# MEASUREMENTS AND BENCHMARK OF PV-T COLLECTORS ACCORDING TO EN12975 AND DEVELOPMENT OF A STANDARDIZED MEASUREMENT PROCEDURE

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## Synopsis

Hybrid Photovoltaic-thermal-collectors (PV-T) may have a number of advantages compared to stand-alone PV or solar-thermal-collectors. To mention one of them for example the overall efficiency of a PV-T-system is higher than the efficiency of the individual systems [1]. Recently, there have been efforts by the “European Solar Keymark Network” and also in national organizations to standardize PV-T collector measurements and make it possible to assign a “Solar Keymark”. That would be a great benefit for PV-T collectors and subsidiary for a successful implementation in the market.

Fraunhofer ISE runs an accredited laboratory for solar thermal components (TestLab Solar Thermal Systems) and also an accredited test centre for PV modules (TestLab PV Modules) and is able to combine both strengths to measure uncovered PV-T collectors and covered PV-T collectors properly. Based on the testing facilities for solar air-collectors, PV-T air-collectors can be tested as well. Recently even Concentrated PV-T collectors are in the process of getting characterised. By testing several PV-T collectors Fraunhofer ISE has created special know-how for measuring different PV-T collectors and developed an automated procedure for efficiency tests.

In this paper, the interest in the standardization of measurements of a PV-T collector is discussed, and different measurement procedures are shown. It illustrates possible testing methods for different collectors, testing procedures and results from tests already performed.

## 1. Introduction

Hybrid Photovoltaic-Thermal collectors (PV-T) are multi-energy and multi-functional components converting solar energy into electricity and heat. In fact, in a PV-T collector, PV cells or modules operate as a thermal absorber and are cooled by circulated water (or air). The heat obtained can be then used, according to the temperature level, as source for different kind of systems, like heat pumps, solar domestic hot water, or swimming pool heating systems, etc. In the last years, many experimental and numerical investigations about PV-T systems have been carried out and a few PV-T products are now available on the market. In spite of a recent and growing interest in this field, there is still no specialized test procedure for PV-T collectors available yet. However, a test procedure can be developed based on the standards for solar thermal collectors and for photovoltaic modules. Therefore Fraunhofer ISE has started some efforts for creating appropriate measurement procedures based on the existing test standards for solar thermal collectors and PV-modules.

### 1.1 Classification of PV-T collectors

In order to get a better overview on the hybrid PV-T collector technologies the different types of PV-T collectors were classified in categories, as presented in the Figure 1. The first category corresponds to concentrated PV-T collector, with either high concentration factor [2-3] or lower concentration factor [4-6].

The second category corresponds to all flat plate PV-T collectors. According to the system where they are integrated, those flat plate PV-T collectors can be either glazed or unglazed. In both case, the cooling fluid can be liquid (water or glycol) or air [7]. Although both C-PV-T and flat plate PV-T systems are investigated at Fraunhofer ISE, this paper only focus on the testing of (covered) flat plate PV-T collectors.

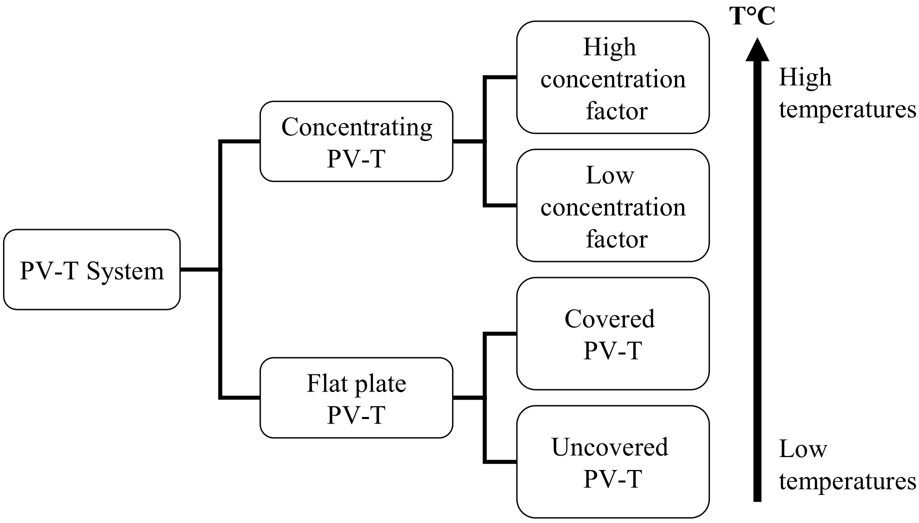



Fig. 1: Classification of PV-T systems

### 1.2 PV-T collector testing at Fraunhofer ISE

The "TestLab Solar Thermal Systems" of Fraunhofer ISE has tested several PV-T flat plate collectors according to the European collector testing standard EN 12975 [8] for solar thermal collectors and some adoptions and adjustments from other related standards. In fact, covered PV-T collectors and uncovered PV-T collectors, liquid and air PV-T collectors can be tested. There is also the possibility to measure PV-T collectors with different kinds of PV technology, like crystalline silicone and thin film modules.

Measuring and characterizing a PV-T collector serves different interests. First one wants to know if the product is reliably running for a lifetime of more than 20 years. Second one wants to know what energy gain both for thermal and for electrical use can be expected per year at different boundary conditions.

So to provide industry with these parameters and information to empower them to differentiate their products in the market one has to think about procedures to generate comparable and repeatable testing results.

First step is of course to analyze the existing standards for both technologies, Solar Thermal collectors at the one and PV modules on the other side. Because of the various possibilities of interacting effects within a hybrid-collector one should as well think about approaching the topic from a systemic point of view.

So the collector as a black box is to balance from a caloric as well as from an electrical perspective. Both effects are during testing interfering with each other. So the challenge is to separate the both energetic effects from each other to provide parameters based on which the product can be characterized well. Later control strategies for the operation can be developed with this knowledge.

For the caloric characterization existing models for thermal collectors can be adopted, as the behaviour of the absorber (PV+hydraulics) is like the one of a non selective absorber. So it has to be differentiated if the absorber is uncovered or covered or if there is concentrating optics used. If there is air used to transport the heat, one should combine the experiences and methodology of air-collector measurement (for example various mass flow rates).

For the electrical efficiency the differentiation as it is recently used when testing PV modules can be adopted. So Silicon based PV modules and thin film cell based modules have to be differentiated [9]. For thin film modules it is necessary to get them in stable condition. Therefore some procedures for thin film modules are in IEC 61464 specified.

Bringing now both methodologies together, it becomes clear that the interacting effects have to be represented. Different boundary conditions have to be defined measuring the performance of the PV-T collectors. In chapter 2.3, the testing sequences reasonable for PV-T collectors based on the existing standards are compared. Obviously some of the tests are appropriate, merging from both technologies and some more specific ones may have to be added. Chapter 2.2 explains a procedure regarding performance measurement.

## 2. Testing of glazed PV-T collectors - reliability test

In the following the focus exclusively is on testing of glazed PV-T collectors. Because they contain both thermal collector and PV module technologies, it is assumed that they have to fulfil both series of standards EN 12975 for glazed solar thermal collectors [8] and IEC 61215 [9] for PV modules. If one wants to characterize other PV-T collector types the following reliability tests have to be re-evaluated and if necessary modified. Table 1 shows, the standard for both solar thermal collector measurements and PV module. In EN 12975 and IEC 61215 reliability tests and performances tests are foreseen.

| EN 12975-1:2006 European standard for solar thermal collector measurements | | IEC 61215 Standard for PV module testing | |
|---|---|---|---|
| 5.3.2 | Internal pressure for absorber | 10.1 | Visual inspection |
| 5.3.3 | High temperature resistance | 10.2 | Electrical performance |
| 5.3.4 | Exposure | 10.3 | insulating stability against voltage |
| 5.3.5 | External thermal shock | 10.4 | Identification of temperature coefficient |
| 5.3.6 | Internal thermal shock | 10.5 | Identification of NOCT |
| 5.3.7 | Rain penetration | 10.6 | Performance at NOCT and STC |
| 5.3.8 | Mechanical load test | 10.7 | Performance at low irradiation |
| 5.3.9 | Thermal performance | 10.8 | Long-term test at outdoor conditions |
| 5.3.10 | Freeze resistance test | 10.9 | Hot-Spot test |
| Annex L Pressure drop | | 10.10 | UV-Aging test |
| | | 10.11 | Temperature cycling test |
| | | 10.12 | Humidity/heat test |
| | | 10.13 | Humidity/freezing test |
| | | 10.14 | Strength test of connectors |
| | | 10.15 | Creepage current test under wet conditions |
| | | 10.16 | Mechanical strength |
| | | 10.17 | Hail test |
| | | 10.18 | Bypass diode test |
| | | 10.19** | Light-aging |

Table 1: Overview on the standards for ST collector and PV module testing.

As presented in the Table 1, some of the reliability tests like freeze test, high temperature resistance, long time exposure and mechanical load test are contained in both sequences. Therefore, by adapting the norms to each other, it could be possible to skip some of those double tests. Some other test like thermal cycling has to be adapted to the PV-T collector temperatures. In chapter 2.1 suggestions are presented regarding specifications for PV-T collector reliability test.

## 2.1 Reliability test to be performed in both EN 12975 and IEC 61215

Outdoor exposure

Aging effects are very relevant in both thermal collectors and PV module technologies, and therefore a major issue for PV-T collectors. In the test cycle for solar thermal collectors, no water flows inside of the pipes and one of the connectors has to be closed, so there is no natural convection in the collector pipe's system. The total irradiation on the collector is at least 30 days with irradiation greater than 14 MJ/day/m² which corresponds to 117 kWh/m². For PV module there is only a requirement on the total irradiation on the collector which has to be at least equal to 60 kWh/m². Therefore it is suggested only to perform the procedure of solar thermal collectors, in which the procedure for PV modules is already completely fulfilled.

High temperature and temperature cycling

Even so in a system installation, there will be regulatory means to prevent critical situations in the PV-T-Panel, respectively the overheat of the absorber, critical situations can occur. What is called the stagnation phase in the solar thermal operation, is not that critical when it comes to uncovered collectors, but with covered and especially with concentrating PV-T the high temperature resistance of all used materials has to be assured. E.g. holiday are times, of exposure without heat load. In solar thermal collectors there is a high temperature test for the capability of withstanding these high temperatures for the materials.

Adaptation and combination of the tests of both, thermal and PV standards is suggested here. The high temperature test for solar thermal collectors is essential. For the cycling test of the PV modules some modifications are necessary, because the temperature range in the PV standard is not suited for covered collectors. On covered collectors the maximum temperature under stagnation conditions will easily reach up to 140 °C. Lately Fraunhofer ISE has done some efforts to develop a procedure for this test.

Mechanical load test

Glazed PV-T collectors interact with their surrounding, very similar to thermal collectors having a transparent cover sheet, a frame, backside insulation and a back plate. Therefore one can say that the mechanical load test can be performed according to the definitions in EN 12975. Because the absorber (=PV module and hydraulics) is not directly exposed anymore to mechanical wind and snow load, the corresponding test in IEC 61215 is not needed. Additionally, Fraunhofer ISE is doing some investigations on this field of mechanical load test for thermal collectors (project "MECHTEST" supported by the German federal environment ministry).

Freezing test

In the solar thermal collector standard a test is described where the collectors have to be filled with the original heat transfer fluid and then a freezing test has to be carried out. This test is not necessary if the manufacturer specify that the collector can only be used with an anti-freeze fluid or in regions without frost. In the PV modules standard the freezing test is included in the temperature cycling test. Therefore it is not necessary to modify or create a special procedure for the freezing test. The procedure of EN 12975 and IEC 61215 can be used.

Rain Penetration

If the collector is ventilated, humidity can enter the collector box. Depending on the design, even rain can enter the collector box. In both cases the water should not condensate inside the collector and should be exhausted by natural convection fast and reliable. Surplus to these effects, the absorber (including the PV-

Module) has to be water tide to avoid any short cuts. So the absorber with the PV-cells has to be tested towards electrical safety separately. Here the test sequence out of IEC 61215 can be adapted to the absorber only.

### 2.2 Reliability tests to be performed only according to EN 12975

Internal absorber pressure test

Installing a system flown through by any medium, leakages are not acceptable, although the induced risk is varying. The internal absorber pressure test has to be performed for the completely assembled PV-T-collector according to EN 12975. This could be a challenge for PV-T collectors, because the absorber is not allowed to bend anyway since the PV cells on the absorber are very fragile.

External Thermal Shock

The external thermal shock seems to be not so relevant anymore today since collector covers are using tempered glass and well designed structures to avoid parts of the absorber touching the cover sheet. Actually still it is recommend to perform this test, especially when concentrating optics are used.

Internal Thermal Shock

This test can be a challenge for PV-T-Collectors, as the different layers of laminates used in an PV-T-Absorber are thermally loaded inhomogeneous, but packed together very tide. Even when strong thermal strength are applied the hydraulics has to be water tide towards the PV cell parts.

### 2.3 Reliability test to be performed only according to IEC 61215

The insulating stability against voltage test, strength test of connectors and creepage current test under wet conditions have to be performed only on the PV-T absorber plate (PV module + heat exchanger) and not on the whole collector. Hot-Spot test and UV-Aging test should be performed directly on the whole collector, as well as the bypass diode test.

### 2.4 Ongoing work on reliability tests

At Fraunhofer ISE, two test centres are dedicated to the testing of as well thermal collectors and PV modules, bringing very good preconditions to combine the two technologies and create more knowledge about PV-T measurement. This work is supported by several projects on PV-T collector development. Testing projects have been started, where for example new consolidated findings about the modification in the temperature cycling tests will be created. These results will be presented in another publication.

## 3. Testing of glazed PV-T collectors - efficiency tests

### 3.1 Specification for thermal measurement of PV-T collectors

Hybrid PV-T collectors are multi-energy and multi-functional components. Therefore the thermal efficiency measurements need to be modified in order to take into account the way how the PV module operates. Three main cases may occur.

Open circuit “oc” mode

When the PV electric cables are not connected to an electric consumer/grid, the PV-T collector operates in a open circuit “oc” mode. All energy absorbed by the solar cells is converted into heat. The collector is operating as a conventional thermal collector, and does not produce any electric energy.

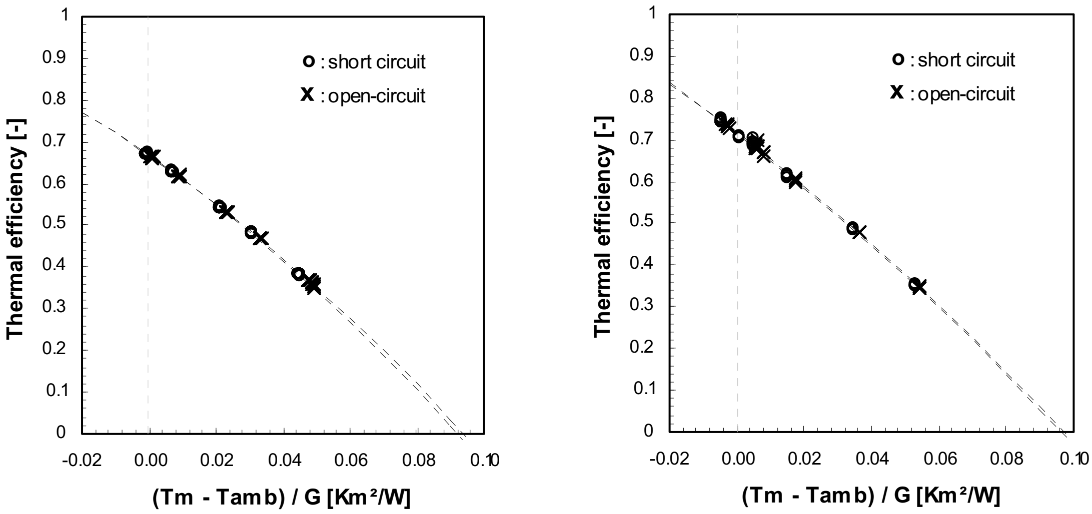
Short circuit “sc” mode

When the PV electric cables are connected in short circuit the collector operates in the sc mode. All energy absorbed by the solar cells is converted into heat. Like for oc mode, the collector is operating as a conventional thermal collector, and does not produce any electric energy.

Maximum power point “mpp” mode

When the PV module is electrically connected using a MPP tracker, the collector is operating as hybrid collector and produces thermal and electric energy;

The Figure 3a presents thermal efficiency measurements made with an indoor solar simulator in both oc and sc modes for a typical glazed PV-T collector with PV module made of crystalline silicon solar cell. The Figure 3b presents thermal efficiency measurements made with an indoor solar simulator in both oc and sc modes for a typical glazed PV-T collector with PV module made of CdTe solar cell.




(a) (b)

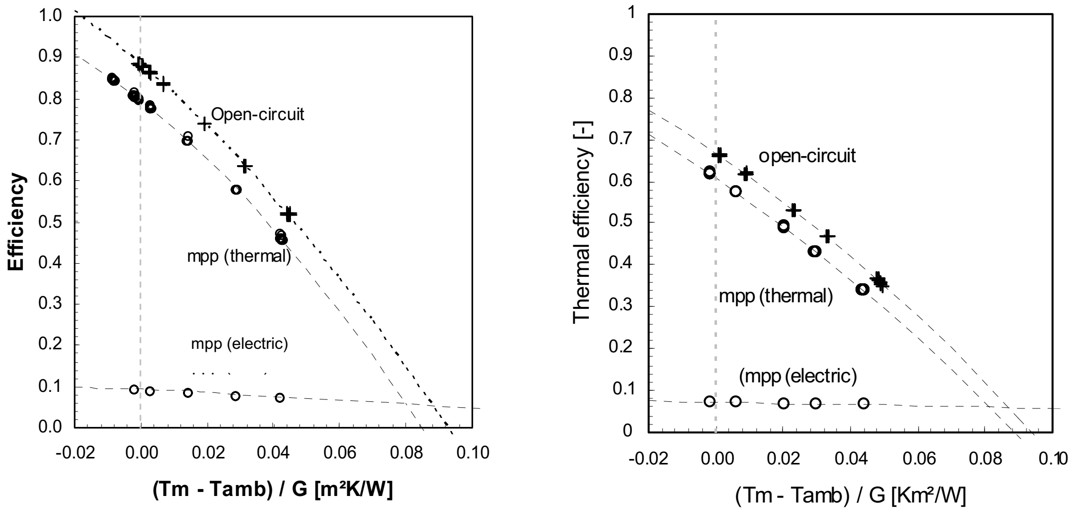
Figure 3: Open circuit “oc”/ Short circuit “sc” of a typical glazed PV-T collector with c-Si (a) and CdTe (b) as cell technology

As expected, there were no differences observed between the thermal efficiency curve in sc and the thermal efficiency curve in oc mode for both kind of collector.

For the measurements of PV-T collectors in a real operating mode mpp (production of heat and electricity), it has been decided to use also the indoor solar simulator. The artificial radiation reaching the collector is usually not so homogeneous; the lamp spectrum is not so close to AM1.5 in a sun simulator dedicated to the testing of thermal collectors than in a flasher for PV modules. However, it gives a good approximation on the thermal performances of the collector in a real operating mode. In order to measure the thermal efficiency curve in the maximum power point, the mpp tracker is connected as an electrical load. For each different inlet temperature, a series of I(V) characteristic curves were taken by the mpp tracker in order to determine the PV-T module electric efficiency.

The Figure 3a presents thermal efficiency measurements made with the indoor sun simulator in both oc and mpp modes for typical glazed PV-T collectors with PV module made of crystalline silicon solar cells (different collector than in Fig 4a). The Figure 3a presents thermal efficiency measurements made in indoor sun simulator in both oc and mpp modes for a typical glazed PV-T collector with PV module made of CdTe solar cell (same collector than in Fig 3b). In both Fig 3a and b, the electrical efficiency calculate using the I(V) measurements of mpp tracker is also plotted as function of the reduced temperature.

In maximum power point “mpp” mode, the collector is operating as hybrid collector and the absorbed radiation is converted in both thermal and electric energy. As presented in the Figure 4, it affects the thermal behaviour of the collector. Thermal losses coefficient and efficiency at Eta0 point are different that in the open-circuit mode.




(a) (b)

Figure 4: Thermal and electrical performance measurements of a typical glazed PV-T collector with c-Si as cell technology (a) and CdTe technology (b).

According to the observation and the experiments made at Fraunhofer ISE on different kinds of glazed PV-T collectors based on water circulation, following specifications for thermal measurement of PV-T collectors and efficiency tests are suggested. When the PV module is not connected to an electric grid, the PV-T collector behaves like a thermal collector. However, no significant difference between both sc and oc modes were observed, this is why it is suggested to measure only two thermal efficiency curve (EN12975).

Open-circuit mode

MPP mode with a mpp tracker having an electronic load (Dummy load)

The open-circuit mode corresponds to the worst case in the context of maximal temperature. Therefore it is suggested to perform the stagnation measurements in open-circuit only.

### 3.2 Specification for electrical measurement of PV-T collectors

As presented in the part 3.1, the mpp (at Maximum Power Point) measurements with a sun simulator used for solar thermal collector tests are not fulfilling the requirements of the PV standard. Therefore additional PV efficiency tests are still required. Electrical performance, performance at low irradiation and identification of temperature coefficient has to be performed on the whole collector (absorber + insulation + glazing) according to IEC 61215.

For IEC 61215 it is necessary in 10.5 to measure the NOCT (Normal Operation Cell Temperature). In the case of a PV-T Collector this would be the typical working temperature of the collector. At normal operation the temperature of the collector depends strongly on the needs of the thermal circuit. Therefore the thermal efficiency curve should be measured at different fluid temperatures and the PV efficiency curve is depending on the fluid temperature.

## 4. Conclusion

In spite of a recent and growing interest in the field of hybrid Photovoltaic-Thermal collectors, there is still no specialized characterisation procedure for PV-T collectors defined. By testing several PV-T collectors Fraunhofer ISE has created special know-how for measuring different PV-T collectors based on the standards for solar thermal collectors (EN12975) and for photovoltaic modules (IEC 61215). Both Fraunhofer ISE test facilities for PV and Thermal collectors, have started some efforts for creating appropriate PV-T measurement procedures.

In term of thermal measurements, the suggestion is to measure two different thermal efficiency curves measurements, one in open-circuit mode, when the PV-T collector works exactly like a pure thermal collector, and one thermal efficiency curve in mpp–mode, when the collector operates in a hybrid mode (production of both heat and maximum electricity). The stagnation temperature estimation has to be done in open circuit mode (worst case).

In terms of electrical measurement all tests (temperature coefficient, low irradiation and flasher test) should be performed on the collector with thermal insulation at the back side of the PV-T absorber, and the collector glazing on the front side.

In terms of reliability measurements, some of the tests like long time exposure and mechanical load test are contained in both EN 12975 and IEC 61215 tests procedure and can be performed in just one test. Some of the IEC 61215 tests like thermal cycling or insulating stability against voltage have to be modified in order to take into account the PV-T specifications.

Fraunhofer ISE will further work to enable its accredited TestLab PV Modules and TestLab Solar Thermal Systems to develop and perform well defined PV-T measurements. The suggestions for the specific PV-T measurements will be discussed with the experts of the solar thermal and PV standardisation bodies to develop together a broadly accepted.PV-T standard.

## References


[1] Zondag et al., The yield of different combined PV-thermal collector designs, Solar Energy, Vol. 74 (2003), 253-269.

[2] Mittelman et al., Solar cooling with concentrating photovoltaic/thermal (CPVT) systems, Energy conversion and management 48 (2007) 2481-2490

[3] Mittelman et al., Water desalination with concentrating photovoltaic/thermal (CPVT) systems, Solar Energy 83 (2009) 1322–1334

[4] Coventry, Performance of a concentrating photovoltaic/thermal solar collector, Solar Energy 78 (2005)

[5] Pröll et al.., Schwach konzentrierender PV-Hybrid Kollektor, Proceeding OTTI Solarthermie 2010

[6] Nilsson et al. Electrical and thermal characterization of a PV-CPC hybrid, Solar Energy 81 (2007)

[7] Zondag. Flat-plate PV-Thermal collectors and systems: A review. Renewable and Sustainable Energy Reviews. Volume 12, Issue 4, Pages 891-959, 2008.

[8] EN 12975-1:2006 Thermal solar systems and components.

[9] IEC 61215 – Crystalline silicon terrestrial photovoltaic (PV) modules, 2005; IEC 61464 – Thin-film terrestrial photovoltaic (PV) modules, 2008