www.sunergsolar.com



Use all Energy – Solar Heat Combi
290 Wp
1.6 m²
mono cSi
Type 1b
Use all energy (NL)
www.useallenergy.nl

TwinSolar Compact 2.0
18-36 Wp
2-6 m²
cSi
Type L2
Grammer Solar (DE)
www.grammersolar.de

Wiosun PV-Therm PVT 2.0
280-290 Wp
1.6 m²
mono cSi
Type 1a
SolarzentrumAllgäu (DE)
http://www.solarzentrum-wiosun.com/

2.4 Price survey

A price survey for PVT modules was conducted. 28 prices were received of which 25 fit within the uncovered flat plate liquid category. Three of these 25 submitted the price for the heat exchanging module only (without the PV cells/module) and were omitted from the results. The results for uncovered flat plate liquid collector are shown in Figure 2.12. The left graph shows a box plot of the module price, the middle shows the normalized module price in €/m² and the right graph shows the price per Wp. It can be seen that there is a large range in pricing. The average price of PVT modules is 323 €/m² with a standard deviation of 98 €. The PVT price is about half of that in 2005, however, this decline is mainly caused by declining PV prices. Since PVT is still a technological niche, there are expectations that prices can decline further in the future.

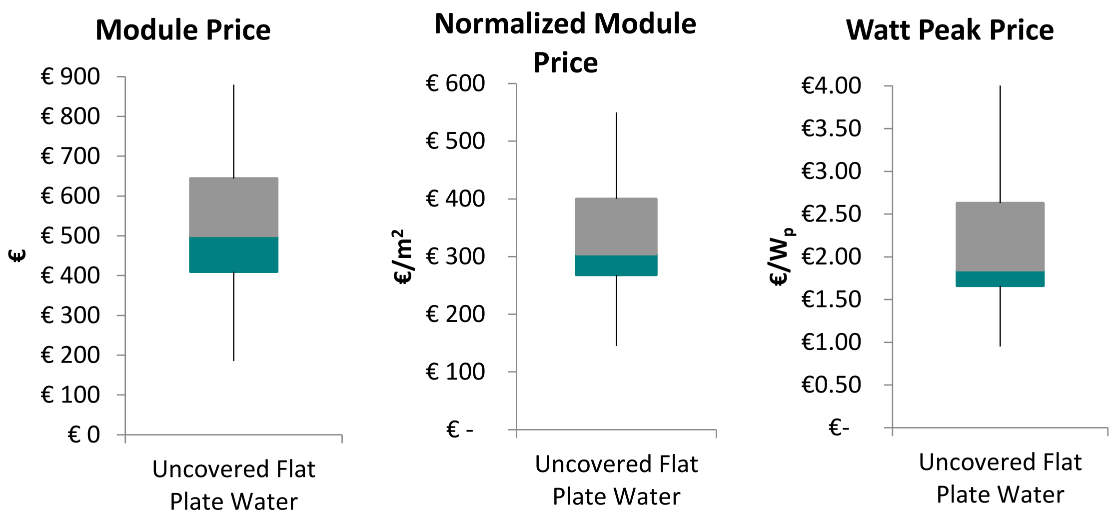


Figure 2.12 PVT Module Price, Normalized Module Price and Watt-peak Price

3 PVT - heat pump systems

3.1 Introduction

The system configuration together with the specifications of the PVT collector and the heat demand determine the thermal yield of a PVT system. Different types of PVT collectors show their optimal performance for different system configurations. If a system is used for domestic hot water, the average collector temperature will be higher and covered PVT collectors show a better thermal performance. However, this may also lead to lower electrical yields, because of higher PV module temperatures. On the other hand, if a PVT system is used to supply heat on the source side of a heat pump, collector temperatures will be much lower and uncovered PVT collectors show higher yields. Furthermore, is important to realise that there is (usually) no grid for heat, therefore heat production is only useful if it can be stored or used directly at the produced temperature level.

We will give a short overview of the different types of system configurations that include PVT modules, that is especially focused on the combination of PVT and heat pump systems.

There are three main categories for combining PVT collectors and heat pumps [14]:

- Series (S): The PVT collector acts as acts as (one of) the source(s) to a heat pump to a heat pump
- Parallel (P): The PVT collector and heat pump can supply the heat independently to e.g. a storage.
- Regenerative (R): The heat produced by the PVT collector is used to regenerate the ground or another main source of the heat pump.

These modes do not exclude each other and combinations are possible.

3.2 PVT on the source side of the heat pump (series and regeneration)

3.2.1 Series concept

A series concept uses the heat produced from the collector directly on the source side of the heat pump. This concept is mainly used for uncovered PVT systems. When outdoor temperatures are very low, the heat pump operates inefficiently or cannot produce enough heat. Therefore, additional electric heating may be required. Furthermore, the limitations of the heat pump with regards to input source temperature should be checked. As an alternative option, a parallel connection can be added for adding the solar heat also on the sink side to a storage. Furthermore, the electrical heater on the sink side can also be replaced by another auxiliary heater.

An example where the heat produced by the PVT collectors is only used as the source for a heat pump is shown in Figure 3.1. The heat pump also heats up a storage for domestic hot water and an auxiliary electrical heater can be used for the peak demand. There is also a possibility to add a cold storage on the source side, see Figure 3.2 and Figure 3.3 (derived from [4]). This can be a solar fluid storage or a e.g. an ice/PCM storage and it can be placed in series with the PVT collector field. The hydraulics can be changed to connect the PVT collectors also directly to the heat pump and only store excess heat. A storage that uses the phase change of a fluid can store additional heat; this is true for an ice storage if it uses the transition from water to ice.

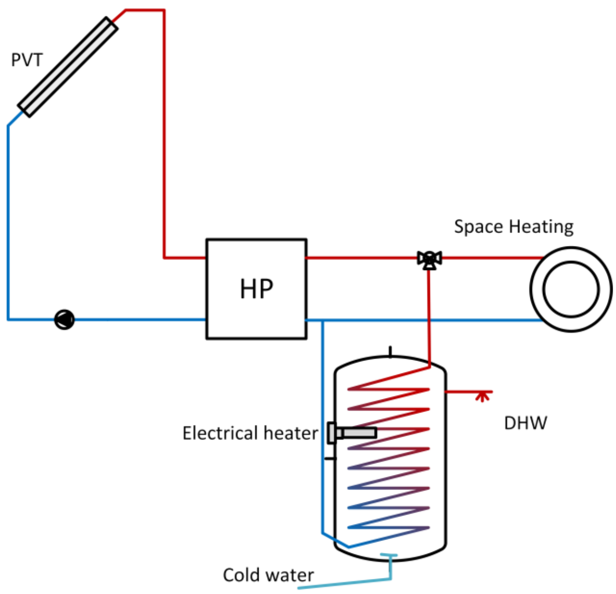


Figure 3.1 PVT-Heat pump configuration as used by e.g. Triple Solar (schematic drawing)

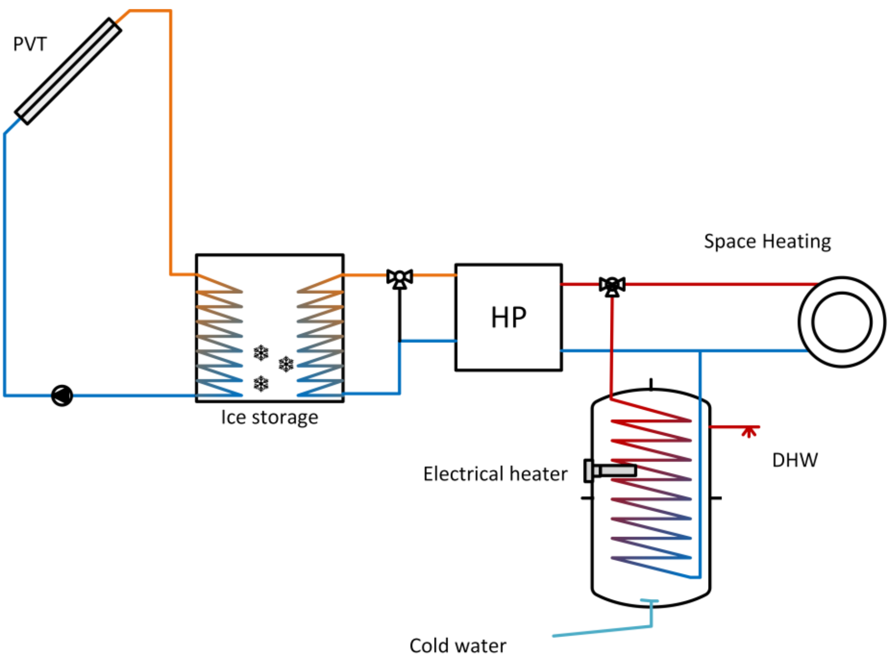


Figure 3.2 PVT-Heat pump configuration with additional ice storage (schematic drawing)

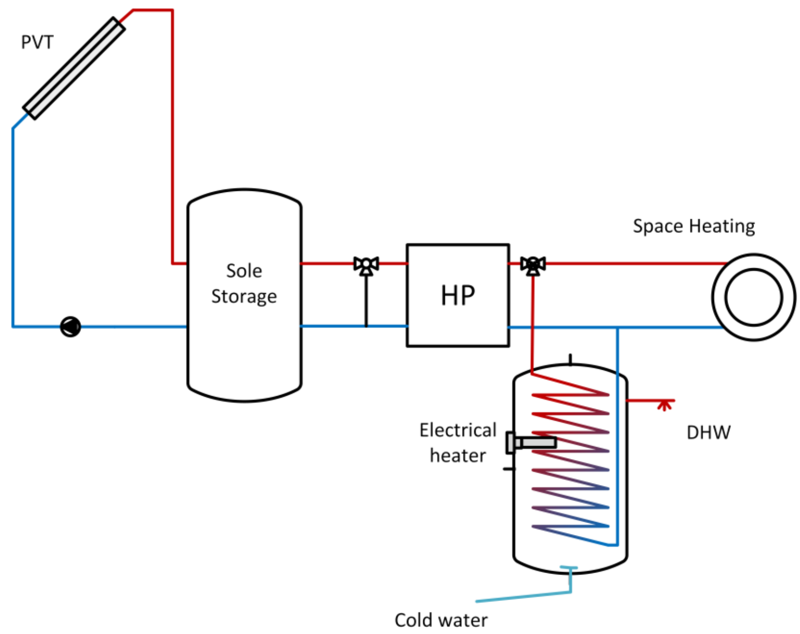


Figure 3.3 PVT-Heat pump configuration with additional Sole storage (schematic drawing)

3.2.2 Regeneration of open or closed ground source

This option is commonly used for energy roofs in the Netherlands. However, it can also be used for PVT systems. Regeneration occurs at low temperatures and therefore the PVT efficiencies are high.

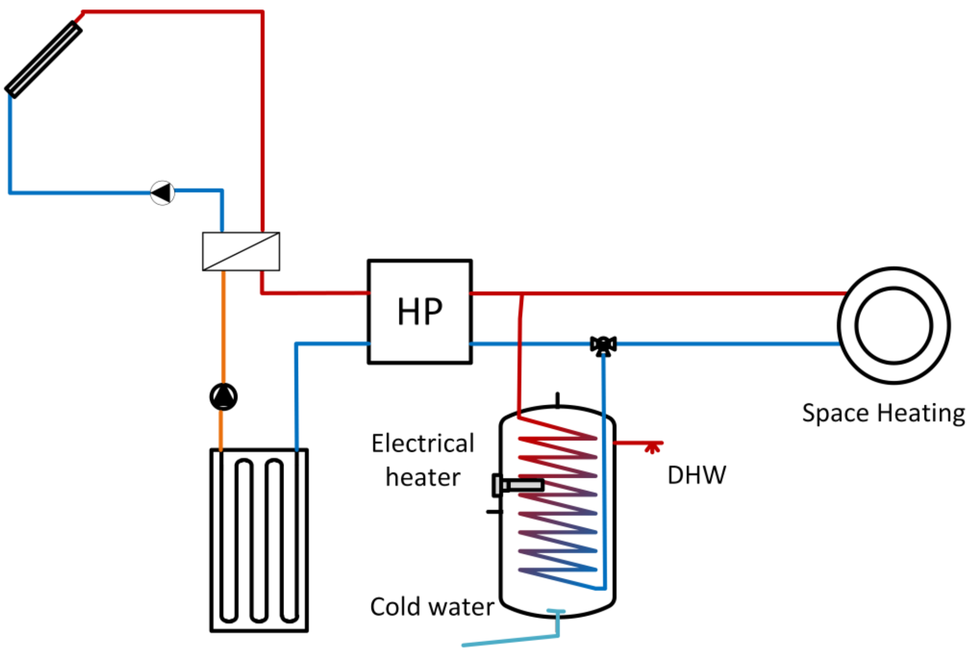


Figure 3.4 PVT for regeneration of ground source (schematic drawing).

There is some evidence that it is best to first use the heat of the collectors directly, before regeneration, also for PVT systems [14].

3.3 PVT on sink side of heat pump (parallel) or non-heat pump systems

3.3.1 Preheating

A PVT system can also generate heat in parallel to the heat pump. The advantage of this is that both heat sources can be used and the by the PVT system produced heat is used directly. However, if the control is not optimized, heat can also be destroyed e.g. if both systems charge the same storage in an unclever way. This is probably more suitable for covered PVT collectors.

3.3.2 Pools

A PVT system can also be used for pool heating. Because low temperatures are required, there is a good match with the demand.

3.4 Conclusion

To conclude a lot of different system configurations are possible. Besides the above mentioned main categories, combinations are also possible between parallel, serial and regenerative PVT heat pump systems. Part of the PVT inSHaPe project is focused on evaluating different concepts for the Dutch housing market.

4 Barriers and opportunities

PVT is a promising technology, as the exergy output of the module can be higher than that of solar thermal collectors or photovoltaic modules per square meter [2]. However, this alone is not a guarantee for becoming a dominant technology or conquering a large share of the market. In this chapter, we describe the current barriers and opportunities for PVT in the Netherlands as perceived by different stakeholders. To this end, 28 interviews of different stakeholders in the Netherlands were carried out. Among the interviewees were PVT, PV, solar thermal and heat pump producers, government parties, experts, installers and project developers. Furthermore, a literature study was carried out that included 15 research papers that were published between 2000 and 2016.

First the summary shows the overview of the different results. The results are then discussed per topic: Technological, Social, Economic and Political barriers and opportunities.

4.1 Summary

In general, many opportunities are identified in the literature and interviews, while also many barriers are mentioned. The literature seems more optimistic. Table 4.1 shows an overview of the most frequently mentioned barriers and opportunities.

According to literature, the advantages of PVT heavily outweigh the disadvantages. About half of the papers analysed, mention economic aspects for PVT as an opportunity as well as a high energy efficiency and yields. However, from the interviews it was concluded that the economic profitability is still low, while initial investment costs are high and that can be a hurdle. Some synergy effects in literature that would lead to lower pricing, like use of one installer and less material costs than both a separate PV and solar thermal system were not confirmed in the interviews. However, this does not mean it cannot grow into an opportunity in the future.

The main strength of PVT is based on the compactness: PVT is convenient or maybe necessary for those with limited roof area, as well as for consumers demanding the most energy per unit of area. In practice, many solutions do not require the full roof area, unless a transition to a zero-energy home is made. The main barriers for PVT are either in the technical or economic domain; technical improvements often directly improve the economics.

Table 4.1 Overview of opportunities and barriers found from literature (L) and interviews (I)

Strength & Opportunities	L* 15	I* 26		Weaknesses & Barriers	L 15	I 26
Compactness and yields	12	18		Complexity of system design and installation, difficulties in optimisation	9	20
Combination of PVT with heat pump	12	25		Reliability	8	6
BIPVT (Building integrated PVT)	8	2		Low economic profitability and high investment costs	8	21
Third-party owned business models (financing schemes)		3		Competition with PV and solar thermal collectors	5	8
Energy performance regulations for dwelling (EPC/BENG) and renewable energy targets	3	11		Lack of testing, standards and certification, EPC calculations unclear	4	9
Aesthetics (homogenous roof)	10	5		Conflict of interests real estate developer and resident		10
				Subsidy Landscape unclear	3	3
				Thermal yield hard to monitor		6
				Lack of awareness	8	12

* L – Literature, I – interview. In the literature also financial attractiveness and reduced cost because of combining installations are mentioned. However, this is currently not the case. Two installers might make it more complicated. In the interviews also an improved PV performance is mentioned, because of lower temperatures.

Table 4.1 shows that many barriers are faced by PVT technology. A PVT system is more complex than a PV system for both planning and installation. There are less rules of thumb and easy planning tools available. Demand for hot water and space heating lead to a higher complexity of dimensioning and optimization of the system configuration and component sizes. The thermal performance for a badly designed system as well as reliability can be low. Furthermore, there has been a lack of continuation of PVT producing companies, this can lead to distrust and lack of warranties. The complexity of the installations, mentioned many times by the interviewees was not foreseen by the literature. In fact, the literature opted for lower installation costs due to a combined installation, but in practice, this is far from happening. The main advantage of PVT is seen as the compactness of the modules and the ability to generate high yields. The combination with a heat pump showed to be the preferred system configuration and the aesthetic integration of PVT can be the first major improvement for PVT. Many interviewees argue that uncovered PVT cannot become financially attractive without a heat pump. Many interviewees expect a longer lifetime and higher electrical efficiency in PVT due to cooling, however this is insufficiently proven in practice yet.

The high investment costs are also a barrier, this could partially be overcome by introducing innovative, third-party owned business models, exploiting the system and omitting the threshold of the initial investment. Having low economic profitability is a common factor for innovations [15]. Having no clear regulations, standards and certifications is a common barrier for niche technologies [16]. Furthermore, the possible conflict of interest between real estate developers and residents retains the diffusion of renewable energy technologies. Despite the lack of a clear overview of calculations, it is expected that installing PVT could contribute greatly to the 2020 and future goals of the government. The social factors show that the aesthetics of a PVT system fits between a BIPV and a side-by-side system, and can be improved if the BIPVT development accelerates. The awareness for PVT is still low for both potential consumers as well as the installers, which should be the largest sales channel.

The conclusion can be drawn that PVT is still a technological niche. The early adopters and especially the innovators consider environmental benefits and being precursors by showing new innovations as requisites for adoption. The uncovered PVT module combined with a heat pump is currently the most promising system configuration according to most interviewees. The barriers of high investments costs and low economic profitability are less relevant for the innovators, while they attach value to the transition towards renewables and aesthetics of their building. Such a system would generate domestic hot water as well as space heating and can be a retrofit, renovation of part of a newly-built dwelling. Such a system with a heat pump is easiest installed in a new dwelling, reducing costs and complexity of the installation. The interviewees consider both the construction and renovation as possible markets for PVT. Furthermore, technological innovation and a growing market could help to overcome certain barriers.

4.2 Technological Factors

The technical challenges and opportunities for PVT are assessed below.

Compactness and Yields
The ultimate strength of PVT seems to be the high combined energetic yield per unit of area, mentioned in nearly all articles and interviews. As PVT can generate higher specific yields than the combination of PV and solar thermal together, a smaller area can be used to get the same yield, being especially convenient when the roof area is the limiting factor [17].

The thermal part of the PVT system produces useful heat. Thermal efficiencies and yields differ largely for different types of system. Good insulation in a covered flat-plate PVT collector leads to higher thermal yields at higher temperatures, but also in a lower PV yield. While for an uncovered PVT module and ambient heat exchanger, thermal yields may be high (but at lower temperature) and PV yields may be higher than that for regular PV modules.

Complexity
PVT systems combine PV conversion and solar thermal conversion. This increases the complexity of the system. Furthermore, dimensioning PV systems is simple and electricity production and area show a linear correlation. Dimensioning the PVT-thermal part is not straightforward (like for solar thermal systems), as it is dependent on demand and application. There are many different system configuration concepts for DHW and space heating and different sizes. Some concepts are not suitable for dwellings without floor heating. Also, there are no easy established design and simulation tools for PVT systems, while these are available for PV and solar thermal systems [17].

Furthermore, the installation of PVT is an unexpected technical barrier: While no issues were foreseen regarding installation in the literature, half of the interviewees stated that the installation of PVT is complex and argue that instead of requiring one installer (and thus saving on installation costs), two installers are needed for connecting the electrical and thermal parts, comparable to the side-by-side system. However, these installers do not usually work together, and two different companies or employees with either solar thermal knowledge or PV knowledge work in sequence on the roof instead of simultaneously, showing a major barrier for PVT.

Compared to the monitoring of PV, which is relatively easy and fashionable for consumers and those interested in technology according to the industry, monitoring thermal systems is more complicated, more expensive and less understandable for the consumer. According to several interviewees, thermal modelling is not available for their product yet, or too expensive for a residential size system. The challenge is to simplify the thermal monitoring and to integrate the thermal monitoring and electrical monitoring in one interface.

Reliability

Moreover, a major technical challenge is the overall reliability of the thermal part of a PVT system [2] [5]: due to low maturity and limited commercial available products, systems are quite new and not thoroughly tested, affecting the reliability, expressed in thermal performance and yields. The interviewees confirmed this, mentioning overall reliability and inconsistent thermal performance as technical barriers. The problem with this is that consumers want and expect comfort from their technology. During cold, dark periods the water storage is not heated fast enough by a PVT-heat pump combination to power for example multiple showers, while a gas-based boiler can. Consumers have higher willingness-to-pay for comfort and therefore often oversize their thermal capacity by increasing the volume of the storage tank.

The stagnation temperature refers to the maximum temperature of the fluid in the collector, when the heat losses to the environment equal the heat gains from the sun. This occurs when the storage tank is full (in e.g. holidays) or when a pump is off. Most flat plate solar thermal collectors have a stagnation temperature between 180°C to 210°C at 1000 W/m^2 irradiance [18]. The fluid in uncovered PVT stagnates at temperatures below boiling temperatures and therefore offer an advantage. Covered PVT can stagnate at 130°C [17]. With an average maximum operating temperature of 80°C for PV cells (found in the market study), stagnation can influence the performance and lifetime of PV cells and affect the lamination. A solution to deal with this is required (coatings, drainback) for covered PVT modules.

Several interviewees mentioned that the PVT industry is very dynamic, with companies attempting to enter the market and companies leaving the market. This stands in the way for long-term business. Therefore, several interviewees hesitate to do business with a PVT company as they question the viability of the company and thus the warranties on their products. When a PVT system breaks, the installer often executes the repairs. However, normally the installer can return to the producer for warranties. If the producer is out of business and has stopped granting warranties, the installer has to face the client. Finally, two interviewees claim that PVT has built up a negative reputation due to lack of warranties and yields not meeting expectation and promises, showing low reliability.

PVT in combination with a Heat Pump

An auxiliary heater is always required for a solar thermal or PVT system to boost temperatures and to guarantee enough heat production in winter. This can be a high-efficiency gas boiler or a heat pump. Nearly all interviewees and articles argued that combining PVT with a heat pump into one thermal system could be a great opportunity. However, the heat pump is considered the base of the thermal system, PVT is a seen a great addition for regenerating a ground source or as a direct source. Despite high initial investment costs of a system of this scope, this combination is very beneficial as the heat pump reaches a higher coefficient of performance (COP) due to the additional “free” solar heat. Furthermore, many PVT producers are interested in PVT heat pump systems.

BIPVT
One of the possible optimizations is integrating PVT to the building. PVT is mostly not really integrated in buildings, however, BIPVT is a promising innovation according to several interviewees to improve the aesthetics of the roof.

4.3 Economic Factors

Besides an enabling technology, a favorable market is required in order for PVT to develop (Johnson & Suskewicz, 2009). This is defined by economic barriers and opportunities, consisting of possible economic profitability, competitors, initial investment costs, possible market segments and the availability innovative business models, each addressed below.

Economic Profitability
Not much research has been conducted in the total cost of ownership (TCO) of a PVT system, defining the economic profitability. Several articles and interviewees argue that the economic profitability is low, mainly due to high investment costs and long payback periods, often exceeding the technical lifetime of the system. They argue that this is the main reason PVT is not widely installed. However, PVT could become a financially attractive investment in the (near) future for optimal configurations matching thermal demand, aimed at the right market segment [19] [17] [20] [21] [22].

Competition
PVT is not capturing a new market, but can compete on the PV and solar thermal market, which already have economically profitable products [20] [21] [23]. Solar systems are, in most situations, mutually exclusive: when a customer installs one system, they do not install another, due to limited roof area and homogeneity in panels bringing higher aesthetic value. Most interviewees agree that the combination of PV modules with an air source heat pump is the main future competitor for PVT Heat pump systems in the Netherlands, as this configuration is suited for the current energy building performance norm and easily fits in the design of new dwellings. The current system has the advantage over this 'all-electric' system that it does not require a large outdoor unit with ventilation, leading to noise disturbance. However, this PV with air heat pump combination is more widely known and currently has lower costs, thus is a real competitor for PVT in the coming decade.

Investment Costs
Besides overall economic profitability, investment costs need to be low in order for the majority of consumers to adopt. Many interviewees and articles state that the investment costs for PVT are too high, being a cause of the low economic profitability, as the investment costs are slightly or nearly earned back at the end of the lifetime. Furthermore, out of the offer for a PV or solar thermal system, the installation costs often take up quite some budget, ranging from 15-40%. However, combined installation of the electrical and thermal system can reduce peripheral costs and therefore the installation costs of a PVT system can eventually become lower than the sum of installing a PV and solar thermal system of the same size [22] [19] [5] [24] [25] . Mentioned in the section on the technical domain, the installation turns out to be a more difficult process in practice, retaining the savings in investment costs.

Market Segments
Limiting to residential installations and the low temperatures generated from PVT, the applications of domestic hot water, space heating and pool heating match the scope.

Looking at the Dutch building stock, the detached, semi-detached, terraced mid-row and terraced end-row make up 68% of the total, shown below in Figure 4.1 and contain mostly privately owned dwellings. Out of the 7 million dwellings, 60% is privately owned, 9% is privately rented and 31% is rented by housing organizations [26].

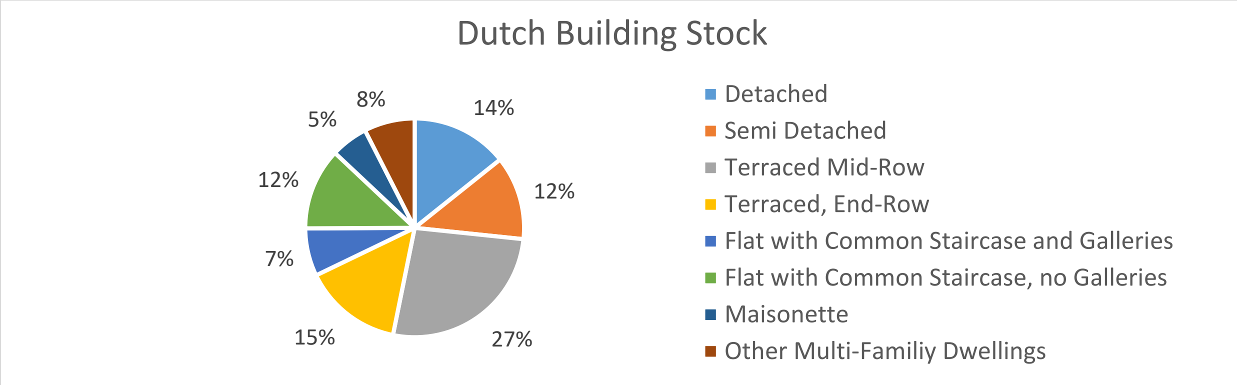


Figure 4-1: Distribution of Dutch Housing Stock

Three segments can be defined: First, those planning on equipping their dwelling with a PV system can install a PVT system instead, reducing their external heat demand and increasing the energy performance of their dwelling. Another group is those having PV installed already on their roofs, wanting to 'hybridize' these to PVT, by adding heat exchangers under the PV modules. This segment is called **retrofitting**, based on the PV installation market. This is considered a small market due to the system scope of PVT.

The second segment is those aiming for full-scale **renovations**, making their dwelling energy neutral. Organizations as *Thuisbaas* execute such projects and can install PVT as part of a large-scale renovation including many measures, for example disconnecting from the gas network. With the national goal of renovating 300,000 dwellings per year [27], this segment has high potential, stated by half of the interviewees.

The final segment is construction, thus, **newly-built dwellings**, which need to comprise to the energy performance regulations. About 0.7% of the building stock is being constructed every year, being 48,381 dwellings in 2016 [28]. Despite the small share of the building stock, half of the interviewees opt for construction as the market segment with highest potential, due to a good fit. Besides the contribution to the energy performance, another argument for this is possible simplification and cost reduction of the installation, as the roof is constructed as well.

Business Models

Current PVT systems require a high up-front investment and have a relatively high payback time. As the financial transaction is made up front and at once, potential customers lacking the liquidity for this are cut out. As this creates a barrier for consumers that do not have the resources to pay the initial investment upfront, the market potential is limited to consumers with high capital resources. Thus, financing schemes could be an option to include also those potential customers lacking liquidity and enlarge the market potential. This can be done by introducing spread payments, and, thus, changing the business model. Other parties, such as Energy Service Companies (ESCo), can take over the investment costs and make paying schemes for the resident, by exploiting the PVT system. This way, the burden of the initial investment costs is covered. This matches with the third party owned business model and recently also by property assessed clean energy financing (PACE) business model, including an energy system e.g. PVT in the mortgage of the dwelling. One of the real estate developers argued that they often work with ESCo's for newly built dwellings and full-size renovations, another mentioned that this decreases feasibility for the resident, as another party enters the financial chain and require a profit as well, increasing the costs for the final consumer.

4.4 Political Factors

Besides the technological and market factors, governmental policies are of influence on the introduction of technology, as the government is an important actor in steering the development of technologies (Rip & Kemp, 1998). The political domain includes all political and legal aspects of the technology, looking at political interests and specific product legislation.

Standards, Testing Procedures and Certification

Both PV modules and solar thermal collectors have their own standards, testing procedures and certifications. However, no specific testing method for PVT as a separate product category exists [3] [22] [19] [17] [5].

Due to PVT modules having both electrical and thermal qualities, they are tested for both systems separately. To test PVT systems for their thermal performance and safety, an annex has been made to the Solar Keymark in 2015 [29]. Michael et al. (2015) argue that there is still no complete testing for PVT anno 2015, despite the annex showing trustworthiness. Concluding, PVT testing procedures, standards and certifications are a barrier for producers selling a trustworthy product.

Energy Performance of Dwellings

The *Energie Prestatie Coëfficient* (EPC) norm is set by the national government to indicate the energy performance of a building. On a European level, this is matched to the European Energy Performance Building Directive (EPBD). This dimensionless number results from a calculation method including the heating, cooling, hot water, lighting and ventilation demand of a building, where a lower EPC value indicates a more efficient building. From 2020, the EPC norm is replaced by the *Bijna Energie Neutrale Gebouwen* (BENG) norm, being the *near Zero Energy Building* (nZEB) norm, which requires partial on site renewable energy generation. In the Dutch situation, instead of only one indicator as the EPC, this regulation consist of three indicators, where the value in between brackets refers to the requirement for dwellings [30] :

- The energy demand of a building (maximally 25 kWh/m^2)
- The primary energy consumption (maximally 25 kWh/m^2)
- The share of renewable energy generated on site (minimally 50%)

As stated by the interviewees, PVT is not yet fully compatible with the EPC and BENG calculations. Though efforts are being made to include this.

Finally, in the building sector, a conflict of interest often arises between the real estate developer and the resident, as mentioned by several interviewees. The real estate developer needs to fulfil the EPC/BENG norm to get the permit to construct a dwelling. However, in their vision, this condition should be met at lowest possible costs. A common situation is that a gas boiler or an air source heat pump and only several PV panels are installed (scenario 2), exactly conforming to the EPC norm and introducing two conflicts: In a row of terraced houses, the end-terraced houses have a slightly higher energy demand than the mid-terraced houses, leading to different amounts of PV/PVT modules, losing aesthetic value for the row of dwellings. Furthermore, the resident might desire generating more renewable energy in the dwelling. Not only to be sustainable but also for investment opportunities, for example installing 16 PV modules with a payback period of 7 years. If PVT is considered such an investment, this should be incorporated from the beginning of designing a house. In other words, the real estate developer is interested in the building phase, thus the financial transaction, and the resident in the exploiting phase, thus environmental and financial benefits in the long term. Several solutions are proposed. For instance, the real estate developer can exploit the dwelling and thus broaden the scope from the completion to the exploitation, including the energy costs, or involve an ESCo, or the real estate developer can unite the architect and possible residents in the designing phase of the dwelling.

Sustainability Goals

Governments set targets for both capacity of renewable energy and renewable energy generation on multiple levels. The European Union, national governments and local municipalities have set targets, including for example the 2020 and 2050 goal. One square meter of PVT can generate more energy than one square meter of PV or solar thermal due to the combined generation. Thus, every square meter PVT installed contributes more to these goals than PV or solar thermal collectors. Moreover, when considering the entire system, the level of self-consumption of PVT is higher than for PV, as all heat generated is used locally, whereas electricity is often exchanged with the grid for PV systems.

4.5 Social Factors

The social factors refer to the cultural and psychological barriers for the introduction and diffusion of innovations [15]. Two social factors arise and are explained below.

Aesthetics

The aesthetical value of a PVT system fits between the side-by-side system and the BIPV system. The opportunity is the increased aesthetical value over side-by-side systems, containing solar thermal collectors and PV modules on the same roof, as the PVT system has a homogeneous appearance. The solar thermal modules and PV modules currently do not have the same dimensions and colors, thus lacking homogeneity on the roof. Furthermore, as a PVT system is mostly dimensioned for thermal demand, additional PV modules can be placed with the same appearance. An article on the opportunities for PVT refers to these as “PVT-T” modules, being PVT modules with the same dimensions, appearance, and, thus, aesthetical value as the PVT module [25]. Currently, PVT is not yet optimally building integrated, and thus, has lower aesthetical value than BIPV systems installed on pitched roofs. However, research is already being conducted to create BIPVT, as mentioned above, increasing aesthetic value and financial value as roofing costs are partly avoided.

Awareness

Many consumers have heard of PV systems and to a lesser extend of solar thermal systems, but not of PVT systems, indicating the awareness for PVT is low. This was the case a decade ago [2] [21], and has not improved according to the interviewees. If awareness is raised people have more information on what kind of systems they can obtain and which kind of investments they can make. The industry confirms the lack of awareness amongst the public on PVT. The awareness can be improved by building demonstrators and conducting experiments [15]. However, even more important is the lack of awareness and knowledge of the installers. In the solar energy business, the installers are often the company that sells the product to the customer, not the PV or PVT module producer. Thus, if installers are not aware of the product, they cannot sell it and the largest sales channel is lost, or in this case, not even available.

5 Conclusion

The market for Photovoltaic-Thermal (PVT) systems and the number of PVT module suppliers is growing. This report presents a market survey of PVT modules and a classification of PVT heat pump systems. Furthermore, a list of barriers and opportunities was presented as perceived by a wide range of stakeholders in the Netherlands.

In our market investigation we found 54 different PVT module types that are currently being sold. 11 of these originate from the Netherlands. The largest share of these, roughly three out of four, are uncovered flat plate PVT collectors. The other types of PVT collectors in the market survey are covered PVT collectors, PVT collectors with vacuum tube and PVT-air collectors. Uncovered PVT collectors supply lower temperature heat in comparison with traditional covered solar thermal collectors. Therefore, systems with uncovered PVT collectors are often used in combination with heat pumps or for pool heating.

Opportunities and barriers were identified by interviews with 28 stakeholders in combination with a literature review. The stakeholders ranged from PVT, PV, solar thermal and heat pump producers to government parties, experts, installers and project developers. The main opportunities that were identified are a higher combined thermal and electrical yield per area. Furthermore, a combination with heat pumps and the possibility to achieve a (near) zero energy building with these technologies was seen as an opportunity. Also the more unified appearance offers opportunities to reach a better aesthetic roof. Several barriers were identified. The largest is the complexity of the system design, the optimization of the system and installation. Furthermore, the high upfront costs and the lack of standardization were mentioned.

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