Final report, 31 March 2017

PVT Wrap-Up

Energy systems with photovoltaic-thermal solar collectors

energieschweiz
Unser Engagement: unsere Zukunft.

Study commissioned by

SwissEnergy, 3003 Bern

Contractor

Institut für Solartechnik SPF
HSR Hochschule für Technik Rapperswil
8640 Rapperswil

Authors:

Daniel Zenhäusern
Evelyn Bamberger
Aleksis Baggenstos

daniel.zenhaeusern@spf.ch
evelyn.bamberger@spf.ch
aleksis.baggenstos@spf.ch

This study was commissioned by SwissEnergy.
Its content is the sole responsibility of the authors.

SwissEnergy, Swiss Federal Office of Energy (SFOE)
Mühletalstrasse 4, CH-3063 Ittigen. Postal address: 3003 Bern
Information: 0848 444 444; www.energieschweiz.ch/beratung
energieschweiz@bfe.admin.ch, www.energieschweiz.ch

CONTENTS

ABSTRACT

Solar radiation that reaches a photovoltaic cell is only partially converted into electricity, whereas a large proportion of the solar irradiation is converted into heat. Photovoltaic-thermal (PVT) solar collectors (also referred to as “hybrid collectors”) enable the collection and thus utilisation of this heat. PVT collectors thus produce solar electricity as well as solar heat on the same surface and attain high surface-related yield levels.

There are various types of PVT collectors. A distinction is made between collectors with and without transparent front cover for reducing heat losses (covered / uncovered). A distinction is also made between collectors from which heat is extracted via a heat transfer liquid or via air as a heat carrier medium.

The market overview carried out within the framework of this study identified 53 products, the majority of which (38) are uncovered liquid-cooled PVT collectors. The 5 Swiss manufacturers only produce this type of PVT collector. There are currently very few covered collectors on the market. The dissemination of uncovered PVT collectors with heat extraction by air is on the increase.

In Switzerland, around 300 PVT systems are currently in operation with a total surface area of approximately 15,000 m^2, almost all of which are equipped with uncovered liquid-cooled collectors. At present around 3,000 m^2 of PVT collector surface is installed per year in Switzerland. By way of comparison, around 100,000 m^2 of purely thermal solar collectors and approximately 2,200,000 m^2 of photovoltaic modules are installed each year.

PVT collectors are used on the one hand in conventional areas of solar thermal energy such as hot water (pre)heating systems (~ 30% of the systems in Switzerland) and systems for hot water heating plus space heating support (~ 15% of the systems in Switzerland). Uncovered liquid-cooled PVT collectors are however also specially used in heat pump systems where the low-temperature heat is primarily utilised on the source side of the heat pump. Particularly worthy of mention is the regeneration of geothermal boreholes (~ 30 percent of the systems in Switzerland).

Seven largish PVT systems with collector surface areas between 50 and around 3,500 m^2 were developed as part of, or in the framework of, flagship or pilot and demonstration projects promoted by the Swiss Federal Office of Energy (SFOE). In these systems the use of PVT collectors for geothermal borehole (ground source) regeneration, the preheating of groundwater in combination with heat pumps, and their use in combination with an anergy (low-temperature) network was studied. All these systems are closely monitored.

The magnitude of the annual solar yields of uncovered PVT collectors (with a low inclination angle ~ 10°) in Switzerland’s central plateau is around 160 kWh/(m^{2}a) (electricity) plus a thermal yield of ~ 150 kWh/(m^{2}a) (hot water), ~ 250 kWh/(m^{2}a) (hot water preheating) and 300-400 kWh/(m^{2}a) (ground source regeneration or preheating of groundwater). With systems for hot water preheating and those for ground source regeneration, thanks to module cooling, electricity yields about 5% higher in comparison with basic PV modules are obtained.

Around 20% of the approximately 600 contacted solar technology companies participated in the survey concerning PVT systems. Roughly 80% of the companies have not yet realised PVT systems, while the remainder were already involved in the realisation of one or more systems. The majority of the companies are interested in PVT systems and have a fundamentally positive view of the technology. The companies see challenges as well as improvement potential with respect to the increased use of PVT systems, especially relating to economic viability, know-how, familiarity with the technology and product design.

The report makes the following conclusions in particular:

- Fully developed products in the area of uncovered, liquid-cooled PVT collectors are available and can be successfully put into operation.
- Other types such as covered PVT collectors or air PVT collectors are not yet widely available and some of them need further technological development.
- Well-conceived system integration and control is essential, especially for uncovered collectors, in order to ensure that the collectors are operated at low temperatures, and thus efficiently.
- Know-how regarding the use of PVT collectors exists, but it needs to be more widely distributed.
- The implementation of PVT systems requires cooperation between various trades (photovoltaics specialists, solar thermal energy specialists, roofers, etc.). To ensure that this does not represent an obstacle, the necessary cooperation should be promoted in a targeted manner.
- Legal provisions stipulating a minimum proportion of renewable energy in buildings open up an opportunity for PVT technology.

1 INTRODUCTION

1.1 MOTIVATION FOR PVT SOLAR COLLECTORS

Photovoltaic thermal (PVT) solar collectors combine the use of photovoltaic and solar thermal energy in a single component, i.e. they produce utilisable solar electricity as well as utilisable solar heat. The fundamental idea of this form of combined solar energy harvesting can be illustrated by the optical properties of a typical photovoltaic cell made of crystalline silicon (Figure 1).

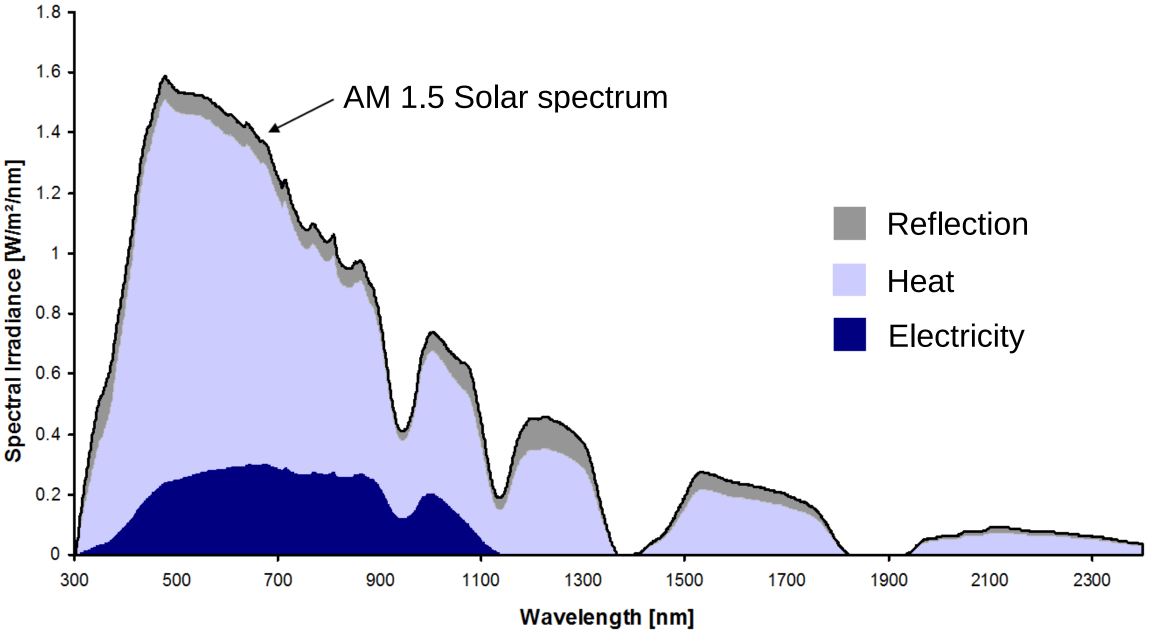


Figure 1: Spectral properties of a crystalline silicon photovoltaic cell. Source: P. Dupeyrat [1].

Approximately 10% of the solar irradiation on a crystalline photovoltaic cell is reflected and cannot be utilised. Around 17% of the remaining 90% of the irradiation that is absorbed by the cell can be converted into electricity and 73% are converted into thermal energy.[1] In a photovoltaic module the thermal output remains unused. It raises the temperature of the cell and can thus have a negative effect on the electrical efficiency of the module. In standard silicon solar cells, an increase in the cell temperature results in a reduction of the open-circuit voltage and a less pronounced increase of the short-circuit current (Figure 2). This results in a reduction of the electrical efficiency at the maximum power point. The corresponding temperature coefficients[2] of PV modules are between – 0.37%/°C and - 0.52%/°C for crystalline silicon modules and between - 0.25%/°C and - 0.29 %/°C for high-performance modules (HIT, SunPower) [2].

---

[1] The average efficiency of commercial cells based on silicon wafers is currently 17% [37]. Figure 1 applies to a cell with an efficiency of 15%.

[2] Relative reduction (or increase) of electricity output at maximum power point and irradiation of 1,000 W/m^2 for an increase (or decrease) in the module temperature versus 25° C.

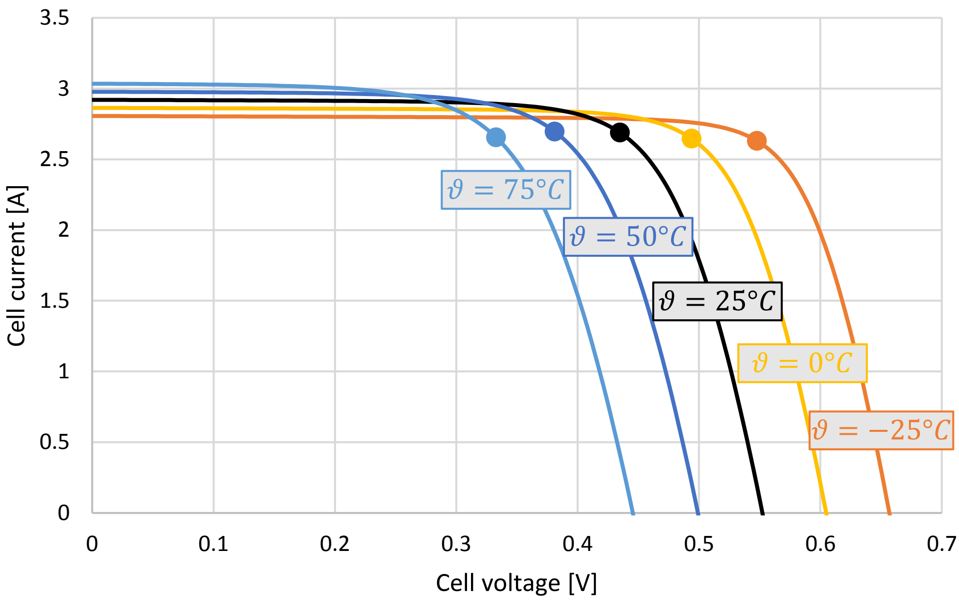


Figure 2: Characteristic curves of a crystalline silicon solar cell at different cell temperatures and constant irradiation of 1,000 W/m^2. The coloured dots indicate the respective operating points with the highest output (maximum power point, MPP).

The basic idea behind PVT collectors is to utilise the solar heat that is produced in PV cells. A simple option for accomplishing this is to attach a fluid-filled metal heat absorber on the rear of a PV module. Instead of the heat being released to the environment, it can then be transferred to a heat sink with the help of the heat transfer fluid. In this way, a large proportion of the solar energy absorbed by the cell can be utilised so that PVT collectors attain higher surface-specific yields than standard PV modules.

PVT collector

Motivation:

- Heat generated in PV cells is made useful.
- Extraction of heat increases the electrical efficiency of PV cells.

Benefits:

- Production of solar electricity and heat from the same surface.
- High surface-specific efficiency.

By extracting the heat produced in the cell, the electrical output of PV cells can simultaneously be increased, thus achieving a synergy effect. In the basic configuration of a non-heat-insulated PV module with a heat absorber attached to the rear, the cooling of the PV cells results in an increase in electrical output in comparison with a standard PV module.

1.2 BACKGROUND INFORMATION

In the field of applied research, efforts have been ongoing for around 40 years to develop various concepts for PVT collectors. For detailed information on this topic and to gain access to the corresponding scientific literature, please consult the articles in [3] and [4].

A number of PVT products have been brought onto the market in recent years and numerous manufacturers have been focusing attention on this technology. While new products are periodically being brought onto the market, some manufacturers have discontinued their activities in this field. For earlier market-related studies and more detailed literature, please refer to [5], [6] and [7].

The PVT market has gained momentum during the past few years. The main reasons for this undoubtedly include the sharply falling prices and the increasing dissemination of photovoltaics. Therefore it is those PVT products which in terms of design correspond to an expansion of standard PV modules that are the most highly represented on the market. In Switzerland, interest in PVT collectors has increased to a particularly notable extent in the context of the growing demand for ground source regeneration in heat pump systems based on geothermal energy.

In the field of PVT collectors, practical experience and know-how are still limited or widely dispersed in comparison with standard thermal solar and photovoltaic systems. However, interest on the part of clients, planners and installers is increasing, as is the demand for know-how and empirical values regarding the utilisation and performance potentials, primarily because PVT systems differ in a variety of significant ways from standard thermal or photovoltaic systems.

1.3 PROJECT

Based on the situation described above, the need was identified to produce an up-to-date overview of PVT technology. This study focuses on three key topics:

1. PVT technology: different types of PVT collectors, different methods of system integration, energy yields for different system configurations.
2. Overview of the market: available products, most important areas of application, current size and structure of the PVT market.
3. Findings from implemented PVT projects: seven pilot and demonstration projects supported through public funding, other realised systems, assessments by the involved players (manufacturers, planners, installers).

The study does not examine questions concerning the economic viability of PVT systems. Further, regarding the utilisation potentials of PVT collectors and the practical experiences obtained with PVT systems, it focuses strongly on the situation in Switzerland.

1.4 PROCEDURE

Based on previous market overviews ([5] and [6]), an updated overview of products was prepared, mainly by carrying out research on the Internet. Additional information was obtained from the Solar Energy Application Centre (SEAC) in Eindhoven (Netherlands), where a PVT collector market study is currently being carried out.

For the study of the PVT technology sector in Switzerland, selected interviews were conducted and a widespread written survey was carried out among manufacturers, planners, installers and system suppliers from the solar energy sector. The manufacturers segment also included companies in the neighbouring countries.

Information relating to the various pilot and demonstration projects was primarily drawn from the corresponding publications by the involved project consortia and from interviews with the involved players. To a certain extent, the findings were supplemented by the authors' own further assessments.

General information about PVT technology was obtained from studies of the existing literature and the experience of the authors.

To calculate the typical heat and electricity yields and extrapolate some of the measurement data, simulations were carried out with the aid of Polysun[3] software.

1.5 STRUCTURE OF THE REPORT

Chapter 2 deals with PVT collectors. It presents the results of the market overview (2.1) and describes the various types of PVT collectors (2.2). The situation regarding testing standards and certification is briefly described in Section 2.3. Section 2.4 deals with performance parameters of PVT collectors, together with heat and electricity yields that can be anticipated from the various types of collectors. Section 2.5 contains information concerning the subsidisation of PVT collectors.

Chapter 3 focuses on the various ways in which the different PVT collector types can be integrated into energy systems.

Chapter 4 describes each of the various pilot and demonstration projects, plus two other PVT systems, together with the main findings and operational experiences. It also presents additional examples of implemented systems.

Chapter 5 presents the results of the survey.

A detailed list of the products included in the market overview is presented in the appendix.

---

[3] Polysun simulation software, www.velasolaris.com

2 PVT COLLECTORS

2.1 MARKET OVERVIEW

The market for PVT collectors is very small in comparison with the photovoltaics and solar thermal energy markets. For example, in Switzerland around 3,000 m^2 of PVT collector surface were installed per annum in 2015 and 2016,[4] compared with around 100,000 m^2 of installed thermal solar collectors and 2,200,000 m^2 of photovoltaic modules [8]. Based on research carried out within the scope of this study, the estimated total number of installed PVT systems in Switzerland is around 300.

The number of manufacturers of PVT collectors is also relatively small, as is the production volume per manufacturer. A market research revealed 53 manufacturers of PVT collectors in 17 countries. No manufacturer dominates the market, nor is there a dominant market. The market research was carried out with a focus on Switzerland and Europe and thus does not claim to be exhaustive. There are undoubtedly other manufacturers that are not included here, especially small producers and those in other parts of the world. The majority of the manufacturers in the market overview come from Germany (10), followed by Italy (8) and France (5). Switzerland shares third place with 5 manufacturers: Meyer Burger, Poly Solar Solutions, Caotec, Soltop and Max Roth M&M Energie. Thus, together with three Austrian manufacturers around 60% of the producers come from Switzerland or one of its neighbouring countries (Figure 3).

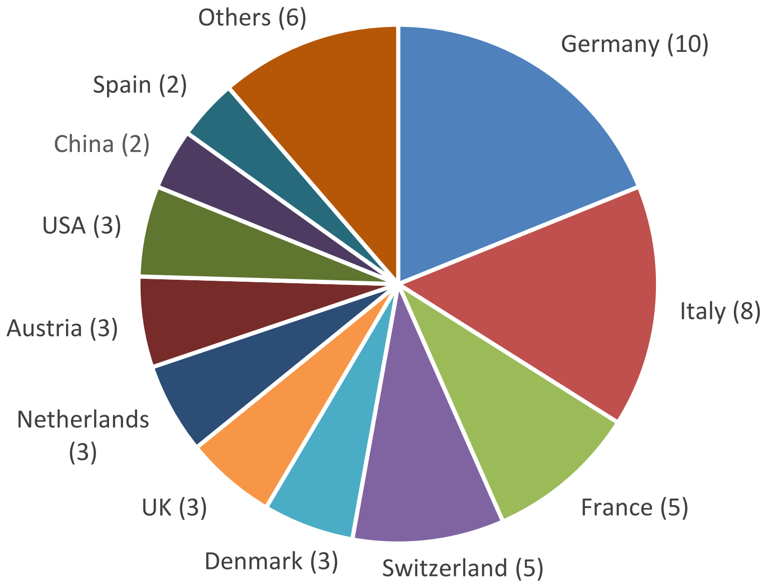


Figure 3: PVT manufacturers by country.

---

[4] Estimate based on figures for 2016 collected within the scope of this study, as well as on unpublished data collected within the framework of the 2015 solar energy market survey [8] and on the provisional data collected within the framework of the 2016 solar energy market survey.

Approximately half these manufacturers possess Solar Keymark certification for at least one of their PVT collector products. Only a handful of the other 50 percent of the manufacturers have Solar Keymark certification, to be specific 3 out of a total of 22. The full market overview is presented in the appendix.[5] The data were derived from the manufacturers' data sheets and websites, as well as from Solar Keymark certificates where applicable, and in a few cases from information provided by telephone. There are clear differences in the degree of professionalism of the manufacturers. Almost all of them have a product data sheet, but the quality and completeness of the cited data differ considerably. Many of the manufacturers offer purely thermal solar collectors or PV modules and list PVT collectors merely as supplementary products. However, there are also companies originating from other sectors, as well as manufacturers, who solely produce PVT collectors. In addition to collectors, most of the companies also offer additional components such as mounting systems, hot water storage tanks and accessories for integration into the system.

Changes in the market have taken place in comparison with previous market surveys ([5] and [6]). In some cases, manufacturers have ceased their production of PVT collectors, been taken over by other manufacturers or become insolvent. But there have also been newcomers to the market in the past few years, and on balance the number of manufacturers has increased slightly. With respect to the utilised technologies, major shifts or tendencies in the market have not become apparent. The distribution by collector type is roughly unchanged.

The various types of PVT collectors are described in detail in chapter 2.2 , together with a list of products of each type. Based on the full market overview it can already be stated that the vast majority of the manufacturers offer collectors for liquid heat transfer media. Only 9 offer collectors that use air as the heat transfer medium. In one case, water and air can be combined: there are air channels in addition to a water absorber (Millennium, Israel). Among the liquid-cooled collectors, 38 do not have a cover to prevent convection, compared with only 6 that are equipped with a cover. Only one manufacturer offers both a covered and an uncovered collector (Solimpeks, Turkey). All Swiss manufacturers offer uncovered collectors only (Table 1).

Table 1: Overview of manufacturers of PVT collectors by region and type of collector

	No. of manufacturers	**Liquid-cooled uncovered collectors, without rear insulation**	**Liquid-cooled uncovered collectors, with rear insulation**	**Liquid-cooled covered collectors**	**Air collectors**
Switzerland	5	4	1	0	0
Neighbouring countries	26	10	9	2	5
Rest of Europe	13	4	3	2	3
Rest of world	9	3	4	2	1
Total	53	21	17	6	9

---

[5] In the Appendix, liquid-cooled collectors are listed as "flat-plate collectors".

2.2 COLLECTOR TYPES

The combined production of solar electricity and heat can be accomplished in a variety of ways. The distinguishing features of the various PVT collector types include the utilised heat transfer medium, measures to reduce the heat losses and the connection between the PV cells and the heat absorber. The PVT collectors considered in this report can be divided into three categories which are described in detail below:

Type 1: Liquid-cooled uncovered PVT flat-plate collectors
Type 2: Liquid-cooled covered PVT flat-plate collectors
Type 3: Air-cooled PVT flat-plate collectors

Other types of PVT collectors are briefly described in chapter 2.2.4 .

2.2.1 Type 1: Liquid-cooled uncovered PVT flat-plate collectors

2.2.1.1 Design

This is the most common type of PVT collector. It uses a heat transfer liquid and is uncovered, i.e. it does not have a transparent or translucent cover on the front which would create an air gap between the cells and the exterior and thus reduce convective heat losses. A typical example of a PVT collector of this type is depicted in Figure 4. As a rule, the design of the PV component resembles that of a PV module. PV cells are laminated in between a front glass and a rear foil. A liquid-filled metal or plastic heat absorber is attached (e.g. with adhesive) to the rear of the module. As with solar thermal absorbers, the heat absorbers can be in various forms (e.g. roll-bonded, meander, harp, extruded double-skin sheet). In the case of a metallic heat absorber, the material layers placed between the absorber and the PV cells have to perform the function of electrical insulation in addition to providing the thermal coupling. The rear of the PVT collector can also be equipped with heat insulation.

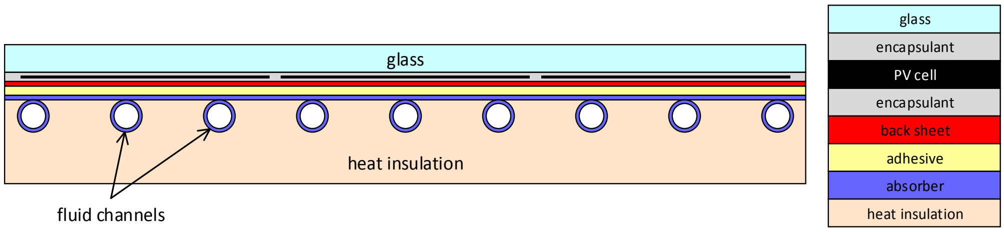


Figure 4: Schematic diagram of a typical liquid-cooled uncovered PVT flat-plate collector.

2.2.1.2 Advantages and disadvantages

The stagnation temperatures (i.e. maximum attainable temperatures) of collectors of this type are within the range of temperatures reached by uncooled PV modules. As a rule, these are below 90° C (without rear insulation) or below 120° C (with rear insulation).[6] In comparison with conventional solar thermal flat-plate collectors or type 2 PVT collectors, this offers the advantage that in stagnation status no steam is formed, which means material wear and tear in the collector cycle is low. This reduces the complexity of the system and can save costs associated with the hydraulic components. For example, low-cost plastics can be used for the piping and the dimensions of the diaphragm expansion tank can be reduced.

---

[6] The effective values depend on the selected product, as well as on the location and the mounting situation.

The low level of shielding against heat losses also results in the disadvantage that this type of collector can deliver heat efficiently only at relatively low temperatures, which means that its scope of use is limited to low-temperature applications.

This type of collector is similar to a PV module. Many products are manufactured on the basis of a standard PV module. This means it is possible to benefit from the high degree of standardisation in the PV sector and thus to manufacture relatively low-price products.

2.2.1.3 Market

The majority of products available on the market (38) are this type of collector. Many of them (21) do not have rear insulation, though two models are available with this feature as an option (Tables 2 and 3). In Switzerland, 5 manufacturers produce this type of PVT collector.

The production of uncovered PVT collectors is almost always based on a standard PV module with glass-backsheet combination, which is then expanded with an absorber on the rear (Figure 5). The combination is usually effected through lamination, gluing or clamping.

Some manufacturers offer a thermal absorber as a hybrid attachment for PV modules as an option or exclusively (4 manufacturers in each case).

Almost all the surveyed manufacturers use solar cells based on crystalline silicon, monocrystalline silicon being used more often than polycrystalline silicon. Some manufacturers also have both types in their programme. Furthermore, the majority offer differing electrical performance classes. Only one manufacturer uses amorphous silicon.

Aluminium, copper, stainless steel or plastics (polyurethane, polypropylene) are the most common materials for absorbers. The designs of the absorbers correspond to those known from solar thermal collectors, i.e. roll-bonded, harp, meander and full-surface flow-through (fully wetted) absorbers are used. For some products the design is not specified.

The collector widths range from 0.40 to 1.24 metres, and lengths from 1.20 to 2.20 metres. This includes two collector products that are designed to be fully integrated into the roof and are similar in appearance to a roof tile (Energyntegration, Italy; PA-ID, Germany; cf. Figure 6). The majority of uncovered PVT collectors have the standard dimensions of a 60-cell PV module: approx. 1.00 x 1.65 metres. In most cases the depth is a maximum of 50 millimetres and the empty weight varies considerably between 9.5 and 40 kilograms.

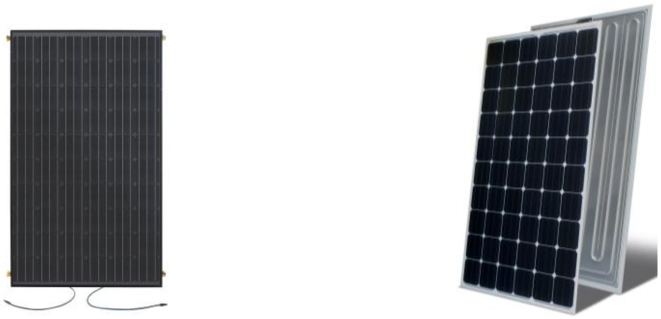


Figure 5: Examples of liquid-cooled uncovered PVT collectors. Left: PIK® Kombi-Solar-Kollektor from Poly Solar Solutions (Switzerland). Right: Meyer Burger Hybrid (Switzerland). Photos: Poly Solar Solutions AG, Meyer Burger AG.

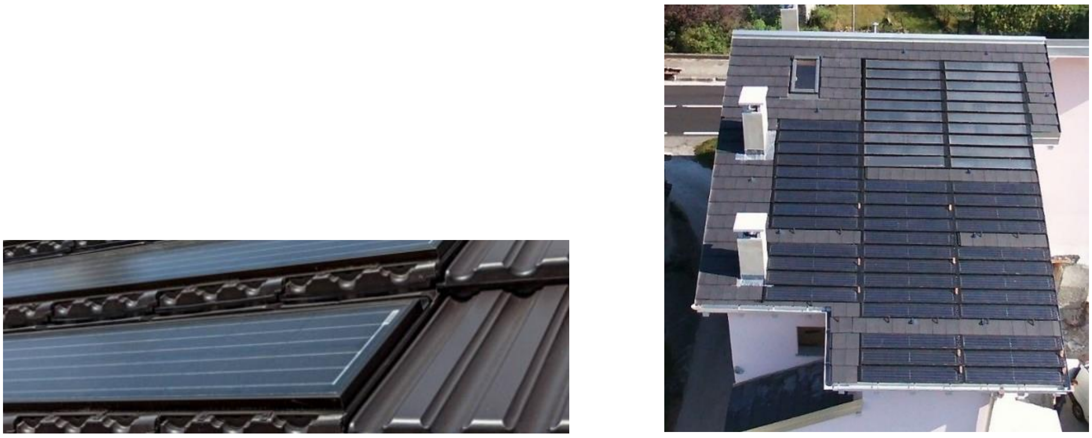


Figure 6: Uncovered collectors as roof tiles. Left: MS 5 2Power, from PA-ID (Germany). Photo: Bedachungshandel Tritschler AG. Right: EY Hybrid from Energyntegration (Italy). Photo: Energyntegration S. r. l.

Table 2: Overview of manufacturers of liquid-cooled uncovered PVT flat-plate collectors without rear insulation.

Manufacturer	Country	Model(s)
Meyer Burger AG	Switzerland	Hybrid
Poly Solar Solutions AG	Switzerland	PIK® Kombi-Solar-Kollektor / PIK® thermischer Kollektor K1
CAOTEC	Switzerland	Hybrid Kollektor
Max Roth M&M Energie	Switzerland	
Building Energy	Belgium	HYBRIDE PV/T
Easy Solar ApS	Denmark	Black Line 250 – 400 W BIPV Hybrid / prev. Aluminiumsabsorber-Hybrid
Solarzentrum Allgäu KG	Germany	WIOSUN Kombimodul PV-Therm monocrystalline / polycrystalline
VALVO GmbH	Germany	PVT 60P
GeoClimaDesign AG	Germany	Sunbag (hybrid attachment for PV modules)
Splus2 GmbH	Germany	Splus2 (hybrid attachment for PV modules)
POWER KOMBI MODULE GmbH	Germany	PKM 96M (BK)
Solaire2G/DualSun	France	DualSun Wave
Pegoraro Energia Srl	Italy	H-NRG
F.D.E. Solar S.r.l.	Italy	FDE-HYBRID
Triple Solar BV	Netherlands	Triple Solar hybrid panel
solator C.Bösch GmbH	Austria	PVTHERMAU280 / 300, PVTHERMIN190EU / CN, hybrid attachment for PV
KIOTO Photovoltaics GmbH	Austria	PVT Hybrid 900Wp
Energetyka Solarna ENSOL Sp. z o.o.	Poland	E-PVT 2,0
Millennium Electric	Israel	MSS – MIL-PVT-340W-MO3 / 320W-MO2 / 190W-MO2 / 195W-MO3
ecoTec Energy AG, Inc.	USA	coolPv CPV288
TES Group Limited	China	TESZEUS PV-T

Table 3: Overview of manufacturers of liquid-cooled uncovered PVT flat-plate collectors with rear insulation.

Manufacturer	Country	Model(s)
SOLTOP Schuppisser AG	Switzerland	Soltop Alpha hybrid ID
PA-ID GmbH	Germany	2Power HM 1000 Mono Black / Nelskamp MS 5 2Power
res – regenerative energietechnik	Germany	res-PV++ / res-PV++ 300 / res-PV++ Projekt
Nieberle Solar	Germany	ISIEtherm WRS 200-ST48F/250-ST60F/R 200 M/ISIEtherm (hybrid attachment)
Natural Technology Developments	UK	Solar Angel DG-01
Minimise Generation	UK	PowerHybrid 240
FOTOTHERM S.r.l.	Italy	Serie Cs / Serie AL
BRANDONI SOLARE S.p.a.	Italy	HYBRID SOLAR PANEL SBP-XXX
Energyntegration S.r.l.	Italy	EY-Hybrid
MAS srl	Italy	MAS roof Conditioned Photovoltaic
CGA Technologies Srl	Italy	inside Hybrid Solar Thermal (hybrid attachment for PV modules)
SUNERG Solar s.r.l.	Italy	TESP-P60
SolarTech International B.V.	Netherlands	Energiedach®-Plus
Solimpeks Solar Energy Corp	Turkey	Volther PowerVolt
SunDrum Solar	USA	SDM 100 (hybrid attachment for PV modules)
ChinaLand	China	CHN-72M(PVT)
Tractile Pty Ltd.	Australia	Eclipse Solar Tile - TR-EC-ST1001-PV76M

2.2.2 Type 2: Liquid-cooled covered PVT flat-plate collectors

2.2.2.1 Design

The design of this type of collector (Figure 7) essentially corresponds to that of a solar thermal flat-plate collector. Here the PV cells are used instead of a spectrally selective absorber coating. The combination of PV cells and heat absorbers is similar to that of type 1 collectors. “Mechanical” protection of the cells (e.g. with a laminated glass panel) is not necessary, but in the same way as a thermal flat-panel collector, this type of collector is fitted with an additional transparent (or translucent) cover which reduces convective heat losses on the front of the collector. Thanks to efficient thermal shielding of the absorber towards the environment, higher temperatures can be attained with this type of collector. At the same time, the stagnation temperatures are significantly higher and typically reach levels in the region of 150° C.[7] This results in a higher thermal load on the utilised materials in the event of stagnation. For this reason, the use of a standard PV module as photovoltaic component is not normally possible. The EVA (ethylene vinyl acetate) that is typically used as encapsulating material would rapidly degrade at the cited temperatures. Furthermore, the utilised adhesives have to have a correspondingly high temperature resistance. Instead of the use of materials with high temperature resistance, measures to protect against high stagnation temperatures can be applied, though these increase the complexity of the collector or system.

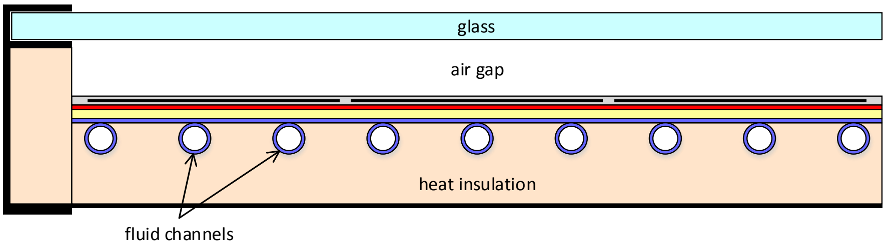


Figure 7: Schematic diagram of a typical liquid-cooled covered PVT flat-plate collector.

---

[7] However, the temperatures are lower than those in thermal flat-plate collectors because the PV cells produce higher thermal radiation losses compared with a spectrally selective absorber.

Besides the described design, there exist products where the PV cells are laminated on the underside of the glass cover and a coated absorber is used in the same way as in a pure solar thermal collector. In this case only a very weak thermal coupling exists between PV cells and absorbers. The heat generated in the PV cells only contributes to a minor extent to the useful heat output and the cells are not cooled. With this concept, useful heat is mostly generated from solar radiation penetrating between the cells and reaching the absorber. The cell spacing or surfaces not occupied by cells is usually larger than in the case of PV modules.

2.2.2.2 Advantages and disadvantages

This type of collector is able to supply useful heat at higher temperature levels than type 1. It therefore has a broader scope of application and can be used in a similar manner to a solar thermal flat-plate collector.

However, it is a more complex product and places higher requirements on the utilised materials. Its manufacture cannot benefit to the same extent from the high degree of standardisation in the PV sector, and this means that it tends to be more difficult for these products to be rendered economically competitive.

2.2.2.3 Market

There are no manufacturers of covered PVT collectors in Switzerland, and in the neighbouring countries there is only one in Germany (Hörmann, cf. Figure 8 and Table 4) and one in Austria (3F Solar Technologies). Only one of the six manufacturers of PVT collectors included in the survey has Solar Keymark certification for its PVT product, namely Solimpeks.

There are products in which the PV cells are attached to the absorber, as well as others in which the PV cells are attached to the underside of the glass cover.

Here, too, both monocrystalline and polycrystalline silicon cells are used. Aluminium or copper are used as absorber materials. One manufacturer uses a harp absorber and another manufacturer a full-surface absorber, while the others do not specify the design.

Covered collectors tend to be larger than uncovered ones. The dimensions range from 0.72 to 1.66 metres in width and 1.38 to 2.46 metres in length. Due to their design the depth is greater (between 85 and 111 mm) and the empty weight is usually higher (between 17 and 95 kilograms).

Figure 8: Examples of liquid-cooled covered PVT collectors: left, Volther PowerTherm from Solimpeks (Turkey); right, Solarhybrid from Hörmann (Germany). Here only a portion of the collector surface is covered with PV cells. Photos: Solimpeks Solar Energy Corp. and Hörmann-Barkas Metallbau GmbH.

Table 4: Overview of manufacturers of liquid-cooled covered flat-plate collectors.

Manufacturer	Country	Model(s)
Hörmann-Barkas Metallbau GmbH	Germany	PT-U 250/145 / PT-U 250/193
3F Solar Technologies GmbH	Austria	Solar One Hybridkollektor
SELA SOLAR, S.L.	Spain	SELA SOLAR M-240PVT
EndeF Engineering S.L.	Spain	Ecomesh
Solimpeks Solar Energy Corp	Turkey	Volther PowerTherm
Power Panel Inc.	USA	PVT1

2.2.3 Type 3: Air-cooled PVT flat-plate collectors

2.2.3.1 Design and market

In this type of collector, air is used instead of liquid as a heat transfer medium. Similar to the case of liquid-cooled PVT collectors, both covered and uncovered versions can be realised

A distinction has to be made between collectors or systems that draw in and heat up outside air, and those that use air as a circulating heat transfer medium.

The market survey identified nine manufacturers in this segment (cf. Table 5), five of which have Solar Keymark certification for their PVT air collector. The products are described in more detail below.

They are all based on standard PV modules and the utilisation of a portion of the heat produced in the PV cells through the cooling of the rear of the module. None of the products are equipped with an additional cover on the front for reducing heat losses. Like uncovered collectors with a liquid heat transfer medium, these PVT collectors are therefore suitable for low-temperature applications and reach stagnation temperatures that are not significantly higher than the maximum operating temperatures of uncooled PV modules.

The French company Base offers air PVT collectors that are ready for installation as a finished component (Figure 9). With this product, it is possible to realise both open circuit (fresh-air heating) and closed circuit (use of air as circulating heat transfer medium) systems.

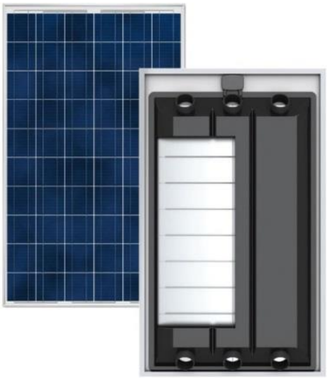


Figure 9: Air-cooled PVT flat-plate collector as finished component: Cogen'air from French company, Base. Photo: BASE/Sellande.

With R-Volt from Systovi (France) and GSE Air'System from Groupe Solution Energie (Figure 10) the combination of airflow and the PV module is only implemented after assembly on the roof. A plastic half shell is used as substructure for a PV module. The air that transfers the heat flows between the rear of the module and the plastic half shell.

Figure 10: Air PVT systems R-Volt from Systovi (left) and GSE Air'System from Group Solution Energie. Photos: Systovi and Groupe Solution Energie.

Under the name Easy Roof Boost'R, as an extension of its Easy Roof PV in-roof mounting system, IRFTS (France) offers a solution for active, evenly distributed rear ventilation of the modules and collection of the heated exhaust air.

With its products SolarWall (for façades) and SolarDuct (for flat roofs), Conserval Engineering Inc. (Canada) offers two solar thermal air collector systems for heating fresh air (Figure 11). The side exposed to the sun is a perforated black trapezoidal plate. Both systems can be used as a substructure for PV modules and thus implemented as PVT systems.

Figure 11: Air PVT systems "SolarDuct PV/T®" (left) and "SolarWall PV/T®" (right) from Conserval Engineering. Photos: Conserval Engineering.

The systems produced by Systovi, Groupe Solution Energie, IRFTS and Conserval Engineering Inc are all of the open circuit type and are used for heating incoming fresh air.

In addition to the described air PVT systems there are also solar thermal air collectors in which only a small portion of the collector surface is equipped with PV cells, the electrical output of which is used for operating the fan (cf. Figure 12). These collectors offer the advantage of fully autonomous operation and are often used for the ventilation and partial heating of holiday homes. Unlike the other products, they do not deliver any useful electrical output except for the operation of the fans, and therefore cannot be classified as "PVT collectors" *per se*. In view of this they have not been examined in detail in this study.

Figure 12: Twinsolar solar-air collector from GRAMMER Solar, with PV cells for fan operation. Photo: GRAMMER Solar.

2.2.3.2 Advantages and disadvantages

The use of air as a heat transfer medium offers certain advantages. In particular, in contrast to liquid-based systems there is no formation of steam and high system pressures at stagnation temperature. There is also no danger of frost. This means lower demands on the utilised materials and the complexity of the system, as well as the elimination of costs for the heat transfer fluid. In systems in which heated air is directly used for heating purposes, there is normally also no longer a need for an additional heat exchanger. This saves costs and increases the efficiency of the collector (thanks to lower operating temperatures).

These are therefore technically uncomplicated and thus low-cost solutions for the combined production of solar heat and electricity.

The main disadvantage is the low heat capacity of the air. Related to the volume, the heat capacity of air is lower than that of water by a factor of 3,400. This means that significantly higher volume flows, and thus duct cross-sections, are required than with a liquid heat transfer medium.

Table 5: Overview of manufacturers of air-cooled PVT flat-plate collectors.

Manufacturer	Country	Model(s)
Scanheat A/S	Denmark	Scansun XL 250 / XL 400 / XL 400 LD / XL 900
Solar Venti A/S	Denmark	Standard SV3 / SV7 / SV14 / SV14K / SV20 / SV20K / SV30 / SV30K
Grammer Solar GmbH	Germany	TWINSOLAR compact 2.0 / 4.0 / 4.5 / 6.0
Systovi	France	R-VOLT
GROUPE SOLUTION ENERGIE	France	GSE AIR'SYSTEM
BASE / SELLANDE	France	Cogen'Air
IRFTS	France	EASY ROOF Boost'R
SCX Solar B.V.	Netherlands	SCX Soloroof ® Home Edition
Conserval Engineering Inc.	Canada	SolarWall PV/T / SolarDuct PV/T

2.2.4 Concentrating PVT systems and new developments

In addition to the described PVT flat-plate collectors, there are also concentrating PVT systems. Here, (high-efficiency) PV cells are integrated in the receiver of a concentrating system, e.g. parabolic troughs or heliostats (Figure 13).[8] This requires a single or dual axis tracking system. Concentrating systems can provide heat at high temperatures which can, for example, be used for industrial processes. As a rule, due to their high system complexity they are not used for supplying energy to houses and apartment blocks. They also only use direct sunlight, which is why they are mainly installed in southern regions where there is abundant sunshine.

Some products are currently in the development stage or already exist as prototypes, e.g. a covered collector from SolVar Systems (Armenia). The British company Naked Energy is developing a solution that is the first of its kind. It concerns the installation of PV cells on the heat exchanger (absorber) of a vacuum tube collector. Another British company, Photonomi, also uses tube collectors, Hone 501 Thermal/Electric. Here a thin-film PV module is placed behind the tubes. In this way, heat and electricity can be produced in a single product, though the two technologies are not directly coupled.

Figure 13: Z10 CHP concentrating PVT system from Suncore (left) and "virtu" PVT vacuum tube collector from Naked Energy. Photos: Suncore U.S. and Naked Energy.

2.3 TESTING STANDARDS AND PRODUCT CERTIFICATION

In order to assess and compare the quality and performance of various PVT products they have to be tested under clearly and uniformly defined conditions. PVT collectors are still classified as PV modules and thus have to meet all the applicable safety requirements of the latter. They can also be tested as thermal collectors and certified in accordance with Solar Keymark (an internationally recognised quality label for solar thermal collectors). A testing standard for PVT collectors that would have to incorporate PVT-specific aspects such as specific degrees of thermal stress or the reciprocal influence

---

[8] Concentrating photovoltaic (CPV) systems always require active cooling of the cells. They can therefore be classified as concentrating PVT systems.

of thermal and electrical output, does not yet exist. This makes it difficult to assess the quality of the products and can thus represent an obstacle to their widespread use. However, efforts to develop a corresponding standard are currently in progress (cf. PVT-Norm project [9], including references). Certain specific testing rules relating to PVT collectors have already been defined for certification in accordance with Solar Keymark.

2.4 PERFORMANCE AND YIELDS

2.4.1 Performance parameters for PVT collectors

2.4.1.1 Electrical performance parameters

Most PVT collectors or the PV modules used therein are certified in accordance with IEC 61215 (for crystalline silicon PV modules) and IEC 61730 safety qualification. This means that the reported electrical output is also standardised. It is expressed in Watt peak (Wp) under defined Standard Test Conditions (STC). It corresponds to the collector's electrical output at 1,000 Watts solar radiation per square meter, 25° C collector temperature and operation at maximum power point (MPP). As a rule, manufacturers also indicate the temperature coefficient, i.e. the temperature dependency of the output at MPP and STC.

2.4.1.2 Thermal performance parameters

The indication of the thermal output of PVT collectors is less standardised. While many manufacturers provide data relating to the thermal output of their products, the conditions under which the figures apply are often insufficiently defined. Good comparisons can be made of products if their output has been tested in accordance with ISO 9806 (or its predecessor, EN 12975-2) for thermal solar collectors. This applies in particular to products with Solar Keymark certification.

In accordance with ISO 9806, thermal output is indicated according to the type of collector and the selected test procedure in the form of a characteristic curve model (set of performance parameters) (Tables 6 and 7).

Table 6: Thermal performance parameters for the various characteristic curve models.

Characteristic curve model	**PVT collector type**	**Test procedure**	**Perform. parameter**	**Unit**	**Description**
1	Uncovered (liquid or air cooled with closed air circuit)	Stationary	η_0	-	Maximum thermal efficiency
			b_u	s/m	Wind dependency of max. thermal efficiency
			b_1	W/(m²K)	Heat loss coefficient
			b_2	Ws/(m³K)	Wind dependency of heat loss coefficient
2	Covered (liquid or air cooled with closed air circuit)	Stationary	η_0	-	Maximum thermal efficiency
			a_1	W/(m²K)	Linear heat loss coefficient
			a_2	W/(m²K²)	Quadratic heat loss coefficient
3	All collectors with closed circuit	Quasi-dynamic	$\eta_{0,b}$	-	Maximum thermal efficiency related to direct irradiation
			c_1	W/(m²K)	Linear heat loss coefficient
			c_2	W/(m²K²)	Quadratic heat loss coefficient
			c_3	Ws/(m³K)	Wind dependency of heat loss coefficient
			c_4	-	Influence of longwave radiation exchange
			c_5	Ws/(m²K)	Effective heat capacity of the collector
			c_6	s/m	Wind dependency of max. thermal efficiency
			$K_b(\theta_L,\theta_T)$	-	Incidence angle modifier (IAM) for direct irradiation
			K_d	-	Incidence angle modifier (IAM) for diffuse irradiation
4	Air collector (uncovered) with outside air intake (parameter values to be indicated for each of several volume flows)	Stationary	η_0	-	Maximum thermal efficiency
			b_u	s/m	Wind dependency of maximum thermal efficiency

The thermal output of a PVT collector $\dot{Q}$ depends greatly on the operating and surrounding conditions. Depending on the type of collector, the most significant influencing factors are the solar irradiation per collector surface G, the longwave irradiation per collector surface E_L, the wind speed above the collector field u, the ambient temperature ϑ_a and the mean fluid temperature in the collector ϑ_m.

Modelling of the collector output is carried out on the basis of the following characteristic curve models. Here A stands for the assumed reference area, usually the gross area of the collector.

Table 7: Various mathematical characteristic curve models for describing the thermal collector output.

Characteristic curve model 1	$\frac{\dot{Q}}{A} = G'' \cdot \eta_0 \cdot (1 - b_u \cdot u) - (b_1 + b_2 \cdot u) \cdot (\vartheta_m - \vartheta_a),$
Characteristic curve model 2	$\frac{\dot{Q}}{A} = G \cdot \eta_0 - a_1 \cdot (\vartheta_m - \vartheta_a) - a_2 \cdot (\vartheta_m - \vartheta_a)^2$
Characteristic curve model 3	$\frac{\dot{Q}}{A} = \eta_{0,b} \cdot K_{\theta,b}(\theta_L, \theta_T) \cdot G_b + \eta_{0,b} \cdot K_{\theta,d} \cdot G_d - c_6 \cdot u \cdot G$ $-c_1 \cdot (\vartheta_m - \vartheta_a) - c_2 \cdot (\vartheta_m - \vartheta_a)^2 - c_3 \cdot u \cdot (\vartheta_m - \vartheta_a)$ $+c_4 \cdot (E_L - \sigma \cdot T_a^4) - c_5 \cdot \frac{d\vartheta_m}{dt}$
Characteristic curve model 4	$\frac{\dot{Q}}{A} = G'' \cdot (\eta_0 - b_u \cdot u)$

In the case of characteristic curve models 1 and 4 (uncovered collectors, test method with stationary conditions), instead of the solar radiation G it is the net irradiance G'' that is applied. This contains an additional term for the exchange of heat radiation between the collector and the surroundings. It is defined by $G'' = G + \frac{\varepsilon}{\alpha} \cdot (E_L - \sigma \cdot T_a^4)$, with long wave emittance ε, solar absorptance α, Stefan-Boltzmann constant σ and ambient temperature in Kelvin T_a. As a rule, no data from the manufacturer are provided for ε and α, and $\frac{\varepsilon}{\alpha} = 0.85$ is used. E_L stands for the thermal radiation reaching the collector. $(E_L - \sigma \cdot T_a^4)$ is normally negative. At clear sky conditions and an ambient temperature of 20° C, this figure is typically in the range of -100 W/m^2. Characteristic curve model 3 contains the same term.

According to the standard, the parameters for characteristic curve model 2 are determined at a wind speed of 3 metres per second. For this type of collector, η_0 is barely wind-dependent.

In characteristic curve model 3, a distinction is made between direct solar radiation G_b and diffuse solar radiation G_d.

The product $A \cdot G'' \cdot \eta_0$ (models 1 and 4) or $A \cdot G \cdot \eta_0$ (model 2) is also designated as thermal peak output, if $G = 1000\ W/m^2$.

According to the applicable rules of Solar Keymark, the thermal performance parameters are determined at MPP operation. But this rule was only introduced at the end of 2015. If values are provided that were determined without electricity generation, the thermal output for the case with electricity generation can be modelled approximately by using the above formulae and substituting G through $G - P_{el}^{DC}/((\tau\alpha) \cdot A)$, where P_{el}^{DC} stands for the DC-side electrical output of the collector and $(\tau\alpha)$ stands for the transmission-absorption product of the collector.[9]

---

[9] Typical figures are $(\tau\alpha) = 0.9$ for uncovered and $(\tau\alpha) = 0.85$ for covered collectors.

An additional parameter, "nominal thermal collector output" (TKN), was introduced as the basis for the performance-related calculation of the financial support in the 2015 harmonised subsidy model of the cantons (cf. Section 2.5). This is defined as

$$TKN = \frac{\dot{Q}(\Delta T = 10K) + \dot{Q}(\Delta T = 30K) + \dot{Q}(\Delta T = 50K) + \dot{Q}(\Delta T = 70K)}{4} \cdot \sqrt{K_\theta^L(50°) \cdot K_\theta^T(50°)} \cdot 0.9,$$

Where $\dot{Q}$ is calculated at an irradiation of $G = 1000\,W/m^2$, or $G'' = 863\,W/m^2$, and with $\Delta T = \vartheta_m - \vartheta_a$. $K_\theta^L(50°)$ and $K_\theta^T(50°)$ are the incidence angle modifiers in longitudinal and transversal direction. For more detailed information, see [10].

2.4.2 Thermal output of different types of PVT collectors

2.4.2.1 Liquid-cooled PVT collectors

The thermal outputs of the different types of liquid-cooled PVT flat-plate collectors at solar irradiation of 1,000 W/m^2 are shown in Figure 14. The figures apply for operation with simultaneous electricity generation at MPP. The corresponding performance parameter values are listed in Table 8. The figures for uncovered collectors without insulation are representative for good products that are available on the market. Those for the uncovered type with rear insulation were calculated with the aid of a mathematical model and apply to products with the same design that are in addition insulated against heat losses on the rear. The values for the covered PVT collector are typical for products that are available on the market.

Table 8: Typical values for the thermal performance parameters of liquid-cooled PVT collectors.

Collector type	Characteristic curve model	Typical parameter values
Uncovered, non-insulated	1	$\eta_0 = 0.58, b_u = 0.05\,s/m, b_1 = 12.5\,W/(m^2K), b_2 = 1.5\,Ws/(m^3K),$
Uncovered, rear insulation	1	$\eta_0 = 0.60, b_u = 0.05\,s/m, b_1 = 9\,W/(m^2K), b_2 = 1.5\,Ws/(m^3K)$
Covered	2	$\eta_0 = 0.50, a_1 = 5\,W/(m^2K), a_2 = 0.02\,W/(m^2K^2)$

In the same way as in the case of pure thermal solar collectors, the wind has a significant influence on the thermal losses of uncovered variants and thus on the thermal output. Wind dependency is, however, very low for covered variants.

The performance characteristics of the various products available on the market can differ considerably. Thus the hierarchy between collectors of the different design types does not necessarily have to correspond to that depicted in Figure 14. For example, in the case of uncovered PVT collectors, a product without rear insulation from one manufacturer may have better characteristics than a model with rear insulation from another manufacturer. In this context it should also be noted that in a real system the collector's heat losses greatly depend on the mounting situation. For non-insulated collectors, a strongly restricted rear ventilation can have the effect of a rear heat insulation.

The number of available products in the field of covered PVT flat-plate collectors is currently very low and the existing products are highly heterogeneous. With respect to this type of collector there still appears to be considerable potential for further technical development and for increasing the efficiency. For example, within the scope of the PVTMax research project, prototypes were developed with significantly higher values of the performance parameters than those of currently available products [11].

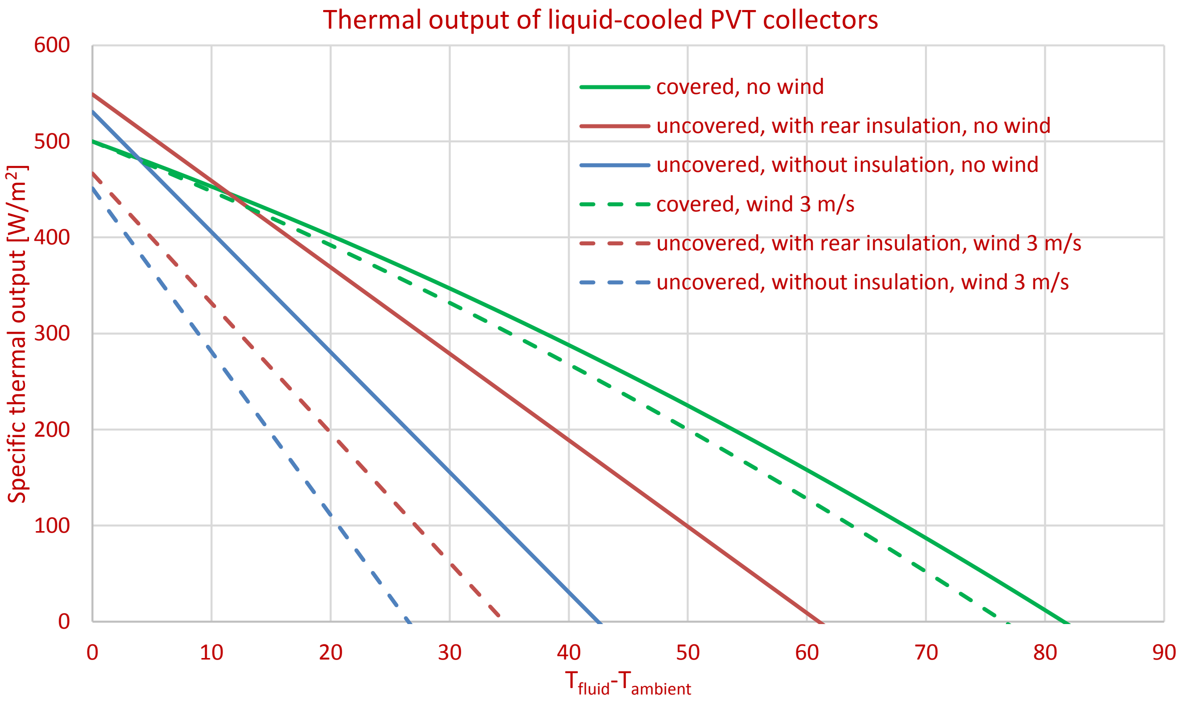


Figure 14: Thermal output of typical liquid-cooled PVT flat-plate collectors at MPP, related to the gross collector surface area at solar radiation of G=1000 W/m^2, $(E_L - \sigma \cdot T_a^4) = -100\, W/m^2$, $\varepsilon/\alpha = 0.85$ *and thus G'' = 915* W/m^2. *Based on empirical values, for covered collectors without wind,* a_1 *was reduced by 10 %.*

2.4.2.2 *Air collectors*

The majority of available air PVT collectors are of the open circuit type. These draw in outside air, the temperature of which is always the same as the ambient temperature. In view of this, in contrast to closed circuit collectors it is not possible to indicate characteristic curves relating to T_{fluid}-$T_{ambient}$. Since the thermal efficiency of this type of collector depends to a relatively large extent on the air-mass flow, the thermal output is normally indicated as a function of the specific air-mass flow (Figure 15).

The thermal output of closed circuit air PVT collectors can be depicted in the same way as that of liquid-cooled models. For the products covered in the survey, however, no figures were available for this operating mode.

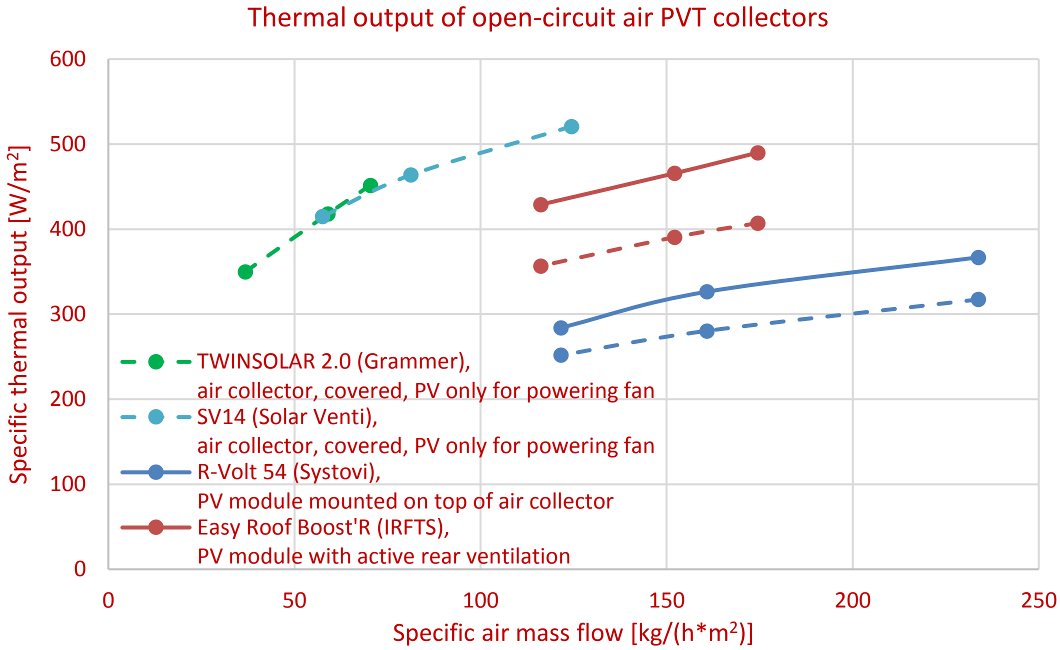


Figure 15: Thermal output of open circuit, air PVT flat-plate collectors at MPP, related to the gross collector surface area at solar radiation of G=1000 W/m², $(E_L - \sigma \cdot T_a^4) = -100\,W/m^2$, $\varepsilon/\alpha = 0.85$ and thus G''= 915 W/m². Solid lines for situation without wind, broken lines for wind speed of 3 metres per second. (At ambient pressure and 20° C an air-mass flow of 1 kilogram per hour corresponds to an air volume flow of around 0.85 cubic metres per hour).

2.4.3 Electrical output

The electrical efficiency (DC) largely depends on the technology and quality of the utilised PV cells. Virtually all available PVT collectors are equipped with mono- or polycrystalline silicon cells. Under standard conditions (G = 1,000 W/m² and T = 25° C), the efficiency of uncovered collectors is in the region of 16%, like that of standard PV modules. The efficiency of covered PVT collectors is lower due to additional reflections at the transparent glass cover. At vertical (normal) incidence of the solar radiation, the reduction is between four (glass with anti-reflection coating on both sides) and eight (standard solar glass) percent.

The dependency of the electrical efficiency on solar radiation and module temperature is the same as that of PV modules. If PVT collectors have an good thermal coupling between the PV cells and the heat transfer fluid, the module temperature can be approximated by the mean fluid temperature.

The electrical efficiency at a given solar radiation G and module temperature (or fluid temperature) ϑ_m can be readily calculated with the aid of the following formula [2],

$$\eta_{el}^{MPP} = \eta_{STC}^{MPP} \cdot \left(1 - 0.04 \cdot \ln\left(\frac{G}{1000\,W/m^2}\right) + \gamma_{MPP}^{STC} \cdot (\vartheta_m - 25\,°C)\right),$$

where η_{STC}^{MPP} and γ_{MPP}^{STC} stand for the efficiency and the temperature coefficient at MPP and STC, which usually can be taken from the product data sheet.

With the aid of the corresponding reference area A the electrical output of a PVT collector can thus be calculated as follows:

$$P_{el}^{MPP} = \eta_{el}^{MPP} \cdot G \cdot A\,.$$

2.4.4 Gross heat and gross electricity gain

In the case of liquid-cooled collectors (and closed circuit air collectors), gross solar gain levels can be taken as the basis for approximately estimating the anticipated yields for different collectors, locations and temperature levels for heat use.

The gross heat gain is the thermal yield of a collector (at the collector connection points) for a certain mean collector temperature and a specified period of time (e.g. a month or a year). It depends on the performance characteristics of the collector, the location (solar irradiation, climate) and the orientation and inclination angle of the collector, and can be calculated with the aid of the corresponding characteristic curve model. The annual gross heat gain of a collector for a mean collector temperature of $\vartheta_m = 30\ °C$, for example, is the hypothetical heat output that a collector at a given location and with a given orientation would attain if it were to be operated at precisely that temperature at every moment in the year at which the efficiency is positive at $\vartheta_m = 30\ °C$. Here, dynamic effects such as heating up and cooling down phases are ignored.

In the context of PVT collectors, a gross electricity gain can be defined in a similar manner to the gross heat gain. It corresponds to the DC output that a PVT collector would attain if it were to be operated from a thermal perspective as described above. In a simplified manner, the mean fluid temperature is assumed as the module temperature during periods of thermal operation (time intervals with positive thermal efficiency). Outside of thermal operating times, the module temperature is calculated from the characteristic curve equation with $\dot{Q} = 0$.

The gross heat and gross electricity gains for various collector types and locations are depicted in the illustrations below. The figures were calculated with the aid of Polysun software. It was assumed that the wind speed at the collector field is 50% of the speed recorded in the weather data that apply to open terrain. The same thermal performance characteristics were used as those for the characteristic curves in Figure 14 (Table 8). For uncovered collectors an electrical efficiency of 16.5% at STC was assumed. In order to take account of the additional reflections for the covered collector a 6-percent lower electrical efficiency of 15.5% was assumed. As temperature coefficient, - 0.37% per °C was applied for all collectors.

Figure 16 shows the annual gross heat and gross electricity gain levels for various liquid-cooled PVT collector types in Zurich. For low operating temperatures, the heat yields contain both the solar energy converted to useful heat as well as ambient heat that is harvested when the collector temperature is below the ambient temperature. Thus at low operating temperatures, uncovered and uninsulated collectors have an advantage. For higher operating temperatures that mostly exceed the ambient temperature in the course of the year, rear insulation and front covering increase heat output. In a system in which the collector is always operated at 50° C, only a covered collector is able to deliver a noteworthy heat output.

The lower the operating temperatures, the higher the electrical output levels. The percentages cited in the illustrations below indicate the relative difference in electrical output compared with a PV module with average rear ventilation.

Uncovered, uninsulated PVT collectors attain the largest increases in electrical output due to cooling of the module. The highest attainable temperatures are equivalent to those of pure PV modules. If no heat is drawn off, they hence deliver the same amount of electrical energy as PV modules.

At low operating temperatures, **uncovered PVT collectors with rear insulation** produce yields similar to those of uninsulated collectors. Because they can attain higher temperatures than PV modules thanks to the insulation, output levels are slightly lower at higher operating temperatures.

Covered PVT collectors (fabricated with equivalent cells) attain slightly lower electrical output levels than uncovered collectors. The reasons for this are on the one hand the larger reflections due to the additional glass panel (higher at vertical irradiation and increasing more strongly for oblique angles of light incidence), and on the other hand the longer operating periods at high temperatures. In comparison with PV modules, at low operating temperatures a slightly higher electrical output results through the cooling of the module, despite the higher reflection losses. But at higher operating temperatures, the electrical output of these collectors is lower than that of PV modules. With covered collectors it is therefore important to avoid longer stagnation phases (i.e. phases without heat use), because these result in a significant reduction of electrical yields.

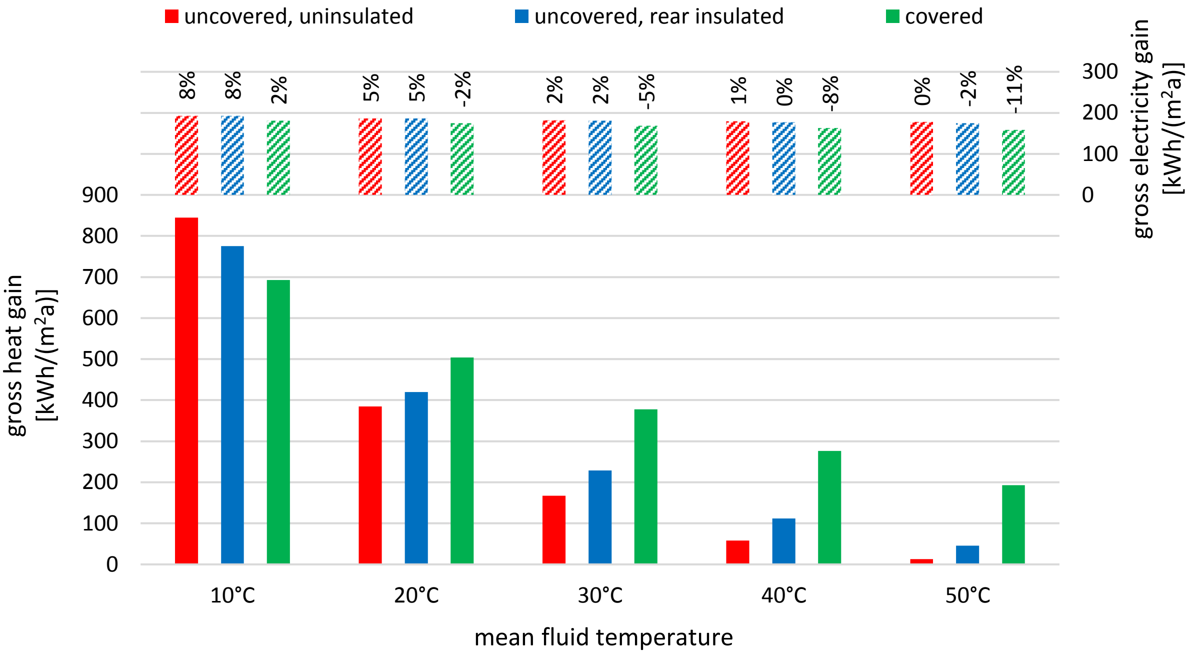


Figure 16: Annual gross heat gain (solid bars) and gross DC electricity gain (shaded bars) for various liquid-cooled PVT collector types related to the gross collector surface area (location, Zurich; orientation, south; inclination angle, 45°). The percentages indicate the increase or decrease of electrical output compared with a PV module with average rear ventilation.

By way of comparison, the gross heat gain of pure thermal solar collectors for the same location and the same orientation are shown in Figure 17.

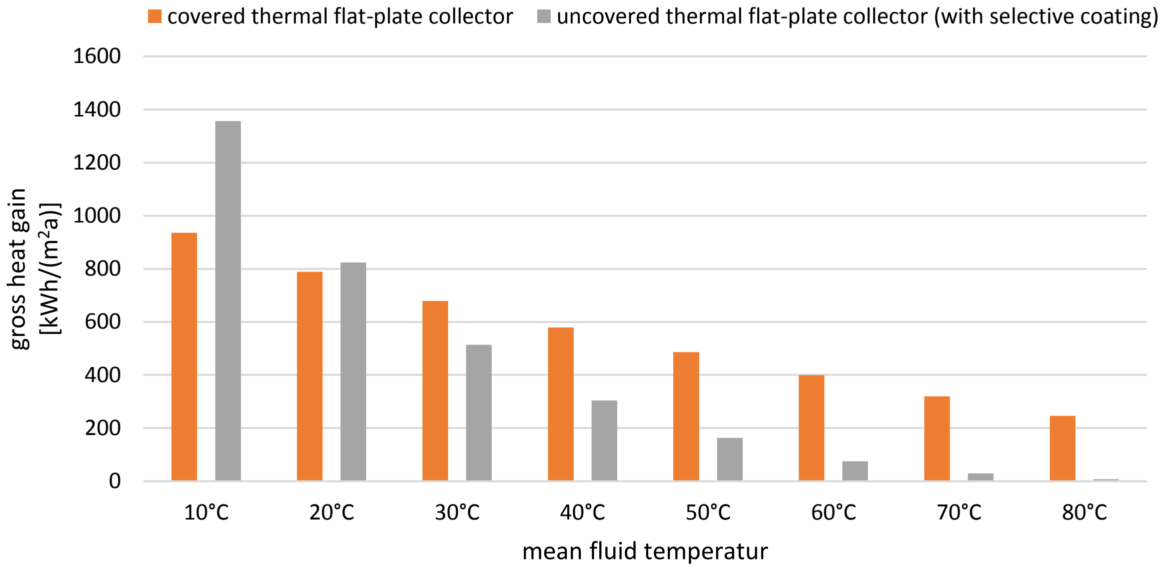


Figure 17: Annual gross heat gain for thermal solar collectors related to the gross collector surface area (location, Zurich; orientation, south; inclination angle, 45°).

Figure 18 shows the gross gain levels for a typical uncovered uninsulated collector at various locations. For the operating temperature of 10° C, the heat gain is greatly influenced by the ambient temperature, which is the reason why in Zurich a higher output is attained than in Davos, despite the lower amount of solar radiation. At a higher operating temperature, the influence of the amount of radiation is stronger. This is also the main influencing factor for the electrical output. The monthly distribution of gross gain levels for the same collector type in Zurich is shown in Figure 19.

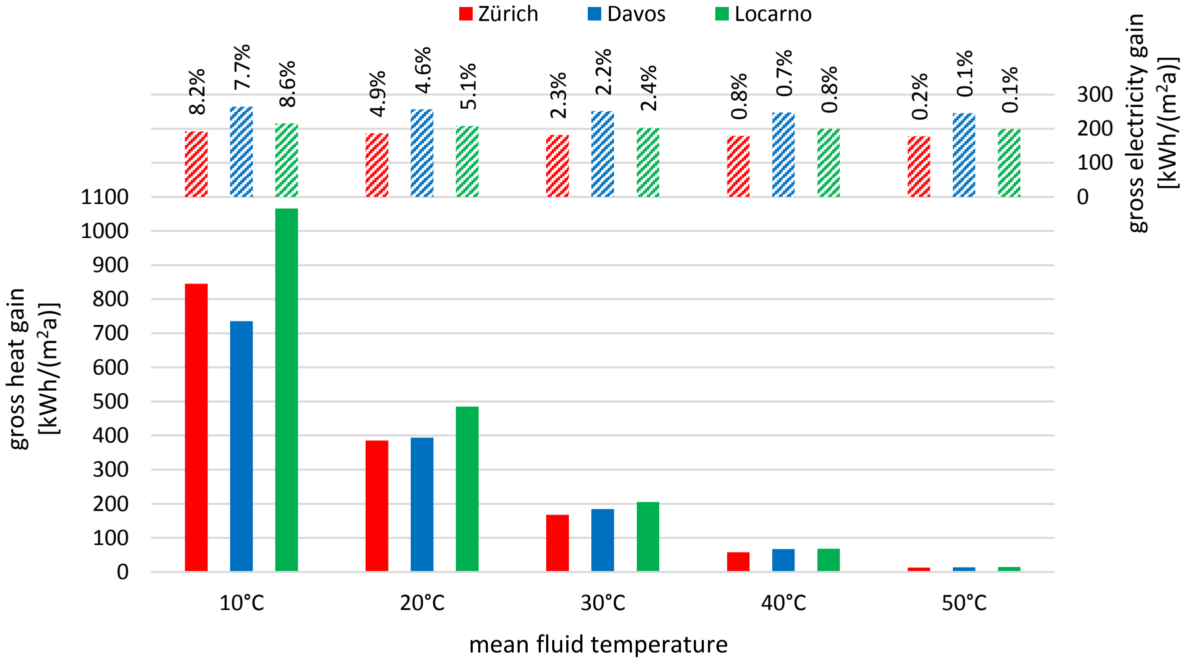


Figure 18: Annual gross heat gain (solid bars) and gross DC electricity gain (shaded bars) related to the gross collector surface area for liquid-cooled uncovered PVT collectors without rear insulation, at various locations (orientation, south; inclination angle, 45°). The percentages indicate the increase or decrease of electrical output compared with a PV module with average rear ventilation.

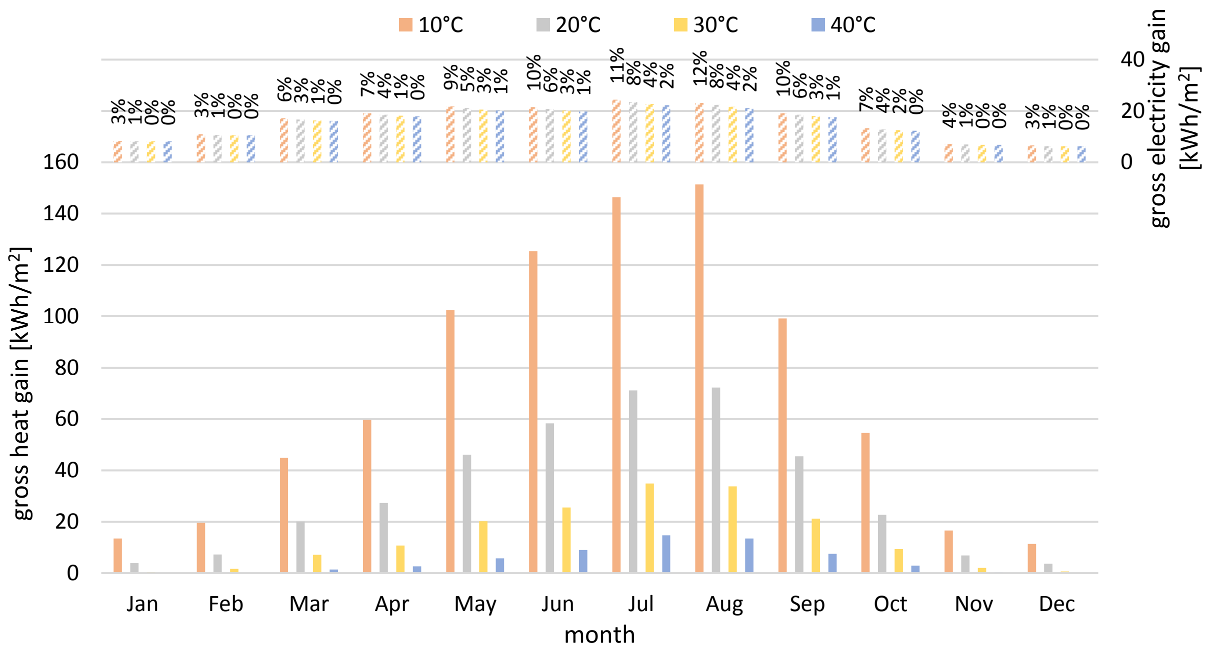


Figure 19: Monthly gross heat gain (solid bars) and gross DC electricity gain (shaded bars) related to the gross collector surface area for liquid-cooled uncovered PVT collectors without rear insulation, in Zurich (orientation, south; inclination angle, 45°). In percent: increased output compared with PV modules with average rear ventilation.

2.5 SUBSIDISATION

In Switzerland, PVT systems can qualify for financial support as both photovoltaic and solar thermal systems.

Photovoltaic systems are supported at the federal level in the form of the non-recurring remuneration, or the remuneration of feed-in at cost. Some cantons and municipalities also offer additional financial support.

The majority of cantons and a large number of municipalities support the installation of solar thermal systems. Guidelines for cantonal support are defined in the 2015 harmonised subsidy model of the cantons [12]. These guidelines concern subsidisation based on the nominal thermal collector output (definition, cf. chapter 2.4.1.2). The current financial contributions for solar thermal systems (including PVT systems) in the various cantons can be determined with the aid of the financial support calculation tool (http://kollektorliste.ch/).

In accordance with the 2015 harmonised subsidy model of the cantons, the minimum level of financial support is 1,200 Swiss francs (basic contribution), plus 500 Swiss francs per kilowatt of total installed nominal thermal collector output. In order to qualify for support, a total nominal collector output of at least 2 kW has to be installed.

A typical uncovered PVT collector without rear insulation as per chapter 2.4.2 has a nominal thermal collector output of 92 W/m^2 (Table 9). In order to attain the necessary minimum output to qualify for support, a collector surface area of at least 22 m^2 must be installed. With a standard collector size of 1.60 m^2, this means that at least 14 collectors have to be installed. PVT collectors with rear insulation typically attain slightly higher nominal output levels. For covered PVT collectors the figure is significantly higher. For comparison purposes, a typical covered thermal flat-plate collector is listed. At 465 W/m^2 the nominal collector output is more than twice that of a covered PVT collector and is roughly equivalent to five times the nominal output of an uncovered and uninsulated PVT collector. For an installation of minimum size corresponding to a nominal output of 2 kW the amount of financial support in accordance with the 2015 harmonised subsidy model of the cantons is 2,200 Swiss francs.

Table 9: Nominal thermal collector output and minimum size for financial support in accordance with the 2015 harmonised subsidy model of the cantons for various collector types and typical performance characteristics.

Collector type	Nominal thermal output	Minimum size
Uncovered, non-insulated PVT collector	92 W/m^2	21.7 m^2
Uncovered PVT collector with rear insulation	129 W/m^2	15.5 m^2
Covered PVT collector	211 W/m^2	9.5 m^2
Thermal flat-plate collector	465 W/m^2	4.3 m^2

Each canton may also offer additional financial support. Various options for increasing the amount of support are cited in the 2015 harmonised subsidy model.

Additional up-to-date information concerning the financial support situation for solar electricity and solar heat can be obtained from the website of the industry association, Swissolar (http://www.swissolar.ch/fuer-bauherren/foerderung/).

3 SYSTEM INTEGRATION OF PVT COLLECTORS

As outlined in the previous chapter, the strengths of the various collector types become manifest at different operating temperatures and thus in different applications. With respect to the amount of useful energy produced by the various collector types, the way in which they are integrated into a heat supply system is decisive. The most important areas of application and system concepts are described below. Here the focus is on liquid-cooled uncovered PVT collectors, which represent the most widely used type in Switzerland.

3.1 SYSTEMS WITH LIQUID-COOLED UNCOVERED PVT COLLECTORS

This most commonly used collector type is especially suitable for low-temperature applications because this is where these collectors attain the highest thermal output and the greatest increase in electricity output through module cooling. An important area of application is the use in combination with heat pumps in which the solar heat is used on the source side. This type of collector is also used in conventional solar thermal applications such as hot water (pre)heating, space heating support and swimming pool heating.[10]

3.1.1 Heat pump systems

The most important options for the use of solar heat in heat pump systems are:

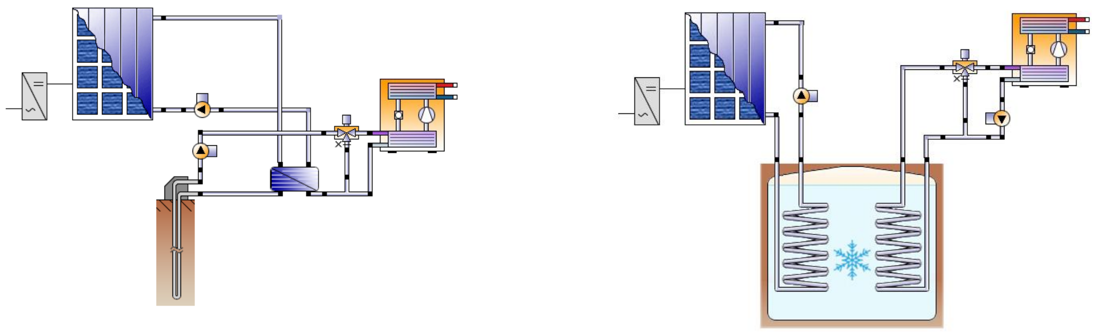
- Regeneration of geothermal boreholes/ground sources (and borehole fields) (GS-Reg)
- Regeneration of an ice storage tank (Ice-Reg)
- Regeneration of a brine storage tank (Brine-Reg)
- Preheating of a groundwater storage tank (GW-Pre)
- As direct heat source for the heat pump (HP-Dir)

---

[10] In principle, uncovered collectors can also be used for cooling applications (nocturnal radiation cooling).

All these options (except the last one) concern the management of a heat storage tank on the source side of the heat pump using solar heat. For these options the possibilities for the hydraulic integration of PVT collectors are depicted in Figure 20 in simplified form. The option of using PVT collectors as a direct heat source for a heat pump can be realised individually, but can also be combined with other options with the aid of suitable hydraulic connections.

Higher source temperatures have a positive influence on the coefficient of performance of a heat pump (approximately 2.5% lower electricity consumption per degree C). However, it is important to ensure that the maximum source temperature accepted by the heat pump is not exceeded. Depending on the system option and the dimensioning of the components, adherence with this threshold has to be actively controlled. This can be achieved via return flow admixture, as depicted in Figure 20. However, interventions of this sort should only be made specifically for dealing with peak production levels. If the temperatures are permanently too high, the inclusion of an additional heat sink should be planned.



a) GS-Reg

b) Ice-Reg

c) Brine-Reg

d) GW-Pre

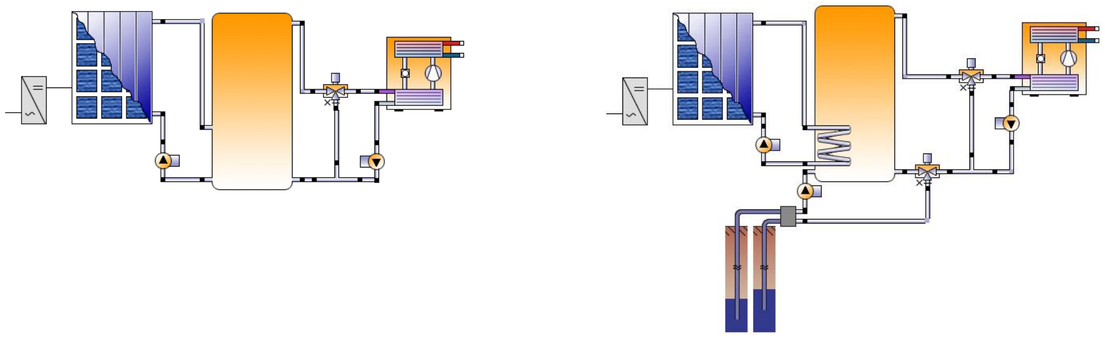


Figure 20: Schematic depiction of various options for the integration of PVT collectors on the source side of a brine/water or water/water heat pump. The heat sinks would be on the right-hand side of the heat pump but are not shown here. Diagrams produced with the aid of Polysun software.

For all options the possibility exists of additionally integrating solar heat on the secondary side of the heat pump so that it can be stored directly in a hot water or space heating tank. This additional option is beneficial in terms of system efficiency. However, the actual degree of benefit greatly depends on the storage temperatures or volumes. The system also becomes more costly and complex. Whether integration into the primary and secondary circuits is worthwhile has to be assessed in each specific case.

3.1.1.1 Regeneration of ground sources (GS-Reg)

In heat pump systems coupled with ground sources it is important to avoid a pronounced longer-term cooling of the ground. Specifically, in accordance with SIA Standard 384/6 the mean brine temperature of a borehole should not fall below -1.5° C at any time of year, even after an operating period of 50 years. In order to comply with this requirement, it may be necessary to feed heat into the ground. Looked at from another perspective, with the aid of active regeneration of the underground it would be possible to waive the construction of longer or additional boreholes.[11] Regeneration of the ground should be considered in particular in the case of geothermal borehole fields, in zones with a high degree of geothermal energy use (e.g. in urban areas), or for deep boreholes (cf. [13] and [14]).

For this purpose, uncovered PVT collectors can be used as low-temperature heat source.[12] A simple option for the hydraulic integration of PVT collectors for ground source regeneration is depicted in Figure 20a. Both the hydraulic separation of the solar loop and the ground source loop (as shown in the figure), and the connection of the two fluid loops, are possible. When the loops are joined the temperature lift on the heat exchanger is omitted, as a result of which the collectors can be operated at a lower temperature, and thus more efficiently. In addition, the costs of the heat exchanger can be saved. The disadvantage is that, due to the possibility of low temperatures in the entire fluid loop (instead of just in the solar loop) during the winter, it is necessary to use a water/glycol mixture with a higher concentration of glycol, which also increases the pressure loss in the ground source loop and thus means that more pumping power is required.

The maximum inlet temperature of boreholes usually has to be restricted due to the limited temperature resistance of the pipe material (manufacturer's specifications) or the applicable (cantonal) legal provisions. Based on a frequency profile of the anticipated borehole temperatures (typically determined through simulation), it is possible to obtain information from some manufacturers regarding the useful life of the pipe material. Depending on the specifications, a material with higher temperature resistance can be used. If necessary, it is possible to set a temperature limit with a return flow admixture at the borehole or the collector field. However, this can result in a significant reduction of the solar yield. Here, from an energy perspective the installation of an intermediate storage facility could be beneficial.

For the planning and control of the system, the electricity consumption of the circulation pumps required for regeneration should be taken into account. It is important to use efficient and, if possible, adjustable pumps. Depending on the dimensioning of the solar collector system and depending on solar irradiation levels, a significantly lower volume flow may be applied in the borehole loop for regeneration operation than for heat extraction. With adjustable pumps, during partial load operation the pumping power can be significantly reduced by maintaining the ratio of thermal output to volume flow over the entire output range.

---

[11] It should be noted that, particularly in the summer, deep boreholes (450 metres, etc.) have higher temperatures (25° C +) than conventional ones, i.e. the operating conditions may not be optimal for use with PVT systems. For this reason, in such cases one may consider a combination of different collector technologies (e.g. unglazed thermal collectors with PVT collectors).

[12] One can also specifically target an over-regeneration of the ground in order to attain a long-term increase of the borehole flow temperatures and thus higher coefficients of performance of the heat pump.

3.1.1.2 Ice storage regeneration (Ice-Reg) and brine storage regeneration (Brine-Reg)

Here, as an alternative to geothermal or air/water heat pump systems, the heat pump draws heat from a fluid-filled low-temperature storage unit (Figures 20b and 20c). Both options are similar to one another, with the sole exception that with brine storage only sensible heat is stored, whereas with ice storage, latent heat, i.e. the “storage capacity” of the phase change between ice and water, is also used. Thus ice storage systems have a significantly higher heat storage density at temperatures around 0° C. The energy stored in the phase change corresponds approximately to the energy that is required for heating the same mass of water from zero to 80° C. Consequently, brine storage requires considerably higher storage volumes and a large quantity of water/glycol mixture in order to store the same amount of energy. On the other hand, the advantages of a brine storage system include lower system complexity, because no icing-up occurs, and no temperature level losses caused by the transfer of heat from brine to water/ice and back again. For systems with brine storage, in the same way as for solar ground source regeneration, in each specific case it is necessary to determine whether hydraulic separation between the solar fluid circuit and the fluid circuit that feeds the heat to the heat pump, is beneficial.

3.1.1.3 Groundwater preheating (GW-Pre)

At locations where this possibility exists, a heat pump can draw heat from the groundwater. Here the groundwater is either directly fed to the heat pump or, more commonly, indirectly via an intermediate fluid circuit (water/glycol mixture). Low-temperature heat which can be supplied efficiently by an uncovered PVT collector can be used for raising the source temperature in this type of system, and thus for reducing the electricity consumption of the heat pump (Figure 20d). Here the solar heat can either be fed via a heat exchanger into a ground water storage tank or a storage tank that is integrated into the intermediate circuit. The latter case can be regarded as an extension of the Brine-Reg option.

With this system option the possibility exists of transferring surplus heat to the groundwater and thus to cool the PVT collectors and increase their electrical output. Whether this operating mode makes sense from an energy perspective depends in particular on the power consumption of the circulating pumps.

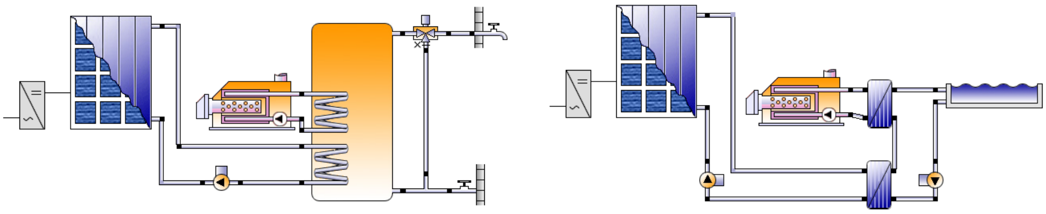
As with the energy-related use of groundwater without solar support, it is necessary to ensure that the return temperature of the groundwater lies within the legally specified range. As a rule, the cooling or warming of the groundwater at a distance of 100 metres from the return feed facility may not exceed 3° C versus the natural seasonal temperature of the groundwater [15].

3.1.2 Direct supply of useful heat

In addition to their integration on the source side of heat pumps, uncovered PVT collectors can also be used for directly supplying useful heat. The applications correspond to the conventional areas of use of solar thermal energy, including:

- Hot water (pre)heating (HW, HW-Pre)
- Hot water heating plus space heating support (HW & SH)
- Swimming pool heating (Pool)

The corresponding hydraulic integrations are shown in simplified form in Figure 21.


a) HW, HW-Pre

b) Pool

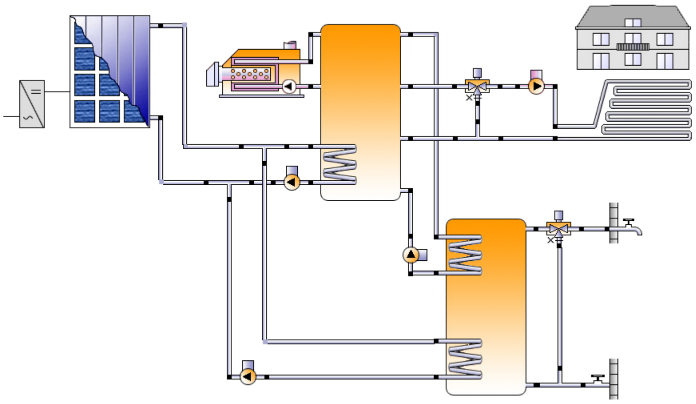

c) HW & SH

Figure 21: Options for hydraulic integration of PVT collectors for the direct supply of useful heat. Diagrams produced with the aid of Polysun software.

3.1.2.1 Hot water (pre)heating (HW, HW-Pre)

With this option (Figure 21a), the solar heat is fed into a hot water storage tank via a coil heat exchanger or an external plate heat exchanger. A storage volume the size of a conventional hot water boiler can be reheated via a conventional heat generator (e.g. fossil boiler, heat pump or electric heating rod). Depending on the size of the system, a two-tank solution involving a preheating tank and a secondary tank may be beneficial, as may one with just one tank (as depicted). Depending on the extent to which the solar heat contributes to the production of hot water, the system option is referred to as hot water preheating (proportion of solar heat typically around 25%) or hot water heating (proportion of solar heat typically higher than 50%). With regard to the surface-specific energy yield, in the same way as unglazed thermal collectors, uncovered PVT collectors are especially suitable for systems with a low solar proportion because the collectors in these systems are operated at a lower temperature. Preheating systems of this nature are particularly suitable for all objects with a high demand for hot water (apartment houses, sports facilities, etc.)

3.1.2.2 Hot water heating plus space heating support (HW & SH)

This option (Figure 21c) concerns a generously dimensioned system for solar hot water heating in which the solar heat can also be used for loading the space heating storage unit. It can only be used in combination with a low-temperature heat distribution system. Some systems exist in which the solar heat is only used for loading the space heating storage unit.

3.1.2.3 Swimming pool heating (Pool)

Due to the required low temperatures, uncovered PVT collectors are very suitable for heating outdoor pools (Figure 21b), especially those without additional reheating. Heating indoor pools is also possible, though the continuously required higher temperatures result in a lower solar thermal yield. Due to the corrosive nature of chlorine, PVT collectors with fluid-carrying components made of metal (especially aluminium) normally have to be coupled via a heat exchanger to the pool water circulation system. For PVT collectors with heat absorbers made of plastic, the possibility exists to feed the pool water directly through the PVT collector. This offers two advantages: there is no need for an additional heat exchanger and the collectors can be operated at a lower temperature, and thus more efficiently.

3.2 SYSTEMS WITH LIQUID-COOLED COVERED PVT COLLECTORS

The areas of use of covered PVT collectors largely correspond to those for covered solar thermal flat-plate collectors. The main applications concern systems for solar hot water heating, with or without space heating support. The options for hydraulic integration correspond to those shown in Figure 21. Due to the somewhat lower thermal output compared with purely thermal flat-plate collectors, the collector area for attaining the same degree of solar coverage has to be slightly larger.

One major difference from systems with thermal flat-panel collectors concerns the handling of stagnation statuses. A number of covered PVT collectors on the market cannot be exposed to stagnation temperatures for lengthy periods due to the utilised materials. This means that these products require a mechanism for limiting the temperature, as a rule a heat exchanger integrated into the collector circuit allowing to release heat to the outside air, and a correspondingly configured control device.[13]

3.3 SYSTEMS WITH AIR COLLECTORS

In practice, PVT air collectors are mainly used in open circuit systems. Outside air is drawn in with the aid of fans and fed behind the PV cells. The heated air is often used directly for space heating or ventilation in buildings (Figure 22). The same system configuration can be used in the summer for cooling the building at night. Another option is to use the preheated outside air as a source for an air/water heat pump for heating up water and/or for space heating (Figure 23). This permits an increase of the coefficient of performance of the heat pump compared with the use of non-preheated outside air.

A system configuration with the option of air circulation operation (closed air circuit) is beneficial if it is possible to use surplus solar heat to directly load a hot water storage unit.

Other interesting areas of use for this collector type include drying systems, e.g. for agricultural products or timber (Figure 24), or for the ventilation of indoor swimming pools, paint shops, etc.

---

[13] Also in some systems with uncovered PVT collectors coolers are built into the collector circuit in order to cool the PV cells during periods in which no heat is required, and thus to increase the electricity output.

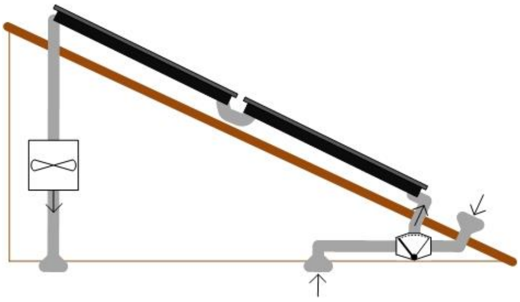


Figure 22: Schematic diagram of an air PVT system for the direct heating or cooling of interior rooms.

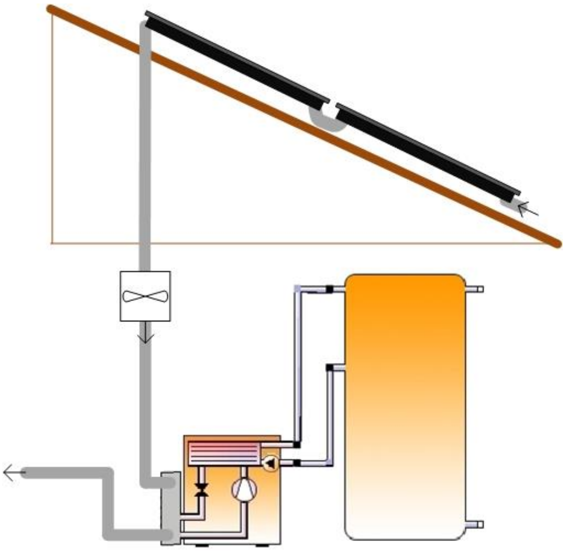


Figure 23: Schematic diagram of an air PVT system for heating a buffer storage unit (for hot water or space heating) via an air/water heat pump.

Figure 24: Air PVT system for drying grass in the French province of Béarn. Product from Cogen'air (BASE).
Source: BASE Innovation.

With little additional technical complexity an option can be realised in air PVT systems for actively cooling the PVT collectors also during periods with no heat demand using the ventilation system, and thus increasing the electricity output.

For further information regarding solar thermal air collector systems, see [16].

3.4 TOOLS FOR CONFIGURING PVT SYSTEMS

In the same way as with solar thermal and photovoltaic systems, detailed system configuration can be carried out with the aid of various simulation tools. Special calculation models for liquid-cooled PVT collectors, as well as system templates, can be found in, for example, the Polysun and Tachion programmes.[14] In some cases, manufacturers also provide their own tools to suit their specific products.

Solar thermal air collector (not specifically PVT) systems can, for example, be calculated using the T*SOL and RETScreen simulation programmes.[15]

Whereas for small and basic systems (e.g. for water heating), it is possible to work with generally applicable rules provided by the manufacturer, for larger and more complex systems (e.g. for the regeneration of geothermal borehole fields), detailed dynamic system simulations are required.

---

[14] Polysun Simulation Software, www.velasolaris.com; Tachion Simulation Framework, www.solarcampus.ch.

[15] T*SOL Simulation Program, www.valentin-software.com; RETScreen Clean Energy Management Software, Natural Resources Canada, http://www.nrcan.gc.ca/energy/software-tools/7465.

4 CASE STUDIES

4.1 SINGLE-FAMILY HOUSE IN WETTSWIL AM ALBIS

Type of project	SFOE pilot and demonstration project
Project title	Integration of PVT collectors into ground-source-coupled heat pump systems Paving the way to practical feasibility and for verifying the potential of low-temperature PVT collectors and their integration into a building heat supply system with heat pump and ground source
Project consortium	Meyer Burger AG NTB Interstaatliche Hochschule für Technik, Buchs
Duration of project	2013 to 2015
Documentation / sources	2012 annual report [17], Final report [18], measurement data

4.1.1 Description of object

The object concerned is a single-family house with a heated outdoor swimming pool, where an existing heat supply system based on a heat pump coupled with a ground source was expanded in 2012 by adding a PVT system. The reason for the integration of the PVT system was an observed cooling of the boreholes.

Figure 25: View of the PVT system on the roof of the single-family house in Wettswil.

4.1.2 Solar installations

28 PVT collectors (Meyer Burger Hybrid 240/900) were installed on the flat roof of the building (total collector area, 45.9 m^2; 6.7 kWp electrical output). The modules are oriented to the southeast (30°) with an inclination angle of 10°. In addition, a PV system with the same orientation comprising 10 modules of the same type, though without heat absorbers, was installed (16.4 m^2; 2.4 kWp).

4.1.3 Heat supply concept and integration of PVT collectors

The heat supply system is depicted in simplified form in Figure 26. It is based on a heat pump coupled with three geothermal boreholes, each with a length of 150 metres. In the summer, the building is cooled through free cooling via the geothermal probes, which are thus partially regenerated. The building also has a wine cellar cooling system, some of the waste heat from which is used for heating-up water, while the remainder is fed into the boreholes.

For the integration of the solar system the boreholes were hydraulically separated. Only two of them are regenerated via the PVT collectors, and the third is used for free cooling. This means that both functions can be used simultaneously. When heat is drawn by the heat pump, all three boreholes are used in parallel. The solar heat can be used for heating the swimming pool in addition to the regeneration of the ground source. The installed hydraulics would also allow for use of the solar heat as a direct source for the heat pump. This operation mode, however, is not planned.

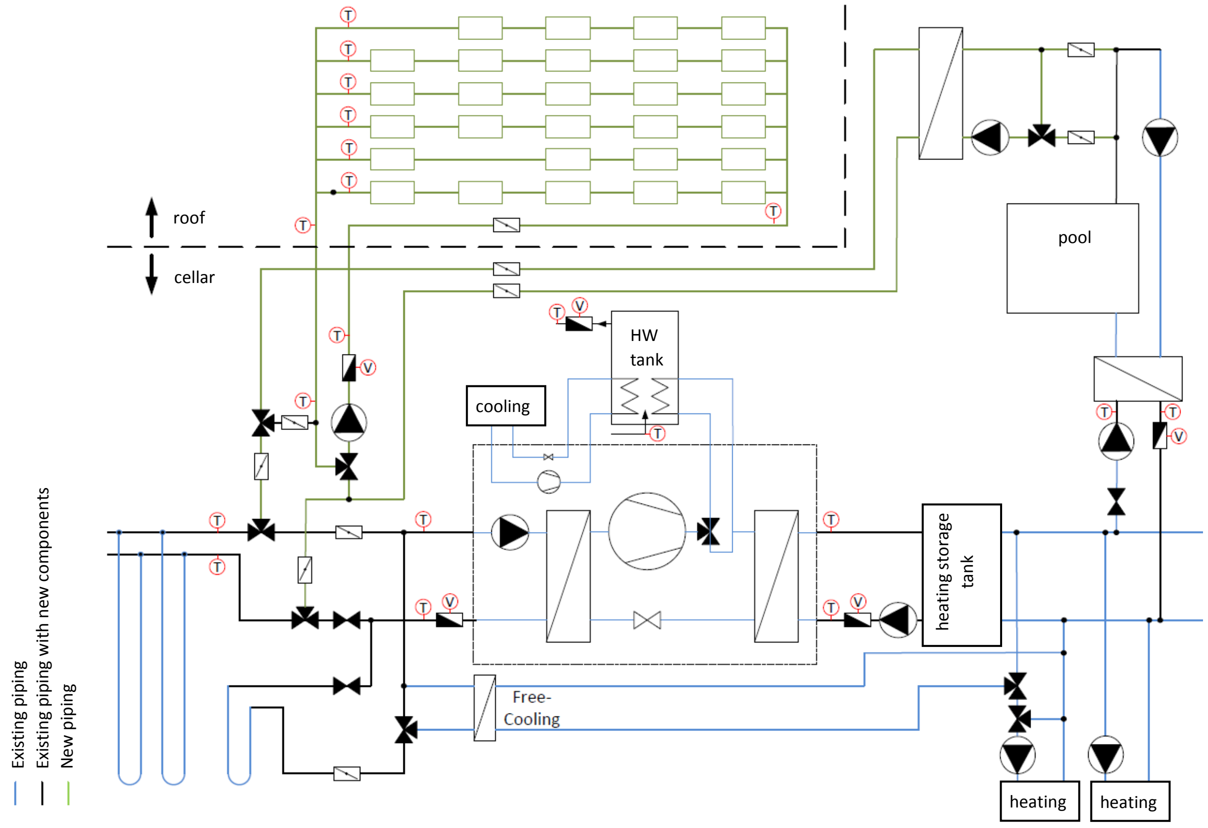


Figure 26: Simplified diagram of the system and integration of the PVT collectors in the single-family house in Wettswil. Source: NTB Buchs (English tags added).

4.1.4 Findings from the operation of the PVT system

Due to initial errors in the control settings, no solar regeneration of the boreholes occurred during the first year of operation (2013). This was ascertained through remote monitoring. In addition, the recording of measurement data in this project did not function as intended, and this gave rise to significant gaps in the recorded data.

The energy yields cited in this report refer to the period from September 2014 to August 2015, during which the system functioned properly, i.e. after various adjustments had been made to the control settings. During this period, the availability of the measurement data was 82%. For estimating the annual output figures, the measured monthly yields were scaled individually to 100 %.

4.1.4.1 Thermal output

The (scaled) thermal output for the period from September 2014 to August 2015 was 267 kWh/m^2 (total, 12.3 MWh) with a solar irradiation on the collector field of 1,179 kWh per m^2. 37% of the solar heat output was used for heating the pool and the remaining 63% for borehole regeneration. The system is configured so that the solar heat during the summer primarily heats the pool, and borehole regeneration only starts in July.

In the course of the year the heat pump drew 17.3 MWh of heat from the ground source. The ground was regenerated to a degree of 45% by the 7.7 MWh of solar heat. It was additionally regenerated by the waste heat from the wine cellar cooling system (around 3 MWh) and through free cooling (not measured).

The lowest monthly average values of the flow temperature of the boreholes were attained in February. During space heating operation mode, these were in the range of 5° C (February 2013 and 2015) and 6° C (February 2014). The flow temperatures are therefore fairly stable, though a longer period would be necessary in order to make a conclusive evaluation of the longer-term temperature trend. The seasonal performance factor of the heat pump was also stable at around 3.2 for all three years.

4.1.4.2 Electrical Output

The (DC) output of the PVT system (again, for the period from September 2014 to August 2015) was 121 kWh/m^2, i.e. a total of 5.5 MWh.

At 131 kWh/m^2, the specific electricity output of the 10 PV modules was higher than that of the PVT system. This is primarily attributable to the fact that the PVT field was shaded considerably due to plant growth around the flat roof. Thus this effect outweighed the positive influence of the module cooling, which accordingly could also not be quantified.

4.1.4.3 Other findings

In this project it became apparent that in the case of such a complex system (space heating, hot water, swimming pool, cooling of building), detailed monitoring and optimisation are purposeful, or even essential, during the first few years of operation.

According to the 2012 annual report, during the planning and installation stages there were some uncertainties regarding responsibilities. In the final report it was emphasised that it is very important to specify the responsibilities and the interfaces between the involved parties for both the initial project stages as well as the subsequent operational stage (monitoring, optimisation, maintenance).

4.2 OBERFELD HOUSING COOPERATIVE, OSTERMUNDIGEN

Type of project	SFOE pilot and demonstration project
Project title	Integration of PV/T collectors into ground-source-coupled heat pump systems Evaluation of the potential of the combination solar & heat pump, and system optimisation through the monitoring of a large-scale solar regenerated geothermal borehole field
Project consortium	Meyer Burger AG EWB (Energy and Water Supply, Bern) Rapperswil University of Applied Sciences, Institute for Solar Technology SPF
Duration of project	January 2014 to April 2019
Documentation	Annual reports, 2014 to 2016 ([19], [20], [21])

4.2.1 Description of object

The sustainable and car-free residential complex in Ostermundigen is a construction project based on the Minergie-P standard, which was developed within the framework of the SFOE Sustainable Housing Districts programme (see http://www.nachhaltige-quartiere.ch and www.wohnen-im-oberfeld.ch). It comprises three buildings with a total of around 100 apartments. Each building has its own heating system, consisting of a heat pump, a borehole field and a PVT solar installation. The low-temperature heat from the PVT collectors is used during the summer for regenerating the borehole fields.

Building C, which has a system comprising 265 PVT collectors and 9 boreholes, was completed in summer 2013 as the first of the three buildings in the complex. Building B (which forms an integral part of this project) and building A were completed in spring 2014. In all, 799 PVT collectors (1,320 m^2) were installed.

Within the scope of the pilot and demonstration project, the heating system, solar installation on the roof (comprising 379 PVT collectors) and borehole field (with 14 boreholes with a depth of 200 metres) of Building B (5345 m^2 energy reference area) were fitted with a monitoring system and will be measured over a period of five years.

4.2.2 Solar installation

The solar installation is distributed over the various flat roofs of the three buildings and has a total electricity output of 207.7 kWp. It comprises PVT collectors from Meyer Burger (type: 260/900), which are installed with a mounting system from the company K2, comprising horizontally fitted laminate clamps (module inclination angle, 0°).

Figure 27: PVT collectors on building C.

Figure 28: View of building B with roofs 1 to 3.

Figure 29: Overview of the Oberfeld complex (building B in the foreground, building C on the left).

4.2.3 Heat supply concept and integration of PVT collectors

The main aim of the pilot and demonstration project is to monitor the supply of heat to the building complex. For this purpose, the two components of the heat supply system (the PVT collectors and the geothermal borehole field) are being closely monitored. Another aspect concerns the optimisation of the control strategy for the entire system.

The system is depicted in the form of a diagram in Figure 30. The heat supply for each building is carried out through two heat pumps (hot water and space heating), which draw heat from the corresponding borehole field and/or the solar collector field which are connected in series. During the summer, the low-temperature heat from the PVT collectors is primarily used for regenerating the borehole field. However, the collector field can also be used as a direct source for the heat pump.

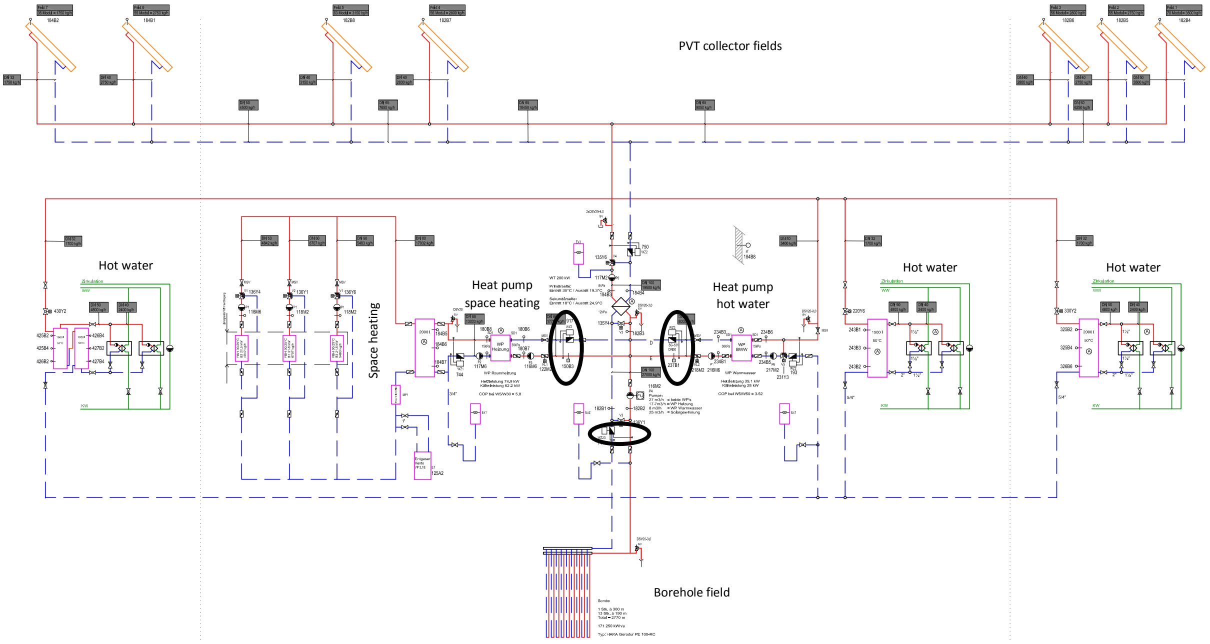


Figure 30: Diagram of the heat supply system of building B in the Oberfeld housing complex. The measurement points for monitoring the quantities of heat within the scope of the pilot and demonstration project are circled.

4.2.4 Findings from the operation of the PVT system

4.2.4.1 Thermal output

The thermal output was 330 kWh/(m^{2}a) in 2015 and 300 kWh/(m^{2}a) in 2016. Because the global solar irradiation in 2016 - 1,184 kWh/(m^{2}a) - was also 8% lower than in the previous year, this does not mean an actual lower yield in the second year. The average thermal efficiency of the solar installation is around 34%. The weighted mean collector temperature was 20.3° C in 2015 and 19.6° C in 2016.

In both years, the borehole field was regenerated by more than 100% (120% in 2015 and 109% in 2016). During all heating periods, the flow temperature of the ground source was in the range of 7° to 9° C. In the second (2015) and third (2016) heating periods, the flow temperatures tended to be slightly higher than in the first season (2014), despite a higher heating requirement in the two later years. This indicates that the regeneration of the borehole field is effective.

This system configuration results in a specific collector surface of 3.7 m^2 per MWh of energy annually extracted from the ground source. The specific peak regeneration capacity of the probes is around 75 W per borehole metre, and the maximum extraction is around 27 W per borehole metre.

The solar thermal output is within the range calculated in the preliminary project stage. A significant optimisation of the operation of the system was carried out regarding the ground source inlet temperature. The maximum return temperature to the borehole field was raised in two steps from 21° to 30° C. In this way the input capacity of the borehole field was increased from 80 kW to above 200 kW. However, this also meant that the heat pump control had to be adapted because during the intensive regeneration phase the return temperature to the heat pump was frequently higher than 20° C. In the initial stage this gave rise to pressure disruptions in the hot water heat pump. This problem was resolved by adjusting the control device.

One of the practical findings was that, when such large-scale solar collector fields are put into operation, special attention has to be paid to correct filling, rinsing and evacuation of residual air. Ideally, large fields should be filled, rinsed and put into operation segment by segment. The flow-through capacity of filling pumps is normally sufficient for a solar collector field of around 100 m^2.

4.2.4.2 Electrical output

The electrical output of the inverters of the entire system is not being recorded in this project, but two adjacent modules of the system (a PV module and a PVT module) on the roof of building B are connected via separate module inverters.

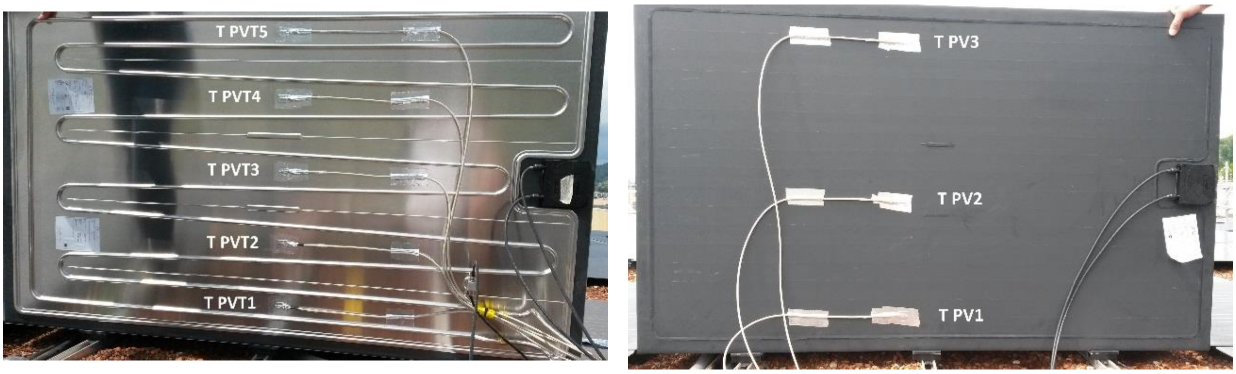


Figure 31: PVT module and PV module equipped with temperature sensors on the rear side.

The electrical output of these two modules is being recorded. In addition, several temperature sensors are attached to the rear side of these two modules. Due to the influence of strong plant growth, however, it was not possible to deduce a meaningful assessment of the difference in electrical output between the PV and PVT collectors. It was found that the rear temperatures of the PVT collector only reach around 40° C on sunny and warm summer days, compared with 70° C that are attained by the PV module.

4.3 REKA VACATION VILLAGE IN BLATTEN, NEAR NATERS

Type of project	SFOE pilot and demonstration flagship project
Project title	Solar energy in the alpine region: Reka vacation village, Blatten
Project consortium	Swiss Travel Fund Cooperative (Reka) ELIMES AG Lauber IWISA AG Lucerne University of Applied Sciences and Arts, Institute of Building Technology and Energy
Duration of project	March 2014 to December 2016
Documentation	2015 annual report [22], Final report, 2016 [23]

4.3.1 Description of object

The Reka vacation village comprises seven apartment houses with a total of 50 apartments, a reception centre with swimming pool and a community centre. After the vacation village was opened in December 2014, its energy system was monitored in detail and optimised over a period of two years.

Figure 32: Aerial view of the Reka vacation village in Blatten, near Naters. Photo: Swiss Travel Fund Cooperative (Reka).

4.3.2 Thermal energy demand

The measured usage from the various heat sinks is listed in Table 10:

Table 10: Measured heat usage from the various sinks.

	2015 GWh/a	**2016** GWh/a
Space heating	316	205
Hot water	119	97
Swimming pool (baths, heating, ventilation)	162	167
Losses	76	94
Total	**706**	**562**

The vacation village is designed for around 50,000 overnight stays a year. In the first two years 2015 and 2016, the numbers of overnight stays were 38,000 and 42,000 respectively. Thanks to system optimisation it was possible to bring about a significant reduction in energy use between the first and the second year.

4.3.3 Solar installations

The roofs of the seven apartment houses have an east-west orientation and have solar systems on both sides. The PVT system with a total of 672 m^2 (102.3 kWp electricity) is installed on four of the buildings. The system is integrated into the roof and comprises uncovered uninsulated PVT collectors (202 Hybrid 240/900 Sky and 207 Hybrid 260/900 Sky modules from Meyer Burger). A PV system with a total surface area of 487 m^2 (70.6 kWp electricity) is installed on three of the buildings.

4.3.4 Heat supply concept and integration of PVT collectors

The heat supply system concept is depicted in the form of a diagram in Figure 33. The heat supply is based on four heat pumps and a ground source with 31 boreholes with a depth of around 150 metres (total, 4,535 borehole metres) spaced approximately five metres apart.

The heat from the PVT collectors is primarily used for the regeneration of the borehole field. But it can also be used as source heat for the heat pumps or fed on the secondary side directly into the low-temperature storage unit.

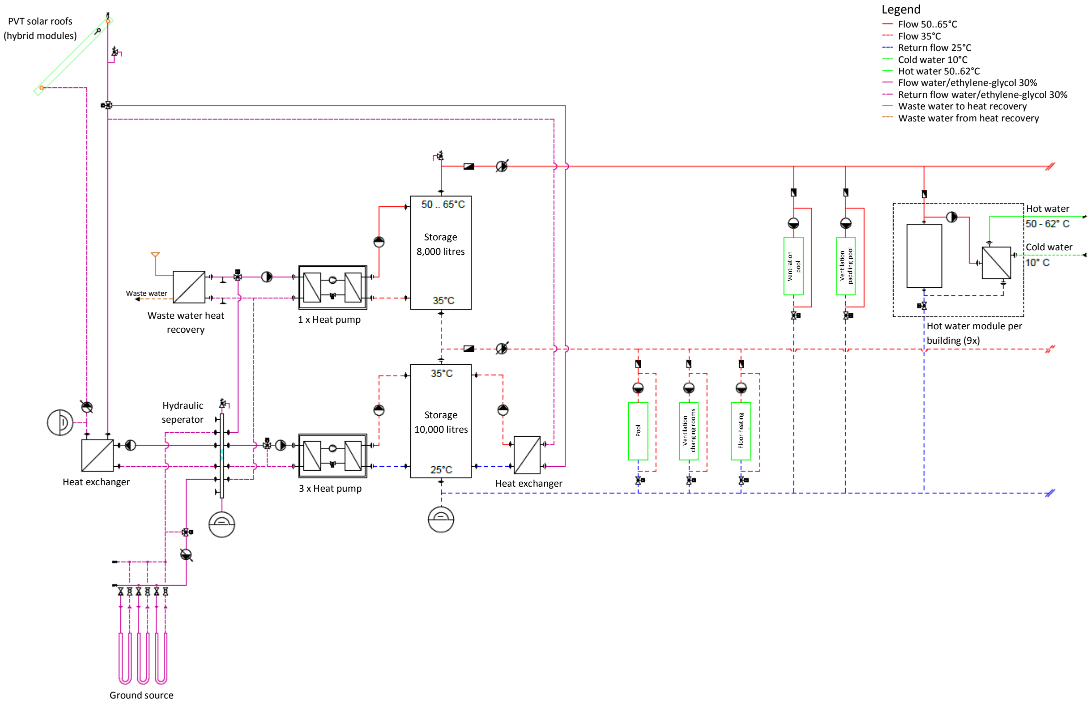


Figure 33: Diagram of the heat supply system in Reka vacation village, Blatten. Source: Lauber IWISA AG, Naters (Englisch tags and legend added).

4.3.5 Findings from the operation of the PVT system

4.3.5.1 Thermal output

The solar thermal output was 325 kWh/m^2 (i.e. a total of 218 MWh) in the first year of operation, and 400 kWh/m^2 (268 MWh) in the second year.

Thanks to waste water heat recovery, a portion of the heat required for the swimming pool and hot water supply was fed back into the system (55% in 2015 and 51% in 2016). Thus the thermal energy supplied to the overall system (extracted heat minus recovered heat) was 551 MWh p.a. in 2015 and 427 MWh p.a. in 2016.

The annual amount of heat drawn from the ground source was 345 MWh in 2015 and 273 MWh in 2016. Based on the simplified assumption that the entire solar thermal energy output was used for regeneration of the ground source, the degree of regeneration of the ground source was 63% in 2015 and 98% in 2016. The average borehole flow temperature was around 9° C in both years. In this system it was hence possible to achieve a practically complete regeneration, and thus the prospect of constant long-term ground source flow temperatures, with around 2.5 m^2 of PVT surface area per MWh and year of energy drawn from the ground source. The mean regeneration capacity was around 60 W per borehole metre and reached peaks of 140 W per metre at an inlet temperature of 23° C. By way of comparison, the extraction rate at simultaneous operation of all heat pumps was 55 W per metre.

In the first year of operation, the solar thermal output was well below the projected level of 450 kWh/(m^{2}a). Two possible reasons for this low figure were identified.

Firstly, thermal images revealed three poorly cooled zones in the PVT fields (cf. images in [23]). In the project report, this phenomenon was attributed to poor flow through. A faulty contact between heat absorber and PV module would though have a similar effect. In order to improve flow through, all fields were rinsed and de-aired. The extent to which this resulted in an improvement was not documented.

Adjustments of system control settings were identified as an additional means of optimisation. In the initial operating phase, a collector temperature of 30° C was the setting for switching on the collector field. Furthermore, the gradual opening of the relevant switching valve took too long (about one hour). This was optimised and the switch-on setting was changed to 20° C. According to the project report, the lower setting resulted in lower peak output levels and increased operation time of the system at lower ambient temperatures. This is most likely a major reason for the increased solar output in the second year of operation. A further lowering of the switch-on setting is to be considered.

4.3.5.2 Electrical output

The DC electricity yields of the PVT and PV systems are summarised in Table 11. One of the PV fields produced extraordinarily low output in both years. The figures in brackets correspond to the average PV output without taking this field into account. Some of the electrical output levels of the other PV and PVT fields also differed considerably, and also showed large differences between the first and second years of operation (for details, please consult the project report).

In 2016, the electrical output per kWp of the PVT system was higher than that of the PV system. The large discrepancies and fluctuations between the output levels of the various fields point to influences, however, that are not related to module cooling and which predominate over module cooling. In view of this, based on the measurement results it was not possible to draw any quantitative conclusions regarding the increase in output attributable to module cooling.

Table 11: Electrical output (DC) of the solar installations.

Year	PVT			PV			Total		
	kWh/(m^{2}a)	kWh/(kWp·a)	MWh/a	kWh/(m^{2}a)	kWh/(kWp·a)	MWh/a	kWh/(m^{2}a)	kWh/(kWp·a)	MWh/a
2015	123	807	83	121 (129)	807 (861)	57	122 (126)	807 (827)	140
2016	130	854	87	116 (123)	779 (826)	55	123 (127)	823 (843)	142

4.3.6 Additional comments

In the project it was originally planned to bring the snow that settles on the PVT collectors to slide off by passing warm fluid through them, but for safety reasons it was decided not to do so. This means that the collectors were covered in snow for around 3.5 months a year and thus did not produce any electrical or thermal output during that period.

4.4 “SUURSTOFFI” SITE, ROTKREUZ

Type of project	SFOE project
Project title	Monitoring of a district heating and cooling network in combination with a geothermal borehole field
Project consortium	Zug Estates AG Lucerne University, Institute of Building Technology and Energy
Duration of project	2012 to 2016
Documentation	2012 annual report [24], Final report, 2017 [25]

4.4.1 Description of object

A mixed housing and commercial development has been under construction at the “Suurstoffi” site in Rotkreuz since 2012. In addition to the main section (housing), the plans include areas for business activities, as well as space for local administration offices and a school. The development of the site is being carried out in several stages and is expected to be completed by 2021. The current energy reference area encompasses 69,646 m^2, and will increase to 172,421 m^2 upon completion of the project.

Within the framework of an SFOE project, the energy supply in the initial construction stage (zones 2 and 5) was scientifically accompanied from the planning stage through to the monitoring and optimisation of the systems. Since the PVT system was only installed in the second construction stage (zones 3 and S41), it was not possible for the detailed monitoring of this project to be carried out in the framework of the SFOE project.

Figure 34: PVT collectors installed on some of the apartment houses in zone 3 of the “Suurstoffi” development site in Rotkreuz. Photo: Zug Estates AG

Figure 35: Overview in diagram form of the "Suurstoffi" site with the roof surfaces intended for (or already utilising) solar energy. The buildings with blue and red roofs have already been completed and are in operation: the blue roofs are covered with PV modules and the red roofs with PVT collectors. The buildings with yellow roofs have not yet been constructed, and according to the current plans are to be equipped with PVT collectors. Photo: modified from [26].

4.4.2 Solar installations

The roofs of nine buildings (eight apartment houses, one school/office building) are currently covered with PVT collectors with a total surface area of 3,487 m^2 (collector type: Meyer Burger Hybrid 260/900 Sky). In addition, eight roofs have been equipped with a PV system with a total surface area of 2,651 m^2. All collectors and modules have been installed horizontally.

4.4.3 Heat supply concept and integration of PVT collectors

The supply of heating and cooling at the "Suurstoffi" site is based on an anergy (low-temperature) network that is coupled with seasonal geothermal storage (cf. diagram in Figure 36). 215 borehole heat exchangers with a depth of 150 metres have been installed to date. Later on it is planned to install an additional 180 heat exchangers with a depth of 300 metres. The heat for the heating and hot water systems is provided via individual heat pumps installed in each building. The buildings are cooled in the summer through free cooling and the heat is fed into the anergy network or ground storage facility.

The monitoring of the initial zones (2 and 5) revealed that, with around 1.5 GWh p.a., the supply of heat by the anergy network significantly surpassed the heat input through free cooling (0.6 GWh p.a.), and thus no balance could be attained over the course of the year. In view of this, as interim measures to prevent the ground storage from cooling down, pellet heaters were used for heating the anergy network and auxiliary electric heaters for the provision of hot water. As part of a long-term solution, the PVT system was then installed in zones 3 and S41 and put into operation in autumn 2014.

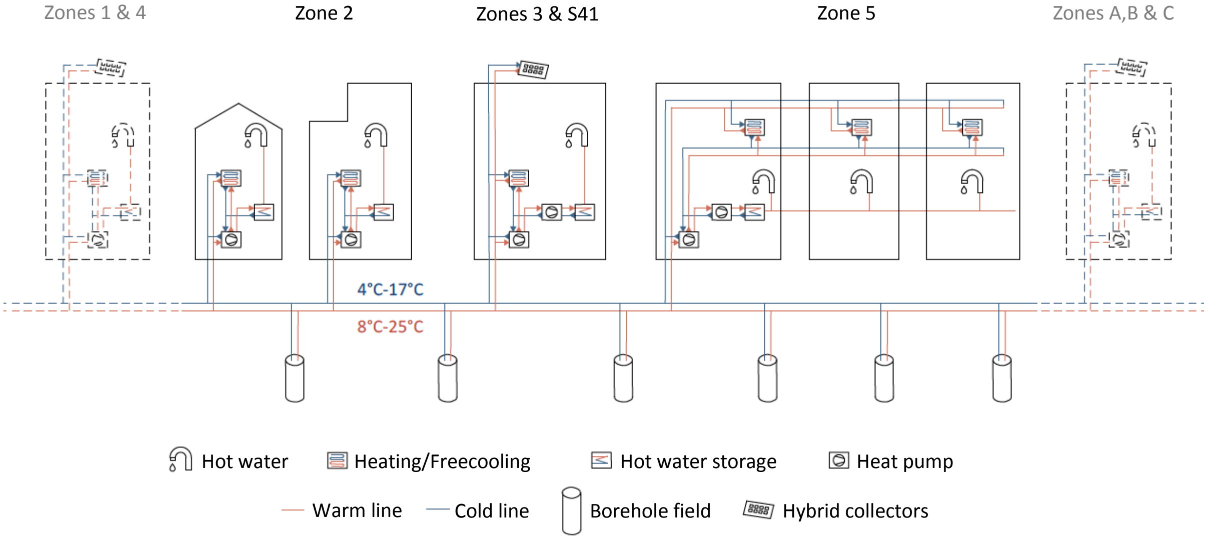


Figure 36: Diagram of the anergy network on the "Suurstoffi" site. Those zones that have not yet been constructed are depicted with broken lines. Source: Final Report [25] (English tags and legend added). Heat exchangers have also been installed between the solar installations and the anergy network, though this is not depicted in the diagram

4.4.4 Findings from the operation of the PVT system

As already noted, a detailed evaluation of the function of the PVT system has not yet been possible. Based on the results of the Oberfeld and Blatten pilot and demonstration projects, with optimal operation of the system it should be possible to attain a specific thermal output of ≥ 300 kWh/(m^2a), and thus a total thermal output of ≥1 GWh p.a.

While the temperature of the anergy network as an average over the full year fell significantly from 12.4° C in the first year of operation to 11.6° C in the second year, in the third year it was 11.5° C and thus appears to have stabilised. In the project report, this is cited as an indication of the fact that the PVT system was able to effectively contribute towards the heat balance of the network. However, definitive conclusions were not possible due to the lack of measurement data.

According to information provided by the developer, it is possible that in the summer a conflict could arise between the solar loading of the ground storage facility, and free cooling. Specifically, in order for free cooling to continue to be utilised, a temperature of 17° C should not be exceeded in the anergy network. In periods of high solar heat feed-in it would therefore be necessary for the PVT system to be switched off in order to comply with this requirement. In this regard, the system clearly possesses optimisation potential.

4.5 LINTH-ARENA SGU SPORTS AND RECREATION CENTRE, NÄFELS

Type of project	SFOE pilot and demonstration project
Project title	PVT solar power plant, linth-arena sgu: electricity and heat from the roof
Project consortium	Zurich University of Applied Sciences, Wädenswil Energieallianz Linth
Duration of project	September 2014 to December 2019
Documentation	Annual reports, 2014 to 2016 ([27], [28], [29])

4.5.1 Description of object

linth-arena in Näfels is a multipurpose complex comprising a sports centre, hotel and restaurant. The solar plant on the roof was put into operation in March 2015.

Figure 37: PVT system (292 m^2) on the roof of linth-arena. Source: Zurich University of Applied Sciences, Wädenswil.

4.5.2 Solar installations

A PVT system with 178 uncovered PVT collectors (type: Meyer Burger Hybrid 270/900; total surface area, 292 m^2; 48 kWp electricity) is installed on the roof of linth-arena (Figure 37). A PV system comprising 699 modules (type: Meyer Burger Sky 270; total surface area, 1,146 m^2; 189 kWp electricity) has also been installed. The arrangement of the various fields is shown in Figure 38. The installed PVT collectors and PV modules have the same electrical specifications, which simplifies the assessment of the higher output from the PVT collectors attained through module cooling. The orientation of all modules and collectors is southeast (-24°) with an inclination angle of 10°.

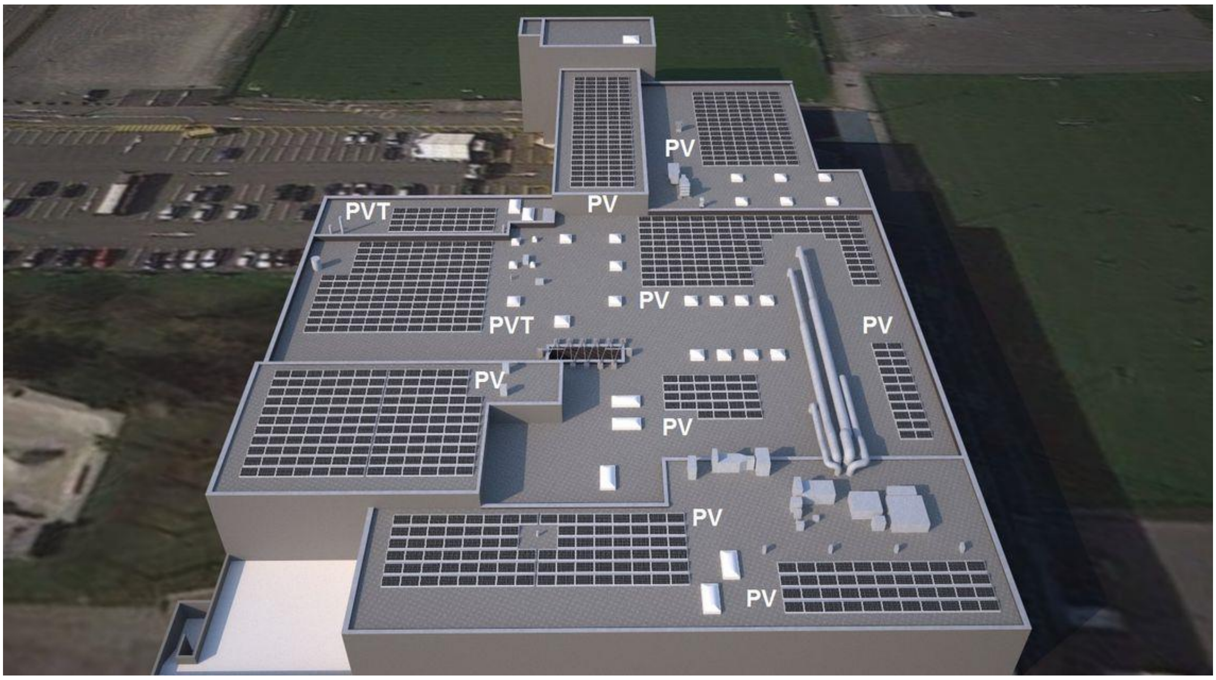


Figure 38: Aerial view of linth-arena, 3D model produced by the Solar Technology Team at the Zurich University of Applied Sciences, Wädenswil. Source: Zurich University of Applied Sciences, Wädenswil. The image shows the various PV fields (total surface area, 1,146 m²; 180 kWp electricity) and the PVT field (292 m²; 48 kWp electricity).

4.5.3 Integration of PVT collectors

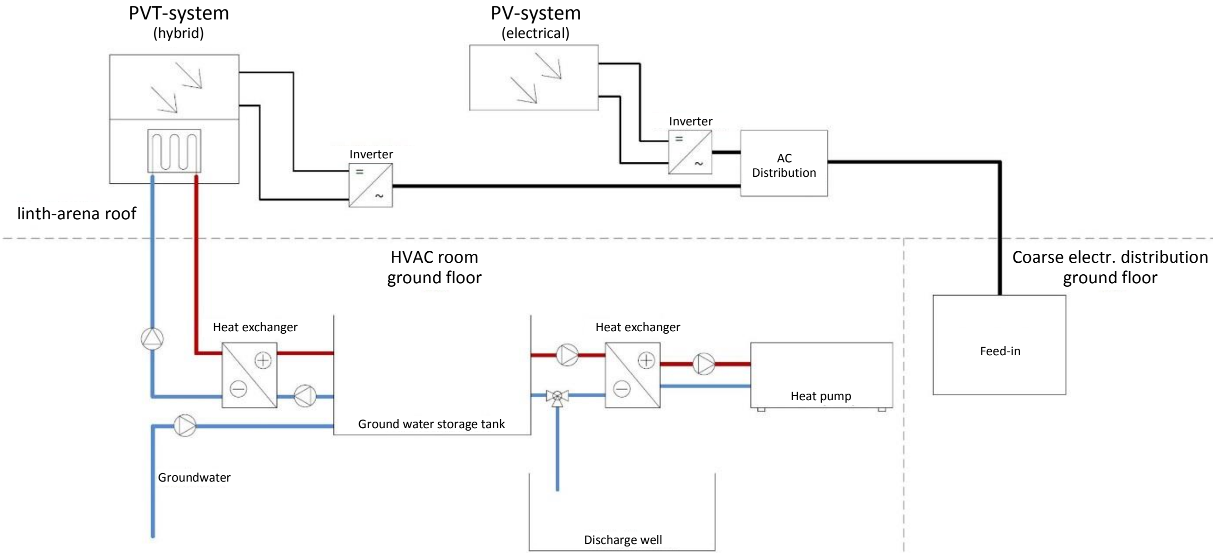


Figure 39: Diagram of the integration of the PVT and PV systems at linth-arena. Source: Zurich University of Applied Sciences, Wädenswil.

The integration of the PVT collectors is depicted in Figure 39 in the form of a diagram. The hot water required by linth-arena is supplied with the aid of two water/water heat pumps, which draw heat from a groundwater storage tank that is heated by the PVT collectors via a heat exchanger. In this way, the PVT system increases the source temperature of the heat pumps and thus reduces their electricity consumption.

4.5.4 Findings from the operation of the PVT system

4.5.4.1 Electrical and thermal output

Due to faulty components, all inverters had to be changed. It was therefore only possible to collect reliable data from April 2016 onwards. Currently, results of output measurements are available for the period from April to November 2016 (8 months).

The thermal output for this period was 122,340 kWh, or 419 kWh/m^2. For the same period, the electrical output from the PVT system was 39,618 kWh, or 136 kWh/m^2. The increase in electrical output from the PVT system versus the PV system (output normalised with system size) was 4.5%, which is equivalent to an additional electrical output of 1,721 kWh, thanks to module cooling.

Gross gain calculations for the same location show that in a typical year around 20% of the electricity output occurs in the period from December to March. At a mean collector temperature of 15° C, these 3 months account for around 5% of the heat output. Thus from the measured yields an approximate annual electrical output of 170 kWh/(m^{2}a) and an approximate annual thermal output of 440 kWh/(m^{2}a) can be extrapolated. Over the full year, the estimated increase in electrical output versus the PV system is around 4%.

According to the annual report the savings in the power consumption of the heat pumps achieved through raising of the source temperatures are expected to be significantly higher than the increased electrical output resulting from module cooling. However, due to the limited duration of the measurement period, no corresponding figures have been published yet.

4.5.4.2 Other findings

In order to increase electrical output during the winter, trials were carried out with the aim of freeing the PVT modules from snow by heating them with groundwater heat [28]. This proved to be difficult because the snow accumulated beneath the modules. As an alternative, the plan now is to adjust the control settings so that the modules can be heated while snow is falling, thus preventing it from settling on the modules.

The groundwater temperature was between 10° and 12° C, and thus on average higher than the 5° to 13° C assumed in the planning stage. With lower groundwater temperatures, the solar yields would be slightly higher.

4.5.4.3 Outlook

The scientific supervision and evaluation of measurement data for this system will continue for a further three years until the end of 2019. Additional significant results can be anticipated here, especially with respect to attained power savings in the heat pumps.

4.6 MINERGIE-A RESIDENTIAL COMPLEX SOTCHÀ, SCUOL

Type of project	SFOE pilot and demonstration project
Project title	Three different innovative solar-assisted heat production systems for three identical Minergie-A buildings
Project consortium	Vassella Energie GmbH Fanzun AG Architects and Engineers Caotec, Building Energy and Solar Technology Rapperswil University of Applied Sciences, Institute for Solar Technology SPF
Duration of project	January 2015 to October 2018
Documentation	2015 annual report [30]

4.6.1 Description of object

One of the first residential complexes in the region of the Alps based on the Minergie-A standard has been constructed in Scuol, Lower Engadine (Figure 40). In this complex, which forms an integral part of the new “Monolith” residential district, three heating systems based on different solar installations were realised in three identical apartment houses. Buildings A, B and C are structurally identical, have the same orientation and each comprise eight apartments. A detailed monitoring system was installed that will permit a comparison between the three systems.

The mountain location poses special challenges due to the low outside temperatures, but thanks to the high level of solar irradiation it also offers advantages for qualifying for the demanding Minergie-A label.

4.6.2 Heat supply systems and integration of solar installations

All three buildings have a power adjustable brine/water heat pump (30 kW heating capacity) that is connected to an individual geothermal borehole field (five boreholes with a depth of 170 metres). The other properties of the three heat supply systems are as follows:

House A: PV system (130 m^2; 21.8 kWp electricity) with electrical storage facility (28 kWh). This building without regeneration of the ground source serves as the reference system.

House B: In-roof PVT system developed by Caotec (130 m^2; 21.8kWp electricity) with uncovered rear-insulated PVT collectors. In addition to ground source regeneration via a brine buffer storage unit, the solar heat can also be used as a direct source for the heat pump and for direct hot water preheating.

House C: Solar thermal installation (40 m^2) with “Alpsun Indach” roof-integrated flat-plate collectors from Caotec. The remainder of the surface of this roof was covered with PV modules (90 m^2). The solar heat is primarily used for providing hot water, with heating support as second priority and borehole regeneration via a brine buffer storage unit as third priority.

The type of PV modules installed on buildings A and C is Capillary G/G 280W from Sunage. All the solar installations have a southern orientation.

The diagram showing the integration of the PVT collectors (building B) and the thermal solar collectors (building C) is depicted in Figure 41. The capacity of each brine storage unit is 1,000 litres. The capacity of the buffer storage tank for hot water and space heating into which the solar heat is fed, is 2,000 litres.

Figure 40: Sotchà complex in Scuol. View of building B (PVT) in the middle; on the right, building D with PV system. This building is not structurally identical to the others and therefore does not form an integral part of this pilot and demonstration project.

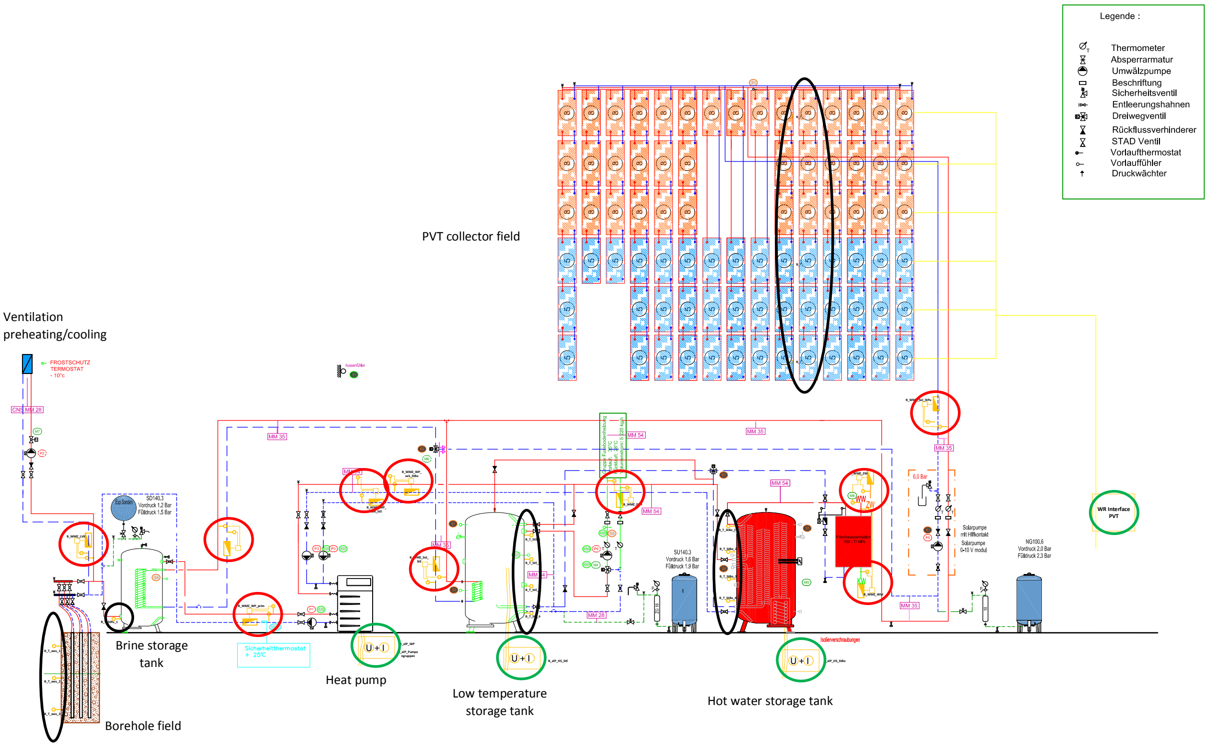


Figure 41: Diagram of the system in building B (PVT), also applies to building C (thermal) in terms of integration, indication of measurement points for monitoring (black = temperature measurement points; red = heat quantities; green = electrical loads).

4.6.3 Findings from the operation of the PVT system

The buildings' heat supply systems were put into operation at the end of 2016. First findings from the 2016/2017 heating period are expected to become available in spring 2017 and will be published in the SFOE annual reports.

4.7 OFFICE AND RESIDENTIAL COMPLEX, USTER

Type of project	Private construction project; Research project Rapperswil University of Applied Sciences HSR, Institute for Energy Technology IET
Project title	Monitoring of Minergie-A office use
Project consortium	Developer: Hässig Sustech GmbH Evaluation of monitoring: IET HSR Rapperswil
Duration of project	May 2014 to April 2016
Documentation	Project report, R. Schwarz [31] and Brenet conference contribution [32]

4.7.1 Description of object

The object concerned is an office and residential building that was completed in 2014 in Uster as one of the first Minergie-A buildings with office use (Figure 42). In addition to other innovative building technology components, a PVT system is installed for preheating the hot water.

Figure 42: Office and residential complex developed by Hässig Sustech GmbH in Uster. Photo: Hässig Sustech GmbH.

4.7.2 Thermal energy requirement for hot water

The monthly figures for the consumption of useful heat in the form of hot water are shown in Figure 43. Based on the assumption of a water withdrawal temperature of 55° C and the figures in Polysun for the cold water temperature in Uster, these measurement readings correspond to an average daily hot water consumption of around 500 litres. However, consumption levels can fluctuate considerably.

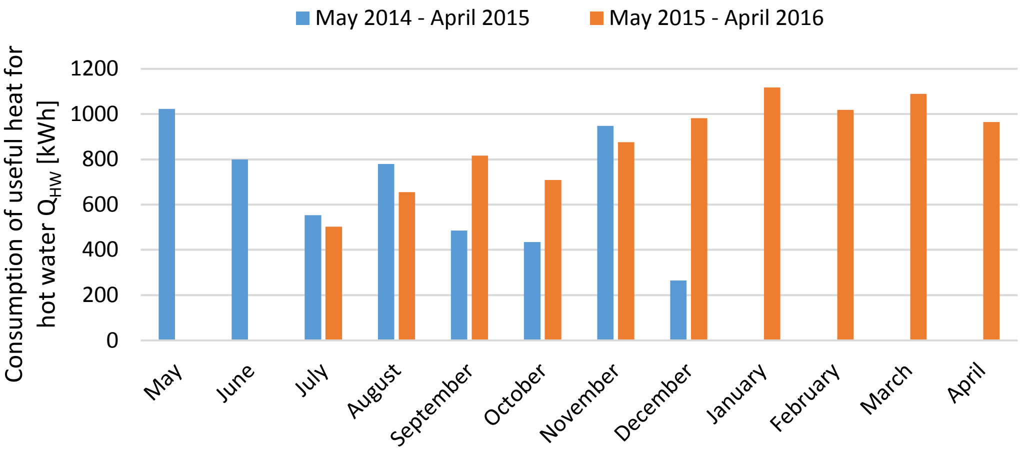


Figure 43: Monthly data for the useful heat consumption (hot water). (Data from the project report [31]). Here, the measurement data for July, October and November 2015 were scaled up in order to compensate for data gaps.

4.7.3 Solar installations

Uncovered PVT collectors from Solimpeks (type: Powervolt) with a total surface area of 7.1 m^2 (1 kWp electricity) have been installed on the roof facing south east with an inclination of 35°. In addition, a PV system with an electrical output of 23.7 kWp is installed on the south west facing roof.

4.7.4 Integration of PVT collectors

The building's heat supply system is based on a heat pump coupled with geothermal boreholes. The heat from the PVT system is exclusively used for preheating the hot water (Figure 44). Via a coil heat exchanger the system loads a preheating storage tank with a capacity of 500 litres. The heat pump heats up an additional stand-by hot water storage tank with a (relatively high) capacity of 1,000 litres to 53° C. To prevent the formation of legionellae, the stand-by tank is heated up to 60° C once a week by an electric heating rod.

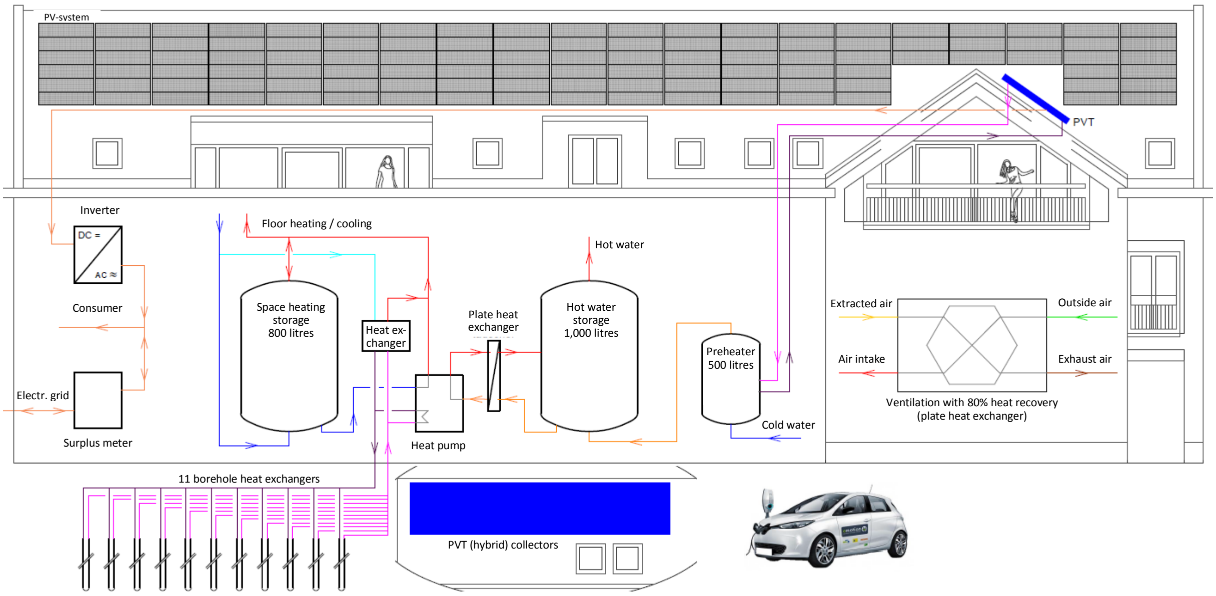


Figure 44: Diagram of the energy system of the building constructed by Hässig Sustech GmbH [31] (English labels added).

4.7.5 Findings from the operation of the PVT system

Expressed as an average over the first two years of operation, the solar irradiation on the PVT collector field was 1,192 kWh/(m^2a). The PVT system delivered an AC electricity yield of 125 kWh/(m^2a). The average solar thermal output Q_{Sol}, measured at the storage input, was around 210 kWh/(m^2a).

It should be noted that, in comparison with the products used in the other described systems, the PVT collector used here has lower electrical and thermal performance characteristics (cf. Appendix).

In order to estimate the contribution of solar heat towards the overall energy consumption for the production of hot water, the degree of solar coverage is defined here as

$$DSC_{HW} = \frac{Q_{Sol}}{Q_{Sol} + Q_{HP,HW} + Q_{HR}},$$

where $Q_{HP,HW}$ refers to the quantity of heat fed by the heat pump and Q_{HR} to the quantity of heat fed by the heating rod to the stand-by storage unit. With the measurement data from the project report [31], the figure for the degree of coverage for the two years in which measurements were carried out is $DSC_{HW} = 13.2\ \%$.[16] In the summer, the degree of coverage reached levels of around 30%. If the energy consumption of the electric heating strips (after optimisation of the system) that are used in the hot water distribution system is taken into account, the figure for the annual solar coverage falls to 10.5%.

The dimensioning of the PVT system here is relatively small, with around 0.7 m^2 of collector surface per 50 litres of hot water consumption at 55° C.

4.8 SPF TRIAL PVT SYSTEM, RAPPERSWIL

Type of project	Research project, Rapperswil University of Applied Sciences, Institute for Solar Technology SPF
Duration of project	May 2013 to April 2014
Documentation	Brenet conference contribution [33]

4.8.1 Description of object

This system was installed on the test roof of the SPF Institute for Solar Technology at the University of Applied Sciences, Rapperswil. Over a full year (May 2013 to April 2014), the system was operated as a hot water preheating facility and measured in detail, and the increased electrical output through module cooling was assessed.

---

[16] For the missing monthly figures in the measurement data, in each case the figure for the corresponding month of the other year was used.

Figure 45: Trial system at the SPF Institute for Solar Technology. 2 PV modules installed at the left-hand edge of the field plus 6 PVT modules with the same electrical specifications.

4.8.2 Solar installations

Six uncovered PVT collectors from Meyer Burger (type: Hybrid 240/900; 9.9 m^2; 1.44 kWp electricity) were installed on the south facing roof with an inclination of 45°. In addition, 2 PV modules with the same electrical specifications were installed (3.3 m^2; 0.48 kWp electricity). The electrical output of the modules was fed into the electricity grid via individual module inverters and MPP trackers.

4.8.3 Integration of the PVT collectors, thermal energy requirement

The heat from the PVT collectors is fed via a coil heat exchanger into a 500-litre preheating storage tank. 600 litres a day were drawn from the preheating storage tank with a typical tapping profile for an apartment house. A system for reheating the water to usage temperature was not installed. For an assumed hot water temperature of 55° C, the total heat demand for hot water was calculated on the basis of the measured cold-water temperatures and the quantities and temperatures of water drawn from the storage unit, and is depicted in Figure 46.[17]

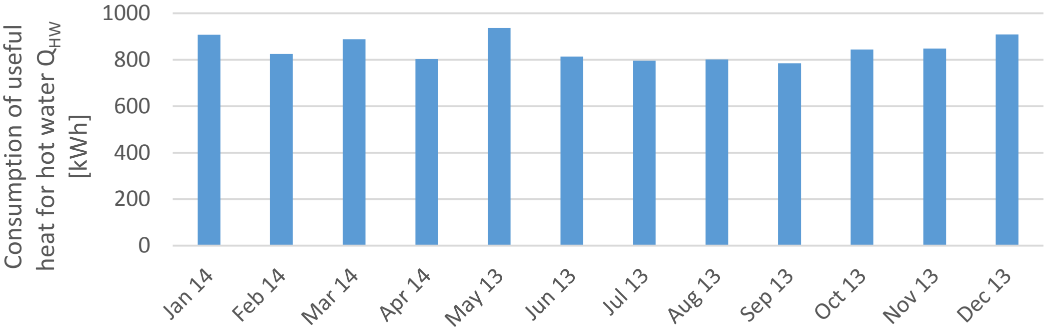


Figure 46: Demand of useful heat for a hot water temperature of 55° C.

---

[17] This represents the useful heat consumption of a fictitious system comprising the system used in the trial plus an additional hot water stand-by storage unit with reheating.

4.8.4 Findings from the operation of the PVT system

4.8.4.1 Solar yields

In the year in which measurements were carried out, the solar irradiation on the collector field was 1,425 kWh/m^2, and thus 15% above a typical level for Rapperswil as issued by Meteonorm.[18] The PVT system attained a thermal output of 279 kWh/m^2 (measured at the collector field) and a DC electrical output of 176 kWh/m^2. The corresponding monthly data are depicted in Figure 47. With 169 kWh/m^2, the PV system attained an approximately 4% lower electrical output than the PVT system.

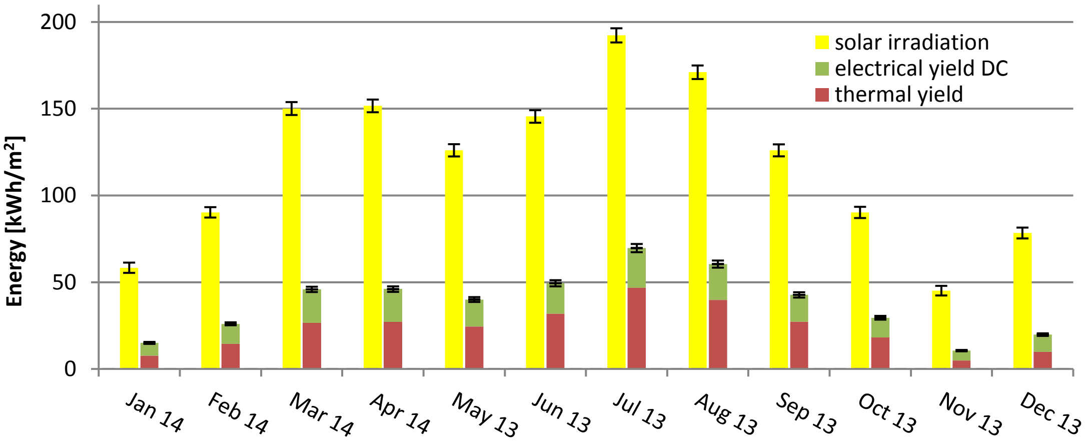


Figure 47: Monthly data for solar irradiation and yields from the PVT system on the SPF test roof.

The degree of coverage for hot water heating can be indicated in the same way as in chapter 4.7.5.[19] Calculated over the full year, the degree of solar coverage was around 24%. During the summer, monthly degrees of coverage of around 50% were attained (cf. Figure 48).

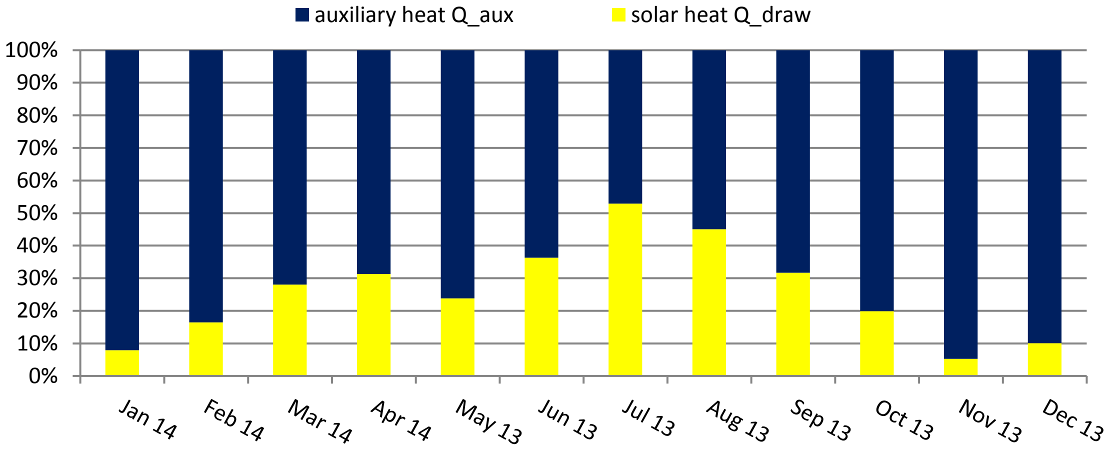


Figure 48: Proportions of useful energy for hot water that were covered by solar preheating or (fictitious) conventional reheating. A hot water withdrawal temperature of 55° C was assumed.

---

[18] www.meteonorm.com

[19] The assumption is made that, in the reheating storage tank that would be available in a real system, in terms of percentage the same level of heat losses would occur as in the preheating storage tank of the test.

4.8.4.2 Increased electrical output of PVT versus PV

In addition to the measurement of the electrical output from the PVT and PV modules, the temperatures at the rear side of both types of modules were also measured. On a sunny summer's day (2 August 2013), the difference in temperature between the rear side of the PVT and PV modules reached a maximum of 22° C (Figure 49). At that moment, the PVT collectors reached a 17% higher electrical power output per m^2 than the PV system. Integrated over the complete day, the difference between the electrical yields of PVT and PV amounted to 8.2%.

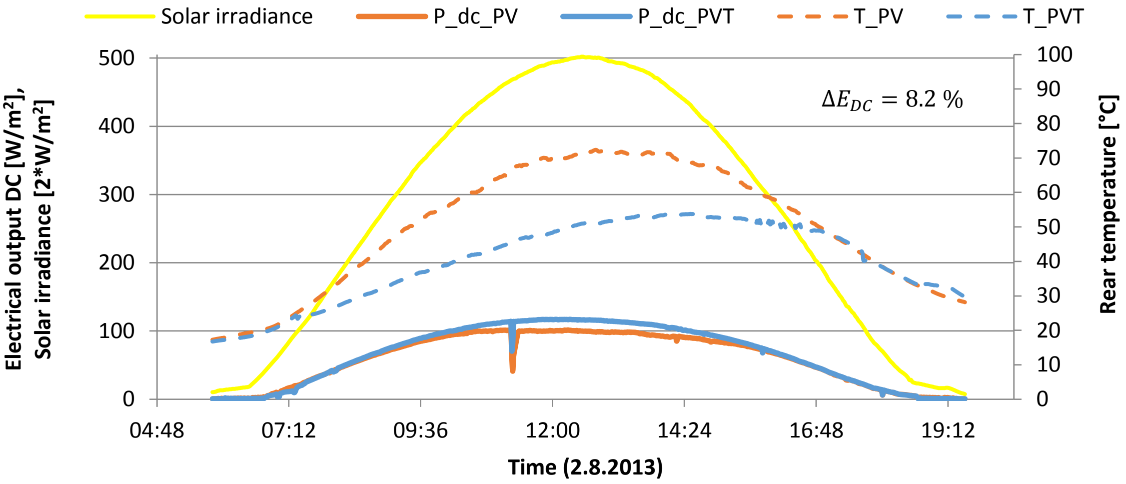


Figure 49: Solar radiation, electr. output and rear temperatures of PVT collectors and PV modules on a sunny summer's day.

The relative additional electrical yields achieved by module cooling for the various months, and the rear temperatures of the modules weighted with the electrical power output, are depicted in Figure 50. The additional yields in the period from November 2013 to February 2014 cannot solely be interpreted as the consequence of module cooling because shading occurred at times during this period. For the full year, the additional electrical yield of the PVT collectors was (4.1 ± 1.8) %.

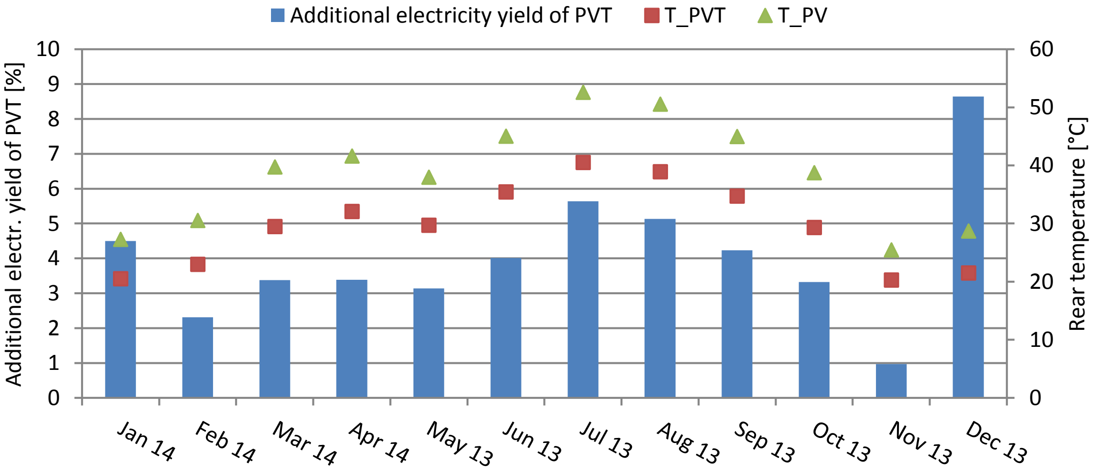


Figure 50: Monthly values of the additional electrical yields of the PVT collectors compared with the PV modules, and average rear temperatures weighted with the electrical power output.

4.8.4.3 Additional remarks

During the winter, shading occurred on part of the PVT and PV fields which resulted in a slight reduction in energy yields.

The solar thermal efficiency greatly depends on the cold water temperature. In the test system this was particularly high with an average of 15.7° C during the measurement period, and especially during the summer. The reason for this was that the cold water that was used had to travel a relatively lengthy distance inside the building between the cold water network and the preheating storage tank of the test system. Simulations show that for 2° C lower cold water temperatures the thermal yield would be around 7% higher, and for the cold water temperatures calculated by Polysun as much as 17% higher. Lower cold water temperatures would also have a positive influence on module cooling and thus on the additional electrical output of the PVT modules compared with the PV modules.

The dimensioning of the PVT system was 0.83 m^2 of collector surface per 50 litres of daily hot water consumption at 55° C. The dimensioning is therefore somewhat greater than that of the system described in Section 4.7. When comparing the results, however, it is important to note that the utilised PVT collectors, as well as the ancillary conditions such as solar irradiation and cold water temperatures, were different.

4.9 SENTMATT COMPLEX, OBFELDEN

Type of project	SFOE pilot and demonstration project
Project title	Emission-free heat production with a deep geothermal borehole heat exchanger, efficient low-lift heat pump and optimised heat distribution
Project consortium	Allianz 2Sol Halter Immobilien AG Rapperswil University of Applied Sciences, Institute for Solar Technology SPF
Duration of project	December 2015 to December 2020

In the Obfelden pilot and demonstration project, an emission-free heat supply of three buildings is being trialled using new technologies. In addition, a comparison is being made between a centralised and a decentralised system concept.

The heat supply system is divided into two zones (A and B):

In the larger zone (A), a system with conventional dual U-pipe borehole heat exchangers is being realised for 108 apartments. The borehole field is to be regenerated through a combination of 294 m^2 of uncovered PVT collectors, 113 m^2 of uncovered solar thermal collectors and an air/water heat exchanger (extracting heat from outside air). A centralised ammonia heat pump (300 kW) is connected to the borehole field.

In zone B, two residential parts (each comprising five apartments) are each to be equipped with a low-lift heat pump (17 kW) and a membrane borehole heat exchanger with a length of 450 metres. The associated solar installation will consist of around 50 m^2 of uncovered PVT collectors and 20 m^2 of uncovered thermal collectors for each of the two parts.

With respect to PVT collectors, in this project their suitability for the regeneration of deep geothermal boreholes is to be examined.

The centralised heat supply system is to be put into operation in spring 2017, and it is planned to put the decentralised systems into operation in summer 2017.

4.10 EXAMPLES OF OTHER SYSTEMS

Four other typical or particularly interesting examples are included in this chapter, with their key data. For these systems, detailed descriptions of practical findings and/or measurement data were not (or not yet) available.

4.10.1 Single-family house, Saxon

Type of property, location	Single-family house, Saxon
Solar installations: type, surface area	6 uncovered liquid-cooled PVT collectors (DualSun Wave), 10 m^2. 6 PV modules (DualSun Flash), 10 m^2.
Integration of PVT collectors	Solar hot water heating: 400-litre hot water tank with electrical reheating (6 kW)
Source of information	www.dualsun.fr

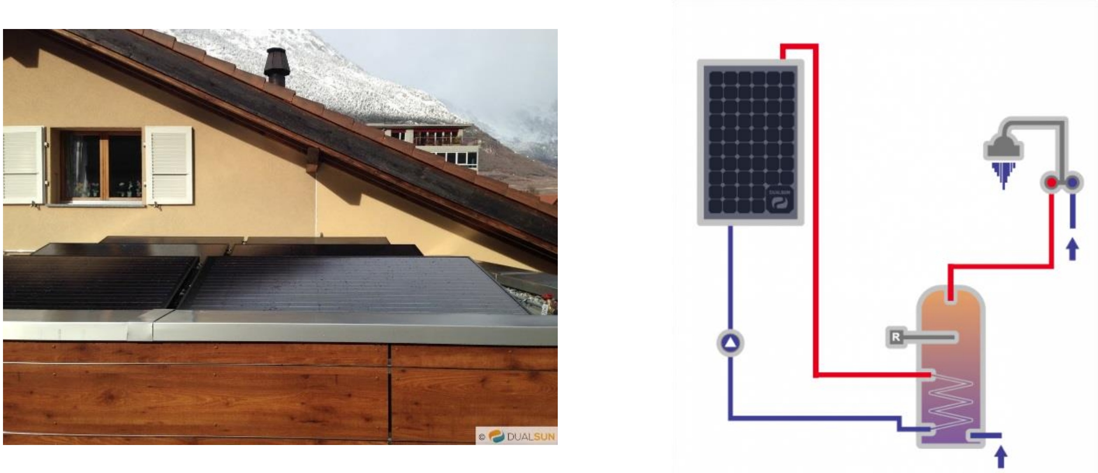


Figure 51: System in Saxon for solar hot water heating and corresponding concept diagram. Photo/Illustration: DualSun.

4.10.2 Outdoor swimming pool, Saint-Livres

Type of property, location	Private swimming pool, Saint-Livres
Solar installations: type, surface area	8 uncovered liquid-cooled PVT collectors (DualSun Wave), 13.3 m^2. 6 thermal collectors (Agena, with absorbers from Energie Solaire) Covered hybrid collectors (Hörmann, formerly Solarhybrid AG), 12 m^2. PV system, 5 kWp
Integration of PVT collectors	Solar heating of an outdoor pool and a 200-litre hot water tank for pool showers
Source of information	www.dualsun.fr

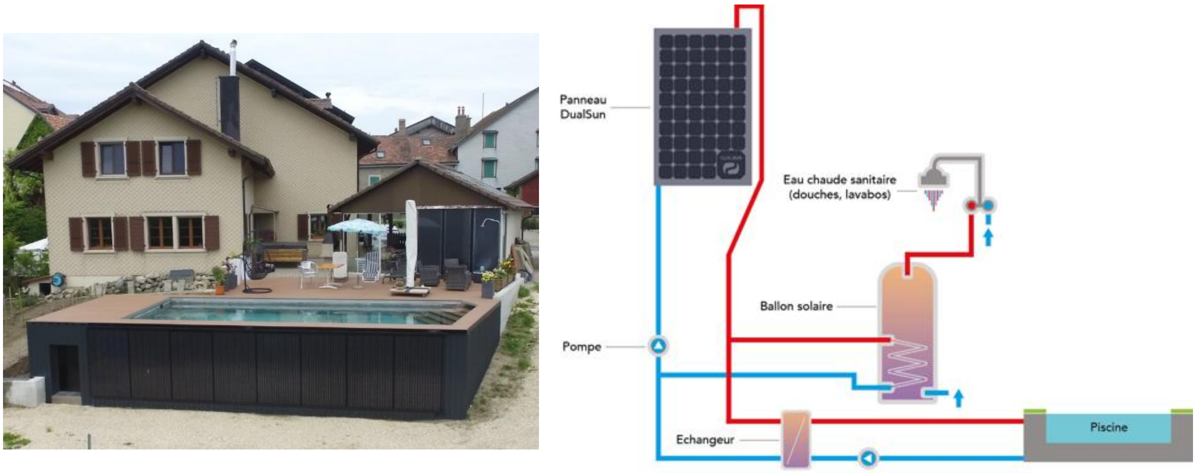


Figure 52: System in Saint-Livres for solar pool heating and corresponding concept diagram. Photo/Illustration: DualSun.

4.10.3 "Wohnen zur Post" residential complex, Watt-Regensdorf

Type of property, location	"Wohnen zur Post" residential complex, four apartment houses, Watt-Regensdorf
Solar installations: type, surface area	4 x 62 uncovered liquid-cooled PVT collectors (Poly Solar Solutions, PIK), total, 413 m^2
Integration of PVT collectors	Ground source heat pump heating system (Bion Bauhaus AG), PVT collectors as direct heat source for the heat pump, for direct provision of floor heating and for borehole regeneration or cooling of the PVT collectors
Sources of information	www.pss-ag.com www.bionbauhaus.ch

Figure 53: Overview and rooftop view of one of the apartment houses in the "Wohnen zur Post" complex in Watt-Regensdorf. Photos: Poly Solar Solutions AG.

4.10.4 Freihof apartment houses, Andwil

Type of property, location	"Freihof" residential development, two apartment houses with six apartments each, Andwil
Solar installations: type, surface area	2 x 90 uncovered liquid-cooled PVT collectors (Poly Solar Solutions, PIK), total, 296 m^2
Integration of PVT collectors	Ice storage heat pumps for heating and cooling (Bion Bauhaus AG), each with 148 m^2 of PVT collectors for regeneration of an 80 m^3 ice storage unit, as direct heat source for the heat pump and for direct provision of floor heating
Sources of information	www.pss-ag.com www.bionbauhaus.ch Newspaper article in "Ostschweizer Rundschau" [34] Periodical article in "HK-Gebäudetechnik" [35]

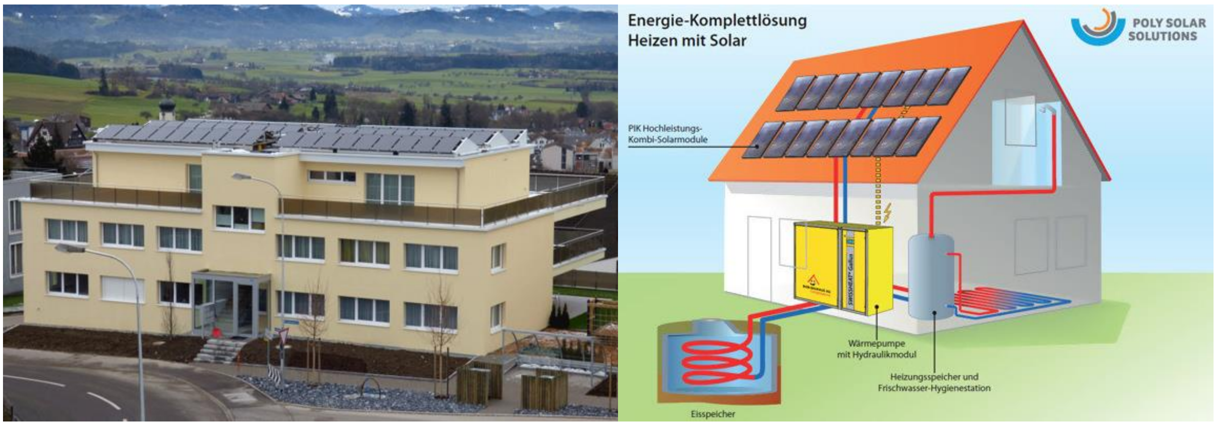


Figure 54: View of one of the apartment houses in the "Freihof" complex in Andwil, with diagram of heat supply system. Photo: Bion Bauhaus AG, Illustration: Poly Solar Solutions AG.

4.10.5 Additional remarks

Some systems that have been realised with covered PVT collectors (mainly in the United Kingdom) are described in [36]. Examples of systems with covered collectors supplied by EndeF (Ecomesh) are described on the company’s home page (http://ecomesh.es/).

Some interesting examples of realised air-PVT systems for drying timber and agricultural products are described on the website of BASE Innovation (www.base-innovation.com).

5 RESULTS OF THE SURVEY

A number of companies have already been able to gather experience with the planning, installation or operation of PVT systems. In order to collect and evaluate their findings, a survey was carried out among manufacturers, system suppliers, planners and installers. The survey was addressed to all members of the industry association Swissolar, plus certain targeted companies that were, for example, named by manufacturers as partners or have already worked with PVT technology in one of the cited case studies.

In the manufacturers segment, companies in German-speaking countries/regions were contacted and surveyed, together with companies that are active in Switzerland. In all, seven manufacturers of uncovered liquid-cooled PVT collectors participated in the survey, plus one manufacturer of an air-cooled PVT collector.

The questionnaire for system suppliers, planners and installers was e-mailed to almost 600 recipients. Feedback was received from a total of 128 entities, 28 of which answered directly by e-mail (not via the questionnaire). As a rule, the latter had not yet planned or installed a PVT system. 100 entities completed and returned the questionnaire. More than 80% of them stated that they have not yet planned or installed a PVT system, and only 20% were already involved in the implementation of one or more PVT systems. Companies from all parts of Switzerland participated in the survey: 81% from the German-speaking region, 17% from the French-speaking region and 2% from Ticino (Figure 55).

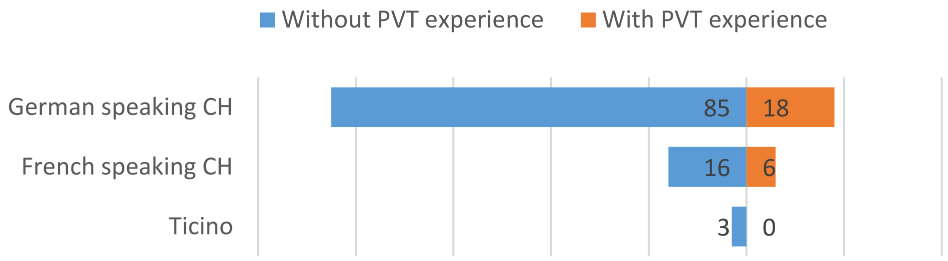


Figure 55: Regional distribution of responding companies, divided into those that have already implemented PVT projects and those that have not yet done so.

Of the contacted companies, 24% indicated to Swissolar that, in the field of solar energy, they are exclusively active in the solar heat segment, while 45% stated they are active in the solar electricity segment and 31% are active in both segments. The distribution is similar for companies that have neither planned nor operated a PVT system. However, among the companies that are already active in the field of PVT technology, the situation is different: here, the proportion of companies that provide both solar heat and photovoltaics is almost twice as high (60%) (Figure 56). For these companies, PVT systems are significantly more suitable for their corporate profile (cf. Figure 64).

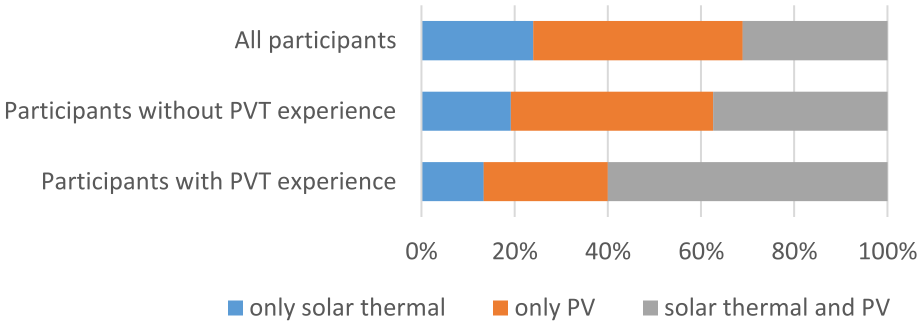


Figure 56: Proportion of companies that work in the area of solar heat only, solar electricity only, or both, for all contacted companies, those that replied they have not yet made PVT systems, and those that already use PVT technology.

Two-thirds of the participants are installers, a quarter are system suppliers and around half are active as planners. Many of them are active in more than one segment. Approximately one in eight stated they are additionally or exclusively active in another field, e.g. project development, energy consulting or contracting.

Eight manufacturers of PVT collectors participated in the survey: three from Germany, two from Switzerland, one from Austria and two from France. With one exception, they all produce liquid-cooled collectors. As heat transfer medium a water-glycol mixture is used, while for two manufacturers water only is a possible alternative. All products are uncovered and are based on standard PV modules.

5.1 PRACTICAL APPLICATION OF PVT SYSTEMS

5.1.1 Products and prices

More than 90% of those installers, planners and system suppliers that had already been involved in PVT installations used liquid-cooled, uncovered collectors. Air-cooled collectors are only used by way of exception. Only two participants use them, who work together as distributor and installer. One participant uses both collector types. Most companies only use one specific collector product, though some include collectors from two manufacturers in their programme. In all, products from nine different manufacturers (from Switzerland, Austria, Germany, Italy and Turkey) are used.

Most of the participants distribute or install other system components in addition to PVT collectors (Figure 57). These primarily include mounting systems, piping for the collector field and inverters, followed by control units, other hydraulic components (diaphragm expansion tanks, pumps, heat exchangers) and heat storage tanks. Almost half of them list all the cited components. And all the participating manufacturers also offer other system components in addition to PVT collectors. These may include specific kits for single-family houses or only the mounting system, through to the entire range of listed components.

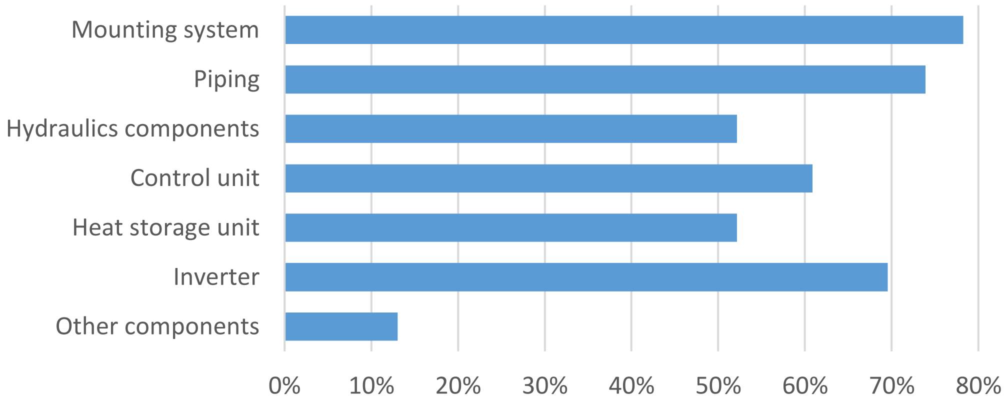


Figure 57: Alongside PVT collectors, most of the participants also install or distribute other system components.

Around half the companies indicate a price for the end customer for their PVT collector, with or without installation. For systems smaller than 50 m^2, the prices per collector range from 400 to 1,050 Swiss francs. For larger systems they start at 350 Swiss francs. The collectors have a surface area of 1.5 to 1.7 m^2. The price per square metre therefore lies between 210 and 650 Swiss francs. The price for the end customer for an installed collector field with system boundary at roof edge is between 400 and 2,000 Swiss francs per m^2. For systems larger than 50 m^2, pricing starts at 300 Swiss francs per m^2.

5.1.2 Integration of PVT collectors into the system

According to the information provided by the participants, all the system options for liquid-cooled uncovered PVT collectors were used that are described in the chapter on system integration. The two groups, manufacturers on the one hand and system suppliers, planners and installers on the other hand indicate very similar figures relating to the proportions of the different system options (Figure 58). Almost half the PVT systems are installed in combination with heat pump systems, where the heat is most commonly used for the regeneration of geothermal ground sources. However, ice storage and brine storage loading, as well as groundwater preheating, are also stated. In a similarly large number of systems, PVT collectors are used for solar hot water heating or preheating, a small proportion of which are also used for space heating support. Swimming pool heating systems account for seven to nine percent of the facilities. In many heat pump systems, the heat can additionally be fed-in on the secondary side for hot water or space heating buffer storage loading. Furthermore, air-cooled PVT collectors are also used for preheating air for use as a heat source for an air/water heat pump.

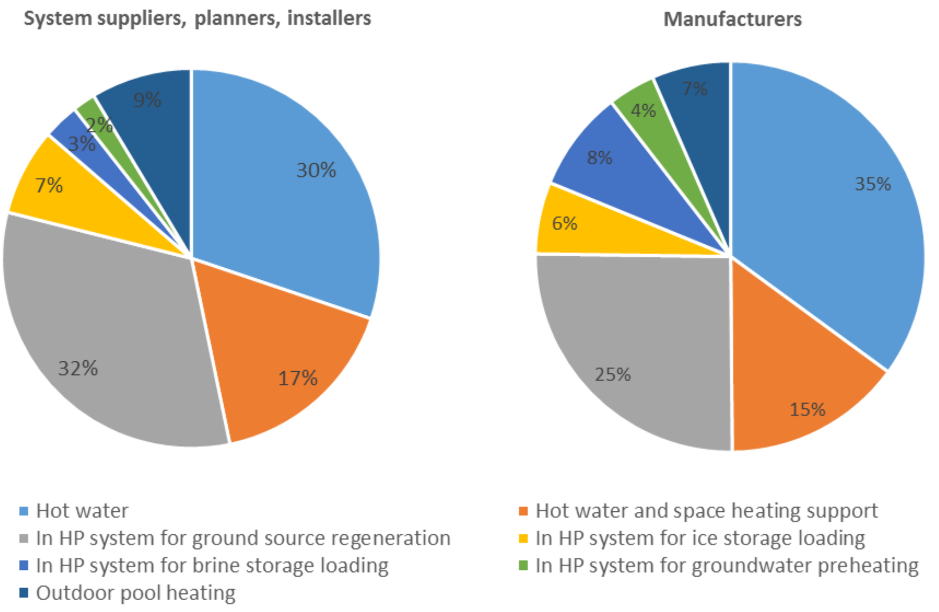


Figure 58: Breakdown of the number of PTV systems in operation in Switzerland by type of system integration, according to information provided by system suppliers, planners and installers as well as manufacturers.

5.1.3 Dimensioning and output energy yields

For the dimensioning of systems, many planners and installers use corresponding simulation software or information provided by the manufacturer. The available roof surface area and the end user's budget are also significant influence factors. Some manufacturers work on the basis of individual design, for example in line with the roof properties, the area to be heated, the insulation of the building and the level of hot water consumption. Others provide general recommendations for certain forms of integration. For hot water heating, for example, a rule of thumb is 1.5 to 2 modules per person, which is equivalent to 2.5 to 3.3 m^2 of collector surface per person. One manufacturer may recommend 50 litres of storage capacity per person, while another recommends 70 litres per PVT module. For outdoor pool heating, one manufacturer recommends a PVT field that is half the size of the pool surface. With respect to borehole regeneration, attention is usually paid to attaining a balance between energy input and withdrawal.

The annual thermal yield that can be attained with uncovered PVT collectors varies according to application due to the different temperature levels. According to manufacturers as well as planners and installers, typical annual output levels are:

- Hot water heating, single-family house: approx. 150 kWh/(m^{2}a)
- Hot water preheating, apartment house: 180-250 kWh/(m^{2}a)
- Borehole regeneration: 330-450 kWh/(m^{2}a)

The additional electrical yield as a result of module cooling compared with a PV system is cited at around 5 to 10%, and in some cases up to 30%, though here it is not clear whether the figure refers to the effective annual yield or the power output in certain situations, e.g. on a sunny summer's day. The additional output also greatly depends on the type of system integration. One respondent stated that lower electrical yields had been measured for PVT collectors compared with PV modules.

In comparison with standard solar thermal systems, there can be differences in the way PVT systems are installed (Figure 59). The most common modification cited by manufacturers as well as planners and installers concerns the fact that, due to the low temperature levels, plastic or compound piping can be used. In addition, as a rule the dimensions of the diaphragm expansion tank are reduced and other mounting systems are used. Other cited deviations include larger collector field surface areas, the necessity to provide access for maintenance, that for certain applications (notably borehole regeneration) it is possible to waive the insulation of the pipes on the roof, and that plug connectors are used or the hydraulic integration is carried out differently. One respondent uses an additional cooler (heat exchanger with outside air) in the collector circuit. Roughly one in five installers or planners say their implementation is identical to that of a standard solar thermal system. Some manufacturers also recommend this, while others emphasise the flexibility of the installer, who is at liberty to use standard solar thermal components or decide to use, for instance, plastic piping.

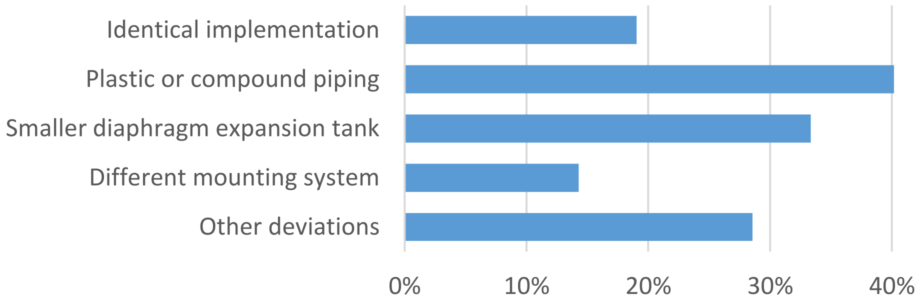


Figure 59: Deviations in the implementation of PVT systems in comparison with standard solar thermal systems.

5.1.4 Planning, implementation and operation

All the responding manufacturers sometimes or always assume other project tasks in addition to distribution (Figure 60). Most of these are performed at the planning stage, but in some cases implementation and operation are also offered. At the planning stage, almost all manufacturers sometimes or always assume the concept planning, the configuration of the hydraulics and the electrical configuration of the collector field. On the other hand, they are less often involved in the configuration of the mounting system and the thermal and electrical configuration within the building. Almost no manufacturers carry out roof or façade static calculations or assume the overall management of the project. Two-thirds of the manufacturers do not install any systems, but some coordinate this task. Half the manufacturers sometimes assume operating tasks: these more frequently involve system monitoring and operational management rather than filling/startup and system maintenance.

Among the planners and installers, some companies have specialised in certain areas, while others cover almost the entire range of planning, implementation and operation of the systems.

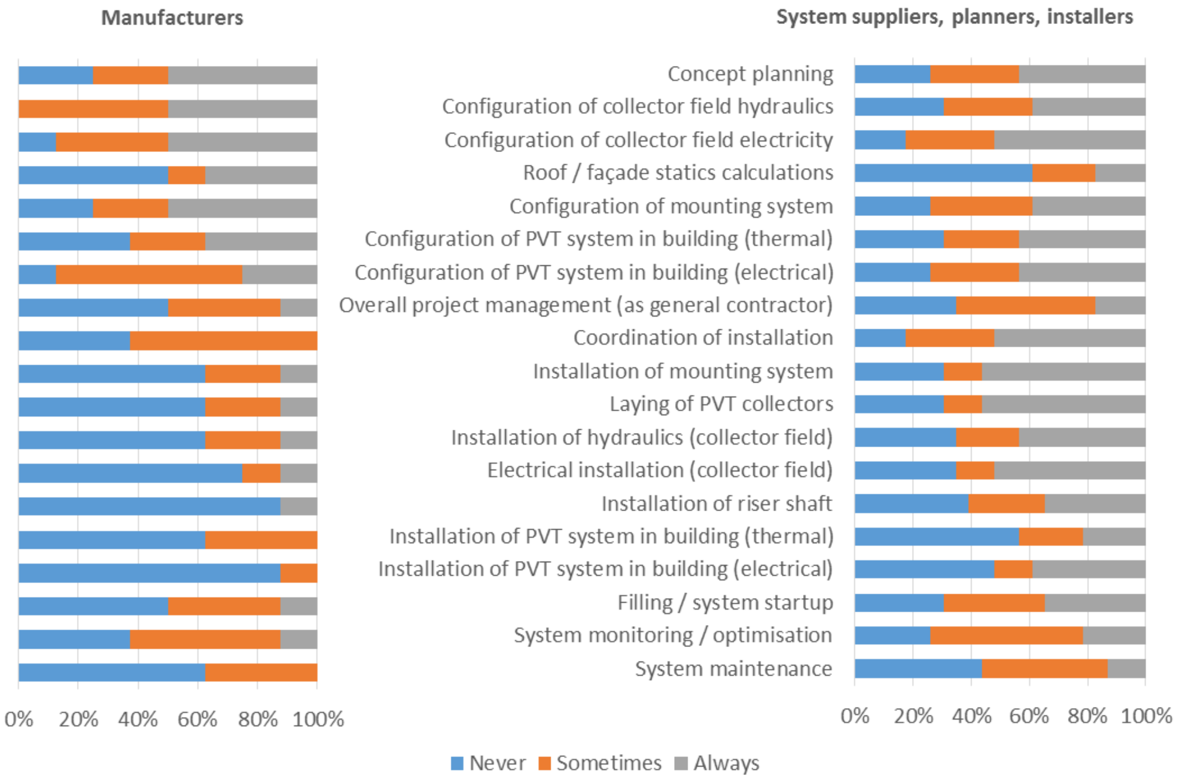


Figure 60: Assumption of project tasks by manufacturers, system suppliers, planners and installers.

Regarding the challenges associated with planning and installation of PVT plants, some of the respondents cited the acceptance of the technology, e.g. among installers or building managers, and to some extent a lack of specialised know-how. Here, one of the raised problems concerns the fact that no learning process takes place, namely that lessons learned from system operation are not fed back into the planning process of subsequent projects. Another challenge concerns cooperation between companies from the electricity and heating sectors with regard to both planning and implementation. The definition of interfaces between the involved players is also important. In some cases, specific issues relating to planning and implementation are cited, e.g. dimensioning of hydraulic circuits, the difficulty of piping installation in renovation projects, short connectors in the case of a particular PVT product, optimisation of the systems, or the fact that repairing or replacing a leaky component can be costly. Some PVT collectors need to be handled with greater care than PV modules, and in some cases they could not be stacked like PV modules.

5.1.5 Market

To date, the responding system suppliers, planners and installers were involved in 90 to 100 systems that are in operation in Switzerland. Here it is possible that the same system was implemented by several companies, with one carrying out the planning and the other responsible for mounting. In 2016, the participants planned or installed around 2,000 m^2. Of this total surface area, around one-sixth was installed in systems smaller than 20 m^2, more than half in systems between 20 and 50 m^2, and around a quarter in systems larger than 50 m^2.

To date, the participating manufacturers have supplied PVT collectors for almost 300 systems in Switzerland. In 2016 they sold around 2,200 m^2 in Switzerland. Three of the manufacturers have not yet sold any collectors in Switzerland.

For some manufacturers, PVT collectors are their core (or sole) business field, while for others they are only a secondary or niche product. For the majority of the installers, planners and system suppliers who have already sold PVT collectors, solar technology is their core business field. For some companies, PVT collectors supplement other activities such as roofing, renovation or the installation of heat pump systems.

5.1.6 Motivation and challenges for PVT collectors

The motivation for clients to use PVT collectors lies on the one hand in the product itself, particularly in the delimitation to solar thermal and photovoltaic systems. Here, efficiency and the combined production of electricity and heat in a single module are particularly important, often when the available roof space is limited. There is also another closely associated important motivation: regulations governing the use of renewable energy such as those in force in the canton of Vaud, or the desire to qualify for a Minergie label, in some cases give rise to the use of PVT collectors if the roof space is insufficient for the installation of separated solar thermal and PV systems. In addition, for many clients the use of a new product, doing something different or simply an interest in new technologies are motivating factors. Some participants also stated that a PVT system is more economical than two separate systems. Other reasons include simple installation and lower system temperatures or the elimination of the risk of overheating, as well as a more uniform and thus more aesthetic appearance in comparison with separate solar thermal and electricity systems. Some arguments are put forward that also apply to other forms of solar energy use. These include ecological considerations, the desire for self-sufficiency or the reduction of ongoing costs. These are cited very frequently by manufacturers (Figure 61). Occasionally, motivations are cited that could also be pursued with other technologies and are therefore not listed further (e.g. the possibility to heat a swimming pool).

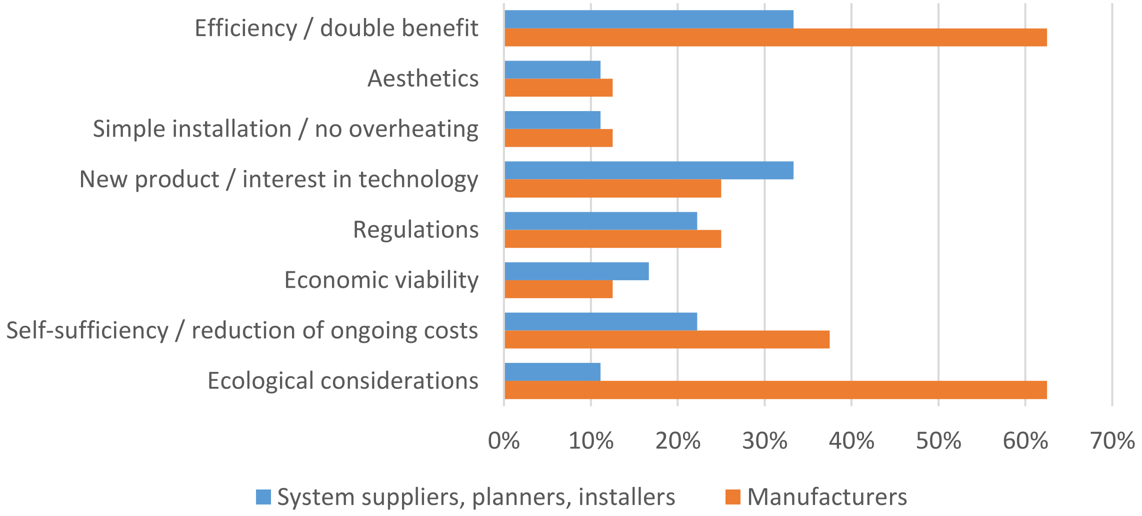


Figure 61: Motivations for clients to choose PVT collector systems from the point of view of installers, planners, and system suppliers on the one hand, and PVT collector manufacturers on the other.

The manufacturers essentially view the future of PVT technology in a positive light, especially in connection with the use of heat pump systems or the heating of outdoor swimming pools. Some of them have noted a sharp increase in demand. Some have pinned their hopes on a new product with a great deal of potential. Others feel that PVT technology is likely to remain a niche market, at least until the difference in cost falls significantly in comparison with photovoltaic technology. The assessments of installers, planners and system suppliers are even further apart. Some envisage a significant increase and major potential, while in the view of others PVT technology will remain a niche market for a handful of specific applications, or there will not be a market at all with the present-day technologies. Three companies that have already used PVT technology say they would rather not do so again in the future, partly due to negative experiences, but also because they regard separate systems to be a better option. All other companies continue to have a positive assessment of PVT technology, even though some consider that there is still a great deal of potential for improvement. They envisage the future primarily in association with heat pump systems, especially for ground source regeneration, though also to some extent ice storage systems, as well as buildings with limited roof area where a high area-specific efficiency is required.

In response to the question of what would have to change for the use of PVT technology to increase, more than 40% of the installers, planners and system suppliers, and 50% of the manufacturers, replied that the costs for PVT systems would have to fall or their economic viability would have to increase. More than half the respondents envisage improvement potential with respect to know-how, cooperation between electricity and heating specialists, or the level of awareness of PVT solutions, among clients as well as planners and installers. For example, as a planner it is difficult to find a skilled installer. Furthermore, more information needs to be provided (including from independent sources) about the potentials of PVT technology, as well as findings relating to attainable energy yields and best practice examples. It would be desirable for an easy to use tool to be available for the reliable and efficient dimensioning of PVT systems without the need for complex simulations. More effective subsidy schemes are called for, especially among respondents in Western Switzerland. They want stronger financial support for uncovered collectors in general, and PVT systems to be placed on an equal footing with solar thermal energy. Some manufacturers propose incorporating PVT technology more firmly into regulations and labels. Planners and installers also propose changes with respect to product design. Examples include less complex piping, standardisation of control devices, in-roof mounting systems, more robust products and in general a broader variety of products on the market. Around a quarter feel that the efficiency and output of the systems would have to be increased. It is interesting to note that the last two aspects (product design and efficiency) were not cited at all by the manufacturers. (Figure 62).

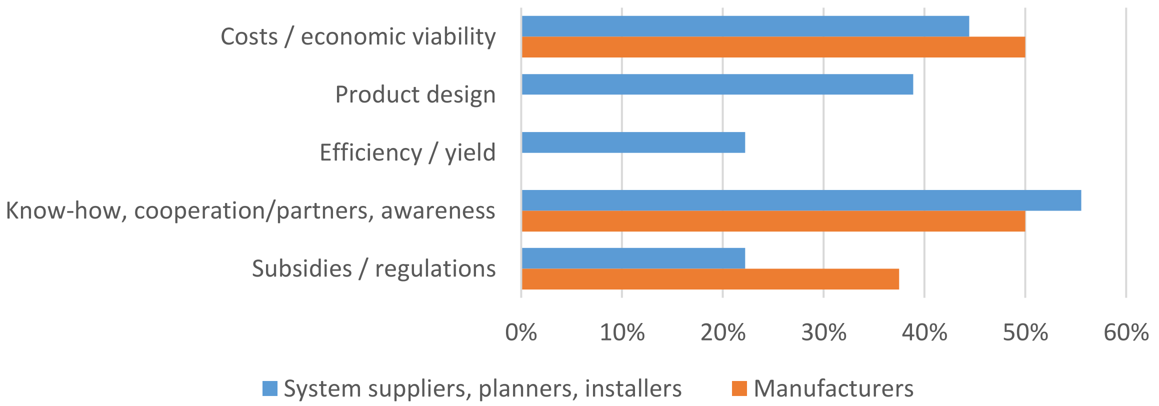


Figure 62: Areas in which there is need for change in order to increase the use of PVT collectors.

5.2 COMPANIES WITH NO EXPERIENCE WITH PVT SYSTEMS

Roughly one-third of those companies that have not yet implemented a PVT system state that their customers are not interested in this technology. Approximately half cite a slight interest, and 14% a high to very high interest among their customers. Around 40% of the companies that have not implemented a PVT system to date tend to view the technology in a rather negative light. 60% have a positive view and would use PVT collectors if requested and in case of availability of a suitable building object (Figure 63).

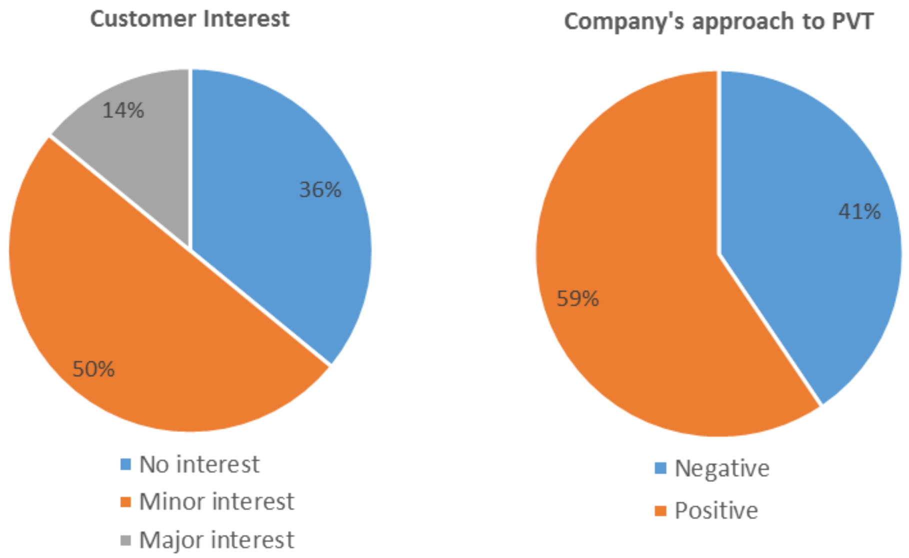


Figure 63: Interest in PVT technology on the part of end customers and approach of the surveyed companies to this technology.

The reasons why companies have not yet implemented PVT systems vary considerably (cf. Figure 64). By far the most usually stated reasons are too high costs and a lack of economic viability. More than a quarter of the companies regard the separation of photovoltaics and solar thermal energy to be more suitable or consider the temperature output level of PVT systems to be too low. Around one in five companies find PVT systems and their installation too complex. A similar number state that there are too few PVT collectors and system components on the market, or that these have not yet reached a sufficiently high technical maturity level. A lack of customer request and suitable objects for the use of PVT systems are also obstacles, though here the notions of which objects and systems are suitable for the integration of PVT collectors tend to differ considerably. For some customers the total investment is too high. They prefer to separately invest in a solar thermal system when renovating their heating system and in a PV system at another point in time.

For many companies, PVT technology is not a business field. They have, for example, specialised in electrical installations and photovoltaics, or heating installations in combination with solar thermal energy. Some state that the necessary know-how in the company is lacking, either for electrical or thermal installations. In some cases, either the company or its customers feel uncertain about the use of PVT technology. They deplore the lack of independent data and evidence regarding its functional capability and quality.

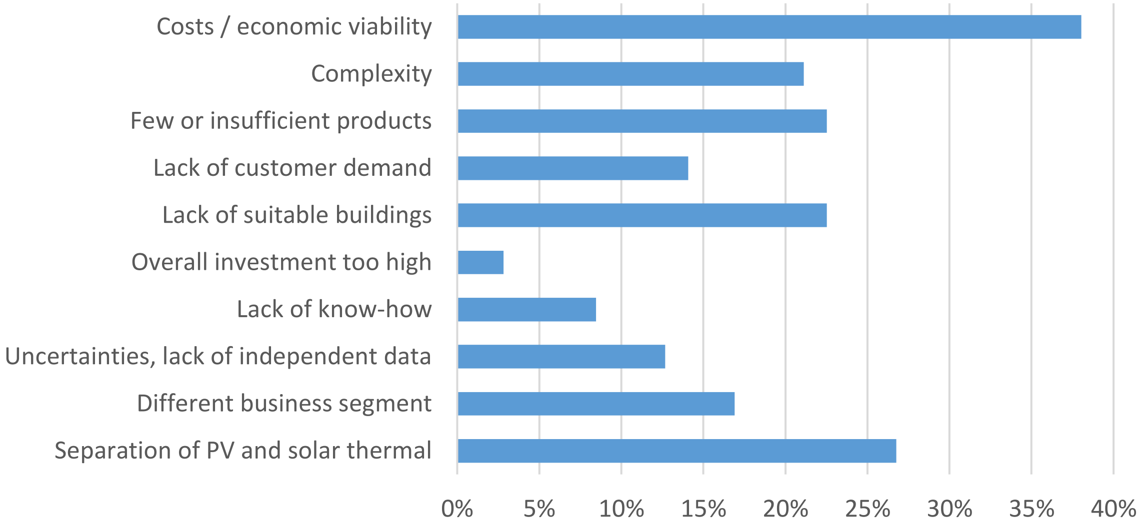


Figure 64: Reasons why some of the participating companies do not use PVT technology.

REFERENCES

[1] P. Dupeyrat, «Experimental development and simulation investigation of a Photovoltaic-Thermal hybrid solar collector,» Institut National des Sciences Appliquées de Lyon, Lyon, 2011.

[2] Deutsche Gesellschaft für Sonnenenergie e. V., «Leitfaden Photovoltaische Anlagen, 4. Auflage,» DGS, Berlin, 2012.

[3] H. A. Zondag, «Flat-plate PV-Thermal collectors and systems: A review,» *Renewable and Sustainable Energy Reviews,* Bd. 12, 2008.

[4] J. J. Michael, S. Iniyan and R. Goic, «Flat plate solar photovoltaic–thermal (PV/T) systems: A reference guide,» *Renewable and Sustainable Energy Reviews,* Bd. 51, 2015.

[5] M. Adam, H. P. Wirth and R. Radosavljevic, «Verbundprojekt: Standardisierung und Normung von multifunktionalen PVT Solarkollektoren (PVT-Norm), Teilvorhaben: PVT-Systemanwendungen und Simulationen,» Düsseldorf, 2014.

[6] J. Cremers, U. Eicker, N. Palla, X. Jobard, F. Klotz and I. Mitina, «Multivalente photovoltaisch-thermische Kollektoren zur Kälte-, Wärme- und Stromerzeugung und Szenarien für die Gebäudeintegration [PVTintegral],» Stuttgart, 2015.

[7] UK Department for Business, Energy & Industrial Strategy, «Evidence Gathering - Low Carbon Heating Technologies, Hybrid Solar Photovoltaic Thermal Panels,» London, 2016.

[8] T. Hostettler, «Markterhebung Sonnenenergie 2015,» ausgearbeitet durch Swissolar, Bundesamt für Energie, Bern, 2016.

[9] M. Adam, H. P. Wirth, R. Radosavljevic, K. Kramer, U. Fritzsche and S. Hamberger, «Verbundprojekt: Standardisierung und Normung von multifunktionalen PVT Solarkollektoren (PVT-Norm), Teilvorhaben Betrachtung Normentwurf und Systemintegration aus Herstellersicht, Information über Notwendigkeit der Norm,» 2014.

[10] SPF, Institut für Solartechnik, «Erläuterungen zur kollektorliste.ch, V1.3,» 2016.

[11] K. Wenker, H. Jäger, A. Dolezal, G. Stryi-Hipp, S. Fortuin, I. Hädrich, M. Wiese, J. Greulich, W. Graf and T. Kroyer, «PVTmax Photovoltaisch-thermische Kollektorsysteme mit maximiertem Gesamtertrag,» Braunschweig and Freiburg, 2012.

[12] INFRAS, D. Sigrist and S. Kessler, «Harmonisiertes Fördermodell der Kantone (2015), Schlussbericht, Revidierte Fassung vom September 2016,» Bundesamt für Energie, Bern, 2016.

[13] R. Wagner and T. Weisskopf, «Erdsondenpotenzial in der Stadt Zürich,» Amt für Hochbauten der Stadt Zürich, Zürich, 2014.

[14] P. Persdorf, F. Ruesch and M. Y. Haller, «RegenOpt Optionen zur Vermeidung nachbarschaftlicher Beeinflussung von Erdwärmesonden: energetische und ökonomische Analysen,» Amt für Hochbauten der Stadt Zürich, Zürich, 2015.

[15] AWEL Amt für Abfall, Wasser Energie und Luft, «Energienutzung aus Untergrund und Grundwasser, Planungshilfe,» Baudirektion Kanton Zürich, Zürich, 2010.

[16] Deutsche Gesellschaft für Sonnenenergie e. V. and Swissolar, «Leitfaden Solarthermische Anlagen, 9. Auflage (ergänzte Auflage für die Schweiz),» DGS und Swissolar, Berlin und Zürich, 2013.

[17] M. Bätschmann, «Einbindung von PV/T Kollektoren in erdsondengekoppelte Wärmepumpen-Systeme,» Projekt Nr. SI/500735-01, Jahresbericht 2012 an BFE, Bundesamt für Energie, Bern, 2012.

[18] F. Hug and R. Gysel, «Einbindung von PV/T Kollektoren in erdsondengekoppelte Wärmepumpen-Systeme,» Projekt Nr. SI/500735-01, Schlussbericht an BFE, Bundesamt für Energie, Bern, 2016.

[19] F. Hug and A. Baggenstos, «Einbindung von PV/T Kollektoren in erdsondengekoppelte Wärmepumpen-Systeme,» Projekt Nr. SI/501010, Jahresbericht 2014 an BFE, Bundesamt für Energie, Bern, 2014.

[20] F. Hug and A. Baggenstos, «Einbindung von PV/T Kollektoren in erdsondengekoppelte Wärmepumpen-Systeme,» Projekt Nr. SI/501010, Jahresbericht 2015 an BFE, Bundesamt für Energie, Bern, 2016.

[21] F. Hug and A. Baggenstos, «Einbindung von PV/T Kollektoren in erdsondengekoppelte Wärmepumpen-Systeme,» Projekt Nr. SI/501010, Jahresbericht 2016 an BFE, Bundesamt für Energie, Bern, 2017.

[22] M. Sulzer and S. Summermatter, «Solare Energieversorgung im alpinen Raum, Reka-Feriendorf Blatten-Belalp,» Projekt Nr. SI/501045, Jahresbericht 2015 an BFE, Bundesamt für Energie, Bern, 2015.

[23] M. Sulzer and S. Summermatter, «Solare Energieversorgung im alpinen Raum, Reka-Feriendorf Blatten-Belalp,» Projekt Nr. SI/501045, Schlussbericht an BFE, Bundesamt für Energie, Bern, 2016.

[24] D. Lüthi and U.-P. Menti, «Monitoring Suurstoffi: Monitoring einer thermischen Arealvernetzung in Kombination mit einem Erdsondenfeld,» Projekt Nr. SI/500836-01, Jahresbericht 2012 an BFE, Bundesamt für Energie, Bern, 2013.

[25] N. Vetterli, E. Thaler, M. Sulzer and P. Ryser, «Monitoring Suurstoffi: Monitoring einer thermischen Arealvernetzung in Kombination mit einem Erdsondenfeld,» Projekt Nr. SI/500836-01, Schlussbericht an BFE, Bundesamt für Energie, Bern, 2017.

[26] E. Fischer, «Energiekonzept Suurstoffi Rotkreuz,» Vortrag bei Energie Apero Schwyz, Hans Abicht AG, Zug, 2016.

[27] J. Rohrer, «PVT-Solarkraftwerk linth-arena sgu: Strom und Wärme vom Dach,» Projekt Nr. SI/501095, Jahresbericht 2014 an BFE, Bundesamt für Energie, Bern, 2014.

[28] J. Rohrer, «PVT-Solarkraftwerk linth-arena sgu: Strom und Wärme vom Dach,» Projekt Nr. SI/501095, Jahresbericht 2015 an BFE, Bundesamt für Energie, Bern, 2015.

[29] J. Rohrer, «PVT-Solarkraftwerk linth-arena sgu: Strom und Wärme vom Dach,» Projekt Nr. SI/501095, Jahresbericht 2016 an BFE, Bundesamt für Energie, Bern, 2016.

[30] C. Vassella and A. Baggenstos, «Drei unterschiedliche innovative solarunterstützte Wärmeerzuegungssysteme für drei identische Minergie-A-Gebäude,» Projekt Nr. SI/501244-01, Jahresbericht 2015 an BFE, Bundesamt für Energie, Bern, 2015.

[31] R. Schwarz, «Monitoring Minergie-A Büronutzung,» Studienarbeit HSR Rapperswil IET, Rapperswil, 2016.

[32] R. Schwarz, J. Staubli, W. Hässig and C. Wemhöner, «Erkenntnisse der Optimierung eines Minergie-A Büro-/Wohn-Gebäudes,» in *19. Brenet Status-Seminar "Forschen für den Bau im Kontext von Energie und Umwelt"*, Zürich, 2016.

[33] D. Zenhäusern, A. Baggenstos, O. Türk, S. Brunold and M. Rommel, «PVT-Kollektoren für die Brauchwarmwasser-Vorwärmung – Mess- und Simulationsresultate einer Testanlage,» in *18. Brenet Status-Seminar "Forschen für den Bau im Kontext von Energie und Umwelt"*, Zürich, 2014.

[34] R. Huber and K. Vogt, «Eine Überbauung mit besonderer Gebäudetechnik,» *Ostschweizer Rundschau,* Bd. März, 2014.

[35] C. Wild, «Ein Maximum an nachhaltiger Energie-Nutzung,» *HK-Gebäudetechnik,* Nr. 1, 2017.

[36] Solimpeks Energy Corp, «Case studies of Volther hybrid collector,» http://www.soleol.ch/documents/installations-hybrides/hybrid_case.PDF.

[37] Fraunhofer ISE, «Photovoltaics Report, updated 17 November 2016,» Freiburg (D), 2016.

APPENDIX

MARKET OVERVIEW OF PVT COLLECTORS

	Classification					Design					General key data		PV key data	
Nr	Type		Manufacturer	Country	Model(s)	PV cell type	PV design	Absorber material	Thermal design	PV/ absorber connection	Dimensions	Weight	Output (STC)	Temp. coeff. P_{STC}
1	Flat-plate, uncovered	No rear insulation	Solarzentrum Allgäu KG Kreener Straße 12 87640 Biessenhofen-Altdorf Tel: +49 8342-8969-0 info@solarzentrum-wiosun.de www.solarzentrum-wiosun.de	Germany	WIOSUN Kombimodul PV-Therm monokristallin	mono Si	Glass-backsheet	Polyurethane	Fully wetted absorber	Fluid directly behind PV module	1315 x 1012 x 40 mm	40 kg	195-205 Wp	-0.46%/K
					polykristallin	poly Si							190-200 Wp	-0.48%/K
2	Flat-plate, uncovered	No rear insulation	solator C.Bösch GmbH Dornbirnerstrasse 8 A-6922 Wolfurt Tel: +43 - 5577 - 82571 office@solator.cc www.solator.cc	Austria	solator PV + THERM PVTHERMAU280	mono Si	Glass-backsheet				1650 x 990 x 35 mm	28 kg	280 Wp	-0,43%/K
					PVTHERMAU300	mono Si					1640 x 1000 x 40 mm	28 kg	300 Wp	-0,41%/K
					PVTHERMIN190EU (EU laminate)	mono Si	Glass-backsheet				836 x 1580 x 36 mm	22 kg	190 Wp	
					PVTHERMIN190CN (China laminate)						836 x 1580 x 36 mm	22 kg	190 Wp	
	Flat-plate, uncovered, retrofitting set	No rear insulation			Hybrid attachment for PV modules					Retrofitting set, clamping				
3	Flat-plate, uncovered	No rear insulation	ecoTec Energy AG, Inc. 391N.W. 179th Avenue Aloha Oregon 97006	USA	coolPv CPV288	mono Si	Glass-backsheet	Stainless steel	Oval capillary tubes	Laminated	1945 x 975 x 5 mm	31.5 kg	288 Wp	-0,51%/K
4	Flat-plate, uncovered	No rear insulation	Meyer Burger AG Schorenstrasse 39 CH-3645 Gwatt (Thun) Tel: +41 33 221 21 21 info.pvsystems@meyerburger.com www.meyerburger.com	Switzerland	Hybrid	mono Si	Glass-backsheet	Aluminium	Meander absorber		991 x 1656 x 17 mm	29 kg	290 Wp	-0.391%/K
5	Flat-plate, uncovered	No rear insulation	Solaire2G/DualSun 2 rue Marc Donadille 13013 Marseille contact@dualsun.fr https://dualsun.fr/	France	DualSun Wave	mono Si	Glass-backsheet	Stainless steel			1677 x 990 x 40 mm	30 kg	250 Wp	-0.44%/K
		mit Rückseitendämmung										31.7 kg		
6	Flat-plate, uncovered	Rear insulation optional	Pegoraro Energia Srl Via Marconi, 112 31050 - Vedelago, TV Tel: +39 0423 400433 pegorarogiorgio@tin.it www.pegoraroenergia.com	Italy	H-NRG	poly Si	Glass-backsheet	Aluminium			1652 x 1000 x 45 mm	34 kg	230 Wp	-0.45%/K
7	Flat-plate, uncovered	No rear insulation	Millennium Electric 11 Hasadna St. P.O. Box 2646 Ra'anana North Industrial Zone 43650 Tel: +972 9 7439490 info@millenniumsolar.com www.millenniumsolar.com	Israel	MSS – MIL-PVT-340W-MO3/ MSS – MIL-PVT-	mono Si	Glass-backsheet	Copper	Fin absorber with air channels	Heat conducting paste	2199 x 1238 x 71 mm	38 kg	320 / 340 Wp	
					MSS – MIL-PVT-190W-MO2 / MSS – MIL-PVT-195W-MO3	mono Si	Glass-backsheet				1580 x 808 x 45 mm	25 kg	190 / 195 Wp	-0.45%/K
8	Flat-plate, uncovered	No rear insulation	Poly Solar Solutions AG Feldrietstrasse 5/PF CH-9204 Andwil Tel: +41 71 388 23 23 info@pss-ag.com www.pss-ag.com	Switzerland	PIK® Kombi-Solar-Kollektor	mono Si	Glass-backsheet	Aluminium		Glued	1666 x 992 x 33 mm	35 kg	255 Wp	-0.37%/K
	Flat-plate, uncovered, retrofitting set	No rear insulation			PIK® thermischer Kollektor K1					Lie loosely on top of one another	ca. 1600 x 900 x 40			
9	Flat-plate, uncovered	No rear insulation	VALVO GmbH Rothenseer Straße 27 39124 Magdeburg Tel: +49 391 733 478 82 info@valvo-deutschland.de http://valvo-deutschland.de QuattroSolarPlus GmbH http://www.qsp-system.de	Germany	PVT 60P	poly Si	Glass-backsheet	Aluminium	Tube register, parallel fluid channels		1623 x 986 x 35 mm	23.8 kg	250-260 Wp	-0.4%/K
10	Flat-plate, uncovered	No rear insulation	Easy Solar ApS Nørretorv 2 4100 Ringsted Tel: +45 26 74 50 49 post@easysolar.dk http://easysolar.dk	Denmark	Black Line 250 – 400 W BIPV Hybrid	mono Si	Glass-backsheet	Aluminium	Meander absorber		1675 x 1025 x 37.5 mm		250 Wp	
	Flat-plate, uncovered, retrofitting set	No rear insulation			Aluminiumsabsorber / Hybrid			Aluminium	Meander absorber	Retrofitting set				
11	Flat-plate, uncovered	No rear insulation?	TES Group Limited tes@tessolarwater.com http://www.tessolarwater.com	China	TESZEUS PV-T	poly Si	Glass-backsheet	Copper/ Alu			1650 x 992 x 50 mm		240 Wp	-0.4%/K
						mono Si					1650 x 992 x 50 mm		250 Wp	-0.4%/K
						poly Si					1956 x 992 x 50 mm		280 Wp	-0.4%/K
						mono Si					1956 x 992 x 50 mm		300 Wp	-0.4%/K
12	Flat-plate, uncovered	No rear insulation	Triple Solar BV New Energy Docks Distelweg 451 1031 HD Amsterdam Tel: +31 20 435 75 55 info@triplesolar.eu http://www.triplesolar.eu	Netherlands	Triple Solar hybrid panel	mono Si	Glass-backsheet?	Aluminium			1735 x 1007 x 30 mm	39 kg	255 Wp	

	Thermal key data																							Certification	
Nr	Gross area	Apert. area	Absorb. area	Charact. curve model	Reference area	Electr. op. mode at measure-ment	Source for key data	eta0	Covered		Uncovered			Quasi-dynamic						Open air collector			Stagna-tion tempe-rature	IEC	Solar Key-mark
									a1	a2	bu	b1	b2	c1	c2	c3	c4	c6	Kθ_d	mdot [kg/h]	eta0	bu			
1	1.33 m2	1.31 m2		Uncovered	Aperture area	OC	Keymark	0.715			0.031	7.98	6.64										75°C	In prepa-ration	Yes
2		1.62 m2		Quasi-dynamic	Aperture area	MPP	Keymark (Data sheet)	0.274 (0.56)						7.684	0.115	0.944	0	0.013	0.908				66°C	IEC 61215 IEC 61730	Yes
		1.64 m2																							No
		1.20 m2																					66°C	IEC 61215 IEC 61730	
		1.32 m2																							Yes
3	1.90 m2						Data sheet																	No	No
4	1.64 m2	1.64 m2		Uncovered	Aperture area	MPP	Keymark	0.578			0.06	12.55	1.3859										69°C	IEC 61215 IEC 61730	Yes
5	1.64 m2	1.58 m2		Uncovered	Aperture area	MPP	Keymark	0.578			0.028	12.08	1.842										74.7°C	IEC 61215 IEC 61730	Yes
6	1.65 m2	1.52 m2	1.46 m2	Covered	Aperture area	Not specified	Data sheet	0.513	7.68	0.014													80°C (Maxim altemp)	IEC 61215 IEC 61730	No
7							Data sheet	0.7																IEC 61215	No
8	1.65 m2	1.57 m2		Uncovered	Aperture area	MPP	Keymark	0.596			0.068	12.88	1.11										85°C	IEC 61215 IEC 61730	Yes
9	1.60 m2																							IEC 61215 IEC 61730	No
10	1.72 m2																							IEC 61215 IEC 61730	No
11	1.64 m2																							IEC 61215 IEC 61730	No
12	1.75 m2																							?	No

	Classification					Design					General key data		PV key data	
Nr	Type		Manufacturer	Country	Model(s)	PV cell type	PV design	Absorber material	Thermal design	PV/ absorber connection	Dimensions	Weight	Output (STC)	Temp. coeff. P_{STC}
13	Flat-plate, uncovered, retrofitting set	No rear insulation	GeoClimaDesign AG Mühlenbrücken 3 - 5 15517 Fürstenwalde / Spree Tel: +49 3361 - 376 42 0 info@geoclimadesign.com www.geoclimadesign.com	Germany	Sunbag			Plastic				3 kg/m2		
14	Flat-plate, uncovered	No rear insulation	KIOTO Photovoltaics GmbH Industriepark, Solarstraße 1 9300 St.Veit/Glan Tel: +43 4212 28 300 499 office@kioto.com www.kiotosolar.com	Austria	PVT Hybrid 900Wp	mono Si	Glass-backsheet?	Copper	Harp		1666 x 992 x 40 mm	27.5 kg	280 Wp	-0.37%/K
15	Flat-plate, uncovered	No rear insulation	CAOTEC La Pergola 241 CH-7743 Brusio Tel: +41 81 8465552 info@caotec.ch www.caotec.ch	Switzerland	Hybrid Kollektor									
16	Flat-plate, uncovered	No rear insulation	Energetyka Solarna ENSOL Sp. z o.o. Ul. Piaskowa 11 47-400 Racibórz Tel: +48 32415-00-80 sekretariat@ensol.pl www.ensol.pl	Poland	E-PVT 2,0	poly Si		Alu-minium	Roll-bonded		1006 x 2007 x 85 mm	37 kg	300 Wp	
17	Flat-plate, uncovered		POWER KOMBI MODULE GmbH Heerstr. 47 D-52538 Selfkant Tel: 49 151 11640960 info@powerkombimodule.com http://powerkombimodule.com/	Germany	PKM 96M (BK)	mono Si	Glass-backsheet				1580 x 1062 x 50 mm	22 kg	250 - 285 Wp	
18	Flat-plate, uncovered	No rear insulation	Building Energy Herlegemstraat 14, 9771 Nokere (Kruishoutem) Tel: +32 (0) 56 62 62 40 info@buildingenergy.be www.buildingenergy.be	Belgium	HYBRIDE PV/T 2-in-1	poly Si	Glass-backsheet	Alu-minium			1640 x 992 x 40 mm	27.4 kg	250 Wp	
19	Flat-plate, uncovered	No rear insulation	Max Roth M&M Energie Forschung/Entwicklung Rationen 2 7310 Bad Ragaz	Switzerland										
20	Flat-plate, uncovered, retrofitting set		Splus2 GmbH Breite Str. 160-166 41238 Mönchengladbach Tel: +49 2166 99886 43 info@splus2.de www.splus2.de	Germany	Splus2									
21	Flat-plate, uncovered	With rear insulation	FOTOTHERM S.r.l. via Olmi 1 33050 Gonars (Udine) Tel: +39 0432 931595 info@fototherm.com www.fototherm.com	Italy	Serie Cs	poly Si	Glass-backsheet?				1638 x 982 x 41 mm	27 kg	220-250 Wp	-0.43%/K
					Serie AL	mono Si	Glass-backsheet?				1660 x 990 x 51 mm	32 kg	275-285 Wp	-0.43%/K
22	Flat-plate, uncovered	With rear insulation	PA-ID GmbH Bruchtannenstraße 9 D-63801 Kleinostheim info@pa-id.de	Germany	2Power HM 1000 Mono Black	mono Si	Glass-backsheet?				1640 x 992 x 45 mm	21 kg	260 Wp	-0.45%/K
	Flat-plate, uncovered, as roof tile		www.2power.de Also via: Dachziegelwerke Nelskamp GmbH		Nelskamp MS 5 2Power	mono Si					1965 x 400 x 25 mm	9.54 kg	100 Wp	-0.43%/K
23	Flat-plate, uncovered	With rear insulation	res – regenerative energietechnik und –systeme GmbH Wolfertsbronn 5 D-91550 Dinkelsbühl Tel: +49 9851 89900 0	Germany	res-PV++	mono Si	Glass-backsheet	Copper	Capillary tubes		1655 x 995 x 40 mm	22.5 kg	265-275 Wp	-0.46%/K
			info.de@res-energie.eu		res-PV++ 300	mono Si					1655 x 995 x 40 mm	22.5 kg	300 Wp	-0.43%/K
			www.res-energie.eu		res-PV++ Projekt	poly Si					1640 x 992 x 40 mm	22.5 kg	250 Wp	-0.46%/K
24	Flat-plate, uncovered	With rear insulation	BRANDONI SOLARE S.p.a. Via O. Pigini, 8 60022 Castlfidardo (AN) Tel: +39 071 78563 info@brandonisolare.com www.brandonisolare.com	Italy	HYBRID SOLAR PANEL SBP-XXX	poly Si	Glass-backsheet	Alu-minium	Roll-bonded		1661 x 997 x 42 mm	32 kg	230-255 Wp	-0.44%/K
25	Flat-plate, uncovered	With rear insulation	ChinaLand +86 18096606899 chn123@chnland.com	China	CHN-72M(PVT)	mono Si	Glass-backsheet?				1580 x 808 x 40 mm	25 kg	200-210 Wp	-0.44%/K
26	Flat-plate, uncovered, retrofitting set	With partial rear insulation	SunDrum Solar 469 River Road Hudson, MA 01749 Tel: +1 508 740 6256 info@sundrumsolar.com www.sundrumsolar.com	USA	SDM 100									
27	Flat-plate, uncovered	With rear insulation	Nieberle Solar Pfarrer-Wilhalm-Weg 5	Germany	ISIEtherm WRS 200-ST48F	poly Si	Glass-backsheet			Snapping system	1320 x 992 x 45 mm	32.5 kg	200 Wp	
			87640 Biessenhofen Tel: +49 8342 965830		ISIEtherm WRS 250-ST60F	poly Si	Glass-backsheet			Snapping system	1650 x 992 x 38 mm	39.5 kg	250 Wp	
			info@nieberle-solar.com www.nieberle-solar.com		ISIEtherm R 200 M	poly Si	Glass-backsheet			Snapping system	1580 x 808 x 35 mm	32.5 kg	200 Wp	
	Flat-plate, uncovered, retrofitting set	With rear insulation			ISIEtherm					Snapping system	je nach PV-Modul			

	Thermal key data																							Certification	
									Covered		Uncovered			Quasi-dynamic						Open air collector					
Nr	Gross area	Apert. area	Absorb. area	Charact. curve model	Reference area	Electr. op. mode at measure-ment	Source for key data	eta0	a1	a2	bu	b1	b2	c1	c2	c3	c4	c6	Kθ_d	mdot [kg/h]	eta0	bu	Stagna-tion tempe-rature	IEC	Solar Key-mark
13																									No
14		1.51 m2					Data sheet	0.4-0.5															60°C	IEC 61215 IEC 61730	No
15																									No
16	2.02 m2	1.86 m2		Uncovered	Aperture area	Not specified	Data sheet	0.555			0.051	9.547	1.389										80°C		No (not for PVT)
17	1.70 m2			Uncovered	Gross area	MPP	Keymark	0.404			0.05	7.918	0.379										90°C	IEC 61215 IEC 61730	Yes
18																									No
19																									No
20																									No
21	1.61 m2	1.59 m2		Covered	Aperture area	MPP	Keymark	0.559	9.123	0													84.5°C	IEC 61215 IEC 61730	Yes
		1.58 m2																						IEC 61215 IEC 61730	Only for Cs series
22	1.63 m2	1.57 m2		Quasi-dynamic	Gross area	MPP	Keymark	0.471						5.999	0	1.299	0.486	0.06	0.811				83°C	?	Yes
		0.64 m2																					80°C	?	Yes
23	1.65 m2																							?	No
24	1.66 m2	1.44 m2		Covered	Aperture area	Not specified	Data sheet	0.538	15.529	0.01													83°C (Datenblatt)	IEC 61215 IEC 61730	? Yes, according to data sheet
25	1.28 m2																							?	No
26																									No
27		1.29 m2																					90°C	IEC 61215 IEC 61730	In prep.
		1.59 m2																					90°C	IEC 61215 IEC 61730	In prep.
		1.29 m2																					90°C	IEC 61215 IEC 61730	In prep.

	Classification					Design					General key data		PV key data	
Nr	Type		Manufacturer	Country	Model(s)	PV cell type	PV design	Absorber material	Thermal design	PV/ absorber connection	Dimensions	Weight	Output (STC)	Temp. coeff. P_{STC}
28	Flat-plate, uncovered, as roof tile	With rear insulation	Energyntegration S.r.l. Via Giosuè Carducci 8 20123 Milano (MI) +39 0342 687218 info@energyntegration.com www.energyntegration.com	Italy	EY-Hybrid	mono Si	Glass-backsheet	Copper/ Alu	Meander absorber		2000 x 500 x 28 mm	18 kg	80 Wp	-0.4%/K
29	Flat-plate, uncovered	With rear insulation	MAS srl Via dell'Artigianato 3 31020 San Polo di Piave (TV) Tel: +39 0422802311 info@roofmas.com www.roofmas.com	Italy	MAS roof Conditioned Photovoltaic	poly Si	Glass-backsheet?	Alu-minium	Roll-bonded		1860 x 930 x 212 mm		215 Wp	
30	Flat-plate, uncovered, retrofitting set	With rear insulation	CGA Technologies Srl Via dell'Industria, 22 33043 Cividale del Friuli (UD) Tel: +39 0432 705111 info@cgatech.it www.cgatech.it	Italy	inside Hybrid Solar Thermal		Glass-backsheet	Alu-minium	Roll-bonded		1652 x 1000 x 45 mm	34 kg		
31	Flat-plate, uncovered	With rear insulation	F.D.E. Solar S.r.l. Viale del Lavoro 39 37044 Cologna Veneta (VR) Tel: +39 0442 84807 info@fdesolar.com www.fdesolar.com	Italy	FDE-HYBRID	poly Si	Glass-backsheet	Copper/ Alu	Harp		1666 x 992 x 40 mm	22 kg	250 Wp	-0.37%/K
32	Flat-plate, uncovered	With rear insulation	SUNERG Solar s.r.l. Via Donnini, 51 - Loc. Cinquemiglia Città di Castello (PG) Tel: +39 075.8540018 info@sunergsolar.com www.sunergsolar.com	Italy	TESP-P60	poly Si	Glass-backsheet?	Alu-minium	Roll-bonded		1645 x 990 x 46 mm	32 kg	250 - 280 Wp	-0.42%/K
33	Flat-plate, uncovered	With rear insulation	Natural Technology Developments Ltd Office 59, Viewpoint Building Derwentside Business Centre Consett Co. Durham, DH8 6BN Tel: +44 191 6450407 contactus@solarangel.com www.solarangel.com	UK	Solar Angel DG-01	mono Si	Glas-Folie	Alu-minium	Harp		1630 x 986 x 35 mm	25 kg	250 Wp	
34	Flat-plate, uncovered	With rear insulation	SOLTOP Schuppisser AG St. Gallerstrasse 3 + 5a CH-8353 Elgg Tel: +41 52 397 77 77 www.soltop.ch	Switzerland	Soltop Alpha hybrid ID	mono Si	Glass-backsheet	Copper	Meander absorber	Laminated	1660 x 985	23 kg		
35	Flat-plate, uncovered	With rear insulation	Minimise Generation 6 Stirling Park, Laker Road, Rochester Airport Estate, Rochester, Kent ME1 3QR +44 (0) 330 313 3220 info@minimisegeneration.com	UK	PowerHybrid 240	mono Si	Glass-backsheet	Copper/ Alu			1582 x 800 x 50 mm	26 kg	240 Wp	
36	Flat-plate, uncovered	With rear insulation	SolarTech International B.V. Postbus 576 5600 AN Eindhoven Tel: +31(0)40 - 888 2992 info@energiedak.nl www.energiedak.nl	Netherlands	Energiedach®-Plus	amorph Si	Roof sheet	Plastic/ Metal				8.66 kg/m2	63 Wp/m2	
37	Flat-plate, uncovered	With rear insulation	Tractile Pty Ltd. 9 Lawson Street Southport QLD 4215 T: 1300 00TRAC (1300 008 722) info@tractile.com.au http://tractile.com.au	Australia	Eclipse Solar Tile - TR-EC-ST1001-PV76M	mono Si	Glass-backsheet				1105 x 690 x 71 mm	19.56 kg	76 Wp	-0.37%/K
38	Flat-plate, uncovered Flat-plate, covered	With rear insulation With rear insulation	Solimpeks Solar Energy Corp Fevzi Çakmak Mah. 10753. Sk. No:3-3A Konya Tel: +90 444 06 02 info@solimpeks.co www.solimpeks.com	Turkey	Volther PowerVolt Volther PowerTherm	mono Si mono Si	Glass-backsheet? Glass-backsheet?	Copper Kupfer			828 x 1601 x 90 mm 870 x 1640 x 105 mm	24.4 kg 34.4 kg	200 Wp 180 Wp	-0,471%/K
39	Flat-plate, covered	With rear insulation	Power Panel Inc. 13881 West Chicago Street Detroit, MI 48228 info@powerpanel.com www.powerpanel.com	USA	PVT1	mono Si	Glas-cells directly on absorber	Alu-minium		Cells directly attached to absorber	1384 x 718 x 111 mm	16.8 kg	115 Wp	
40	Flat-plate, covered, PV attached to front glass	With rear insulation	SELA SOLAR, S.L. C/ Pitera, 16 03700 Dénia (Alicante) Tel: +34 966 420 309 info@selasolar.com www.selasolar.com	Spain	SELA SOLAR M-240PVT	poly Si	Glass-backsheet	Copper	Harp		2350 x 960 x 85 mm	69 kg	240 Wp	
41	Flat-plate, covered, PV attached to	With rear insulation	Hörmann-Barkas Metallbau GmbH Bereich solarhybrid Jochen-Köhler-Str. 3 09669 Frankenberg Tel: +49 37206 56 809 0 info@hoermann-solarhybrid.de www.hoermann-solarhybrid.de	Germany	PT-U 250/145 PT-U 250/193	poly Si poly Si		Alu-minium Alu-minium	Fully wetted absorber Fully wetted absorber		2064 x 1155 x 98 mm 2064 x 1155 x 98 mm	42 kg 42 kg	144.9 Wp 192.8 Wp	
42	Flat-plate, covered	With rear insulation	EndeF Engineering S.L. Polígono Ciudad del Transporte. C/PA nº11 50820 San Juan de Mozarrifar, Zaragoza info@endef.com www.endef.com	Spain	Ecomesh	poly Si		Copper	(with inert gas filling)		1653 x 998 x 104 mm	45 kg	240 Wp	

	Thermal key data																							Certification	
Nr	Gross area	Apert. area	Absorb. area	Charact. curve model	Reference area	Electr. op. mode at measure-ment	Source for key data	eta0	Covered		Uncovered			Quasi-dynamic						Open air collector			Stagna-tion tempe-rature	IEC	Solar Key-mark
									a1	a2	bu	b1	b2	c1	c2	c3	c4	c6	Kθ_d	mdot [kg/h]	eta0	bu			
28		ca. 0.5 m2																					60°C (max. Temp)		No
29																								?	No
30	1.63 m2	1.57 m2		Uncovered	Aperture area	MPP	Keymark	0.486			0.017	13.035	1.057										80°C		Yes
31	1.63 m2	1.48 m2		Uncovered	Aperture area	MPP	Keymark	0.536			0.035	8.23	1.55										90.3°C	IEC 61215 IEC 61730	Yes
32		1.45 m2		Covered	Aperture area	Not specified	Data sheet	0.538	15.529	0.01													83°C	IEC 61215 IEC 61730	No
33		1.55 m2		Covered	Aperture area	MPP	Keymark	0.417	12.488	0.008													79°C	IEC 61215 IEC 61730	Yes
34	1.64 m2			Uncovered	Gross area	MPP	Data sheet	0.638			0.054	10.66	1.1868											No	No
35							Data sheet	0.534	8.37	0.586													93°C		No
36																								IEC 61646 IEC 61730	No
37																									No
38		1.36 m2		Covered	Aperture area	Not specified	Keymark	0.476	8.4	0.588													101°C	?	Yes
		1.42 m2		Covered	Aperture area	MPP	Keymark	0.486	4.028	0.067													135°C	?	Yes
39																								No (UL)	No
40	2.26 m2	2.00 m2		Covered	Not specified	Not specified	Data sheet	0.715	3.176	0.023													75°C		
41	2.38 m2	1.34 m2 1.05 m2 1.05 m2		Covered	Aperture area	Not specified	Data sheet	0.815 0.832	5.00 5.44	0.024 0.033													153.7°C 137.7°C		No (not PVT)
42							Data sheet	0.69	2.59	0.012															No

	Classification					Design					General key data		PV key data	
Nr	Type		Manufacturer	Country	Model(s)	PV cell type	PV design	Absorber material	Thermal design	PV/ absorber connection	Dimensions	Weight	Output (STC)	Temp. coeff. P_{STC}
43	Flat-plate, covered	With rear insulation	3F Solar Technologies GmbH Vorarlberger Allee 38 A – 1230 Wien Tel: +43 1 585 01 78 office@3f-solar.at www.3f-solar.at	Austria	Solar One Hybridkollektor	mono Si	Glass-backsheet	Copper	Ultrasonic-welded absorber, soldered pipe harp		1676 x 1008 x 63 mm	42 kg	265 Wp	
44	Air collector	PV module with plastic half shell on rear side	Systovi 5 rue du Chêne Lassé – CP 1008 44 806 Saint-Herblain Cedex Tel: +33 2 40 92 44 20 contact@systovi.com www.systovi.com	France	R-VOLT	mono Si	Glass-backsheet	PP			1518 x 1011 x 43 mm	27.5 kg	250 Wp	-0.47%/K
45	Air collector	PV module with plastic half shell on rear side	GROUPE SOLUTION ENERGIE 155-159 rue du Docteur Bauer 93400 SAINT OUEN Tel: +33(0)1 70 32 08 00 contact@segroup.fr www.segroup.fr	France	GSE AIR'SYSTEM		Glass-backsheet	PP			Standardmodul, bei Solar Keymark mit Bosch c-Si M60S: 1660 x 990 x 50 mm			
46	Air collector	PV module with plastic half shell on rear side	BASE / SELLANDE Espace Le Trèfle 35 rue Thomas Edison 33610 CANEJAN Tel: +33 5 35 54 49 59 contact@base-innovation.com www.base-innovation.com	France	Cogen'Air		Glass-backsheet			Glued	Standardmodul		250 Wp	
47	Air collector	PV module with plastic half shell on rear side	IRFTS 26, rue du 35ème Régiment d'Aviation 69500 BRON + 33 4 78 38 83 10 info@irfts.com www.irfts.com	France	EASY ROOF Boost'R						1650 x 990 x 73 mm	26 kg		
48	Air collector		SCX Solar B.V. Zaanstraat 2 5712 SN Someren Tel: +31 (0)40 744 02 02 info@scx-solar.eu www.scx-solar.eu	Netherlands	SCX Soloroof ® Home Edition							17-21 kg/m²		
49	Air collector	PV module mounted on air collector	Conserval Engineering Inc. 200 Wildcat Rd. Toronto, ON M3J2N5 Tel: +1 416 661 7057 info@solarwall.com www.solarwall.com	Canada	SolarWall PV/T SolarDuct PV/T		Glass-backsheet	Steel	Fully wetted absorber	PV mounted on trapezoid sheet			100 W/m2	
50	Air collector	Thermal air collector, PV only for operation of fan	Grammer Solar GmbH Oskar-von-Miller Straße 8 D-92224 Amberg Tel: +49 9621 30 85 7 0 info@grammer-solar.de www.grammer-solar.de	Germany	TWINSOLAR compact 2.0 TWINSOLAR compact 4.0/4.5/6.0			Alu-minium Alu-minium	Rib absorber Rib absorber		2000 x 1000 mm 4000 x 1000 mm 2250 x 2100 mm 6000 x 1000 mm	47 kg 90 kg 110 kg 135 kg		
51	Air collector	Thermal air collector, PV only for operation of fan	Scanheat A/S Gotlandsvej 22 8700 Horsens Tel: +45 7628 4100 info@scanheat.dk www.scanheat.dk	Denmark	Scansun XL 250 XL 400 XL 400 LD XL 900						570 x 870 x 60 mm 660 x 1050 x 60 mm 550 x 1250 x 60 mm 900 x 1275 x 60 mm	13 kg 15 kg 14 kg 28 kg	6.7 W 8.2 W 8 W 11.4 W	
52	Air collector	Thermal air collector, PV only for operation of fan	Solar Venti A/S Fabriksvej 8 DK 8881 Thorsø Tel: +45 8696 6700 info1@solarventi.dk www.solarventi.dk	Denmark	Standard SV3/ SV7 SV14/SV14K SV20/SV20K SV30/SV30K						704 x 524 x 55 mm 1004 x 704 x 55 mm 1974 x 704 x 55 mm 1974 x 1004 x 55 mm 3000 x 1020 x 75 mm		6 W 12 W 12 W / 18 W 12 W / 18 W 18 W / 24 W	
53	Vacuum tube collector		Photonomi Global Group Citypoint Tower, 1 Ropemaker St, London, EC2Y 9HT. Tel: +44 2034 115 312 sales@hone.world www.hone.world	UK	HONE 501 Thermal/Electric	amorph Si					1608 x 1045 x 136 mm	51.5 kg	100 Wp	

	Thermal key data																							Certification	
Nr	Gross area	Apert. area	Absorb. area	Charact. curve model	Reference area	Electr. op. mode at measurement	Source for key data	eta0	Covered		Uncovered			Quasi-dynamic						Open air collector			Stagnation temperature	IEC	Solar Keymark
									a1	a2	bu	b1	b2	c1	c2	c3	c4	c6	Kθ_d	mdot [kg/h]	eta0	bu			
43	1.69 m2	1.58 m2			Gross area	MPP	AIT measurement report	0.487	5.881	0.006													90°C		No
44	1.48 m2	1.40 m2		Open circuit air collector	Gross area	MPP	Keymark	0.408 (345.6 kg/h)												346 238 180	0.408 0.363 0.316	0.0450 0.0470 0.0379	75.3°C	IEC 61215 IEC 61730	Yes
45	1.64 m2	1.63 m2																					55.72°C		Yes
46																									No
47	1.61 m2	1.54 m2		Open circuit air collector	Gross area	MPP	Keymark	0.545 (281 kg/h)												281 245 187	0.545 0.518 0.477	0.0564 0.0538 0.0561	80°C		Yes
48																									No
49																									No
50	2.01 m2	1.60 m2		Open circuit air collector	Aperture area	Fan operation	Keymark	0.631 (mdot =141.5 kg/h)												141.5 118.6 74.0	0.631 0.584 0.489		130°C		Yes
51																									No
52	1.39 m2	1.26 m2		Open circuit air collector	Aperture area	Fan operation	Keymark	0.639 (173 kg/h)												173 113 80	0.639 0.569 0.509				Yes (for SV professional)
53	1.68 m2	0.88 m2					Data sheet	0.75	2.368	0													254.4°C		No