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Quality and Energy Yield of Modules and Photovoltaic Plants

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ABSTRACT

The Swiss test centre ISAAC-TISO, built on the work done in the 1980s such as the realisation of the first c-Si module connected to the European grid and the realisation of one of the first silicon amorphous modules in 1988, was created in 1991. The main objective of the test centre is the evaluation of module quality, meaning the assessment of the power values declared by the manufacturer, the electrical behaviour and energy production in different climatic conditions, the stability of these values through time, and module life span. Previously, both an outdoor and an indoor structure for testing the electrical behaviour of modules were created.

Outdoor tests, which began in 1993, are carried out using external stands capable of accommodating 18 pairs of modules. The aim of the developed test procedure is to verify the actual power of modules; to verify if module guarantees are respected; to observe the behaviour of modules under real climatic conditions; to compare the energy yield of the different types of module; and finally, to develop methods for forecasting energy yield. Test cycle number 10, with its new procedures, has been successfully completed. The results indicated that:

- for 3 out of 14 modules, the purchase warranty is not respected;
- after 15 months of exposure, all the modules respected the final warranty. Nevertheless, the warranty declaration is not always clear and, sometime, unavailable;
- after 15 months of exposure, the power of c-Si modules is about **3.6%** lower than the nominal value declared by the manufacturer (Pn), while the real power before the exposure was 2.3% lower.

Module degradation refers to the real power measured before and after a defined period:

- c-Si module degradation in the first stabilization period (H = 20kWh/m2) has been equal to **-1.1%**.
- in the next one-year period a mean degradation of **-1.2%** has been recorded.

Outdoor performance inter-comparison: in technological energy rating inter-comparison, the modules can be separated into 3 groups. The first group with up to 3% difference compared to the best one; the second group, with a difference of 3% and 6% in between; and the third group, with a difference from 6 to 10%. The module can always be correlated to the same groups independently of the 3 investigated cases (1 year, clear sky days, cloudy days). Nevertheless, due to the seasonal variations of a-Si module's performance, the energy rating comparison normalised at P3 (stabilized value after 3 months of exposures) depends on the period in which P3 has been measured. At present, a standard defining the annual reference power for a-Si modules does not exist.

The daily performance ratio (PR) of the HIP (Sanyo) module shows a lower temperature coefficient (-0.32%/°C) if compared to standard c-Si modules (-0.41 to -0.47%/°C). This leads to reduced temperature losses at high temperatures - and consequently at high irradiances – and therefore to a better daily PR in general. Despite the relatively high temperature coefficient of 0.47%/°C, the module MHHplus220 (Sunways cells) performs very well with higher PR at low irradiances and low temperatures. A better performance at high incident angles or high diffuse fraction seems to be responsible for this. Compared to the other technologies, the two Sunpower modules show a higher instability in PR. This effect could be associated to some technology related effects called "surface polarization".

Thin film modules, despite their important initial degradation, usually show a higher PR if compared to c-Si modules, Particularly, FS modules have a low temperature coefficient (-0.2%), just like a-Si modules, but stable power throughout the seasons. In contrast, a-Si modules show a trend with a minimum during winter and recovery during summer. This because of the combination of the typical annealing of the Staebler-Wronsky effect and the low temperature coefficient.

Energy Rating prediction with the Matrix method: the final objective of the matrix method is to develop an energy rating procedure which minimizes the number and the complexity of the required tests and input parameters, while still leading to a prediction accuracy which is in the range of measurement accuracy.

The tests on the third reference module of cycle 10 are performed on short-term indoor and/or outdoor characterisation methods for the determination of the module performance at different temperatures and irradiance levels. The obtained power matrix $P_m(G_i,T_{amb})$, is the primary input parameter of the Matrix Method. At this stage, no spectral, angle of incidence or coverage effects are explicitly considered within the simulations. The assumption made here is that they make either a small contribution to the total energy output, or that they average out over the year.

The indoor approach was the ER method with the highest reproducibility and accuracy for all modules. For all test modules, except for the Kaneka modules that were still not stabilised, the error remained in the range of **±3%.**

A superimposition of the single indoor matrices with the respective measured outdoor matrices demonstrated that they are in fact very close to each other for almost all modules (**±2%**). This explains why the energy predictions through indoor measured power matrices lead to such good results.

To further reduce the error, the other effects (spectral and angle of incidence effects) on simulations probably need to be added. The influence of the stability of the module is probably a more important aspect to investigate. Initial degradation, long term degradation or other degradation/recovery effects such as the well known Staebler-Wronsky effect will be important for a good energy prediction.

A low temperature coefficient by itself does not guarantee a high energy output, a good PR over the whole range of occurring irradiances is also relevant. A future energy prediction method for building integrated modules, especially if of a-Si technology, will need the introduction of some of the up-to-now neglected effects.

New MPPT for outdoor test stand: during the present project a new MPPT (named MPPT3000) has been developed. This version is able to satisfy the demands of the new models of PV module on the market that have ever increasing power and voltage (up to 250Wp and up to 20A). Apart from precisely maintaining a module at MPP, it allows I-V characterisation and direct measurement of temperature and irradiation without need of carrying out another data logger. The new MPPT is particularly suitable for research purposes. A number of universities, research centres and companies, have therefore wanted to acquire it.

Indoor tests, which began in 2000, are carried out using a pulsed solar simulator. During the project, the main activities included the maintenance of ISO17025 accreditation of I-V measurements at STC of crystalline silicon modules; ISO17025 accreditation for test to determine α (Isc), β (Voc) e γ (Pm) temperature coefficients; measurement of I-V characteristics at different irradiances; inverse (from Voc to Isc) and multiflash measurements (to measure modules with capacitive cells); and measurement of thin-film modules.

In order to maintain de ISO17025 accreditation, the following activities were carried out:

- weekly repeatability measurements: ±1%, for reference modules, in the period 2004-2006;
- instruments periodical calibration;
- annual audits by the SAS (Swiss Accreditation Service);
- international Round Robin tests with the 10 main laboratories in the world;
- new uncertainties according to ISO5725: Pm ⇨ ±2.0%; I ⇨ ±1.8%; V ⇨ ±1.0%;
- installation and setting of the thermostatic chamber;
- ISO 17025 accreditation of the temperature coefficients measurement;
- temperature coefficient determination of 27 modules (7 thin-films);
- simulator xenon lamp spectrum measurement and check of the light uniformity on the module area to verify solar simulator class A according to the IEC standard.

Measurements of I-V characteristics at different irradiances on 18 PV modules showed results with linear behaviours. The accreditation of this kind of measurement is foreseen together with a periodical check of the lamp spectrum to assure the measurement reproducibility.

The I-V direct determination (from Isc to Voc) of capacitive modules can lead to important differences between measured and real power (e.g. Sanyo – HIP: -12%). The introduction of multiflash measurements, with at least 15 points per I-V curve, allowed to obtain realistic and accurate results also for modules with capacitive cells.

Finally, the possibility to perform the power matrix determination indoor, with the sun simulator, has been confirmed. Nevertheless, an accurate matrix determination of thin-film modules will not be possible until the laboratory will be able to verify the lamp spectrum at low irradiances.

Building Integrated PhotoVoltaic BIPV: when realising PV plants in an urban context power, energy production and cost are not necessarily the only criteria to be considered. Architectural and aesthetic factors are sometimes predominant in the final choice, and sometimes they clash with the demands of plants solely designed for energy production

Integrating a photovoltaic element into the envelope of a building is becoming an increasingly important factor for the acceptance of photovoltaic technology in an urban context. The integration solutions proposed must be simple and reliable, but must also satisfy non-technical criteria such as colour, shape, lines, and application methods, etc. It must also respect the typical functions of a building element (impermeability, safety, insulation, transmissivity, etc).

In order to confront these difficulties, including non-technical aspects, PV engineers, architects, builders, PV module and building material manufacturers, stakeholders, etc were invited to partake to workshops so to identify the main obstacles to integration. As a result, a website (www.bipv.ch) was created. This aims to satisfy, at least in part, the architectural difficulties that emerged from these meetings.

The PV module's functionality as a building element is not always a strict surrogate of to what it has substituted. The feasibility of some tests on aspects such as thermal behaviour (U-value and g-value) and impact resistance of PV elements integrated into synthetic roofing have been assessed. Finally the absorption/shielding properties of the non-ionising radiation (NIR) of the various types of modules (wafer or thin film) were analysed.

INTRODUCTION

Expansion in the world photovoltaic market over the past ten years has led to a considerable increase in the number of new PV manufacturers. In a rapidly growing market, it is important to ensure quality control. Economies of scale have helped bring down the cost of modules but it is, above all, the introduction of new materials and technologies, in particular thin-film and modules with high-performance cells, that has most greatly influenced cost reduction. Techniques for measuring the quality of the modules must therefore evolve and keep pace with the increasing demands of the market.

In order to evaluate module quality, it is necessary to verify the declared power values of the manufacturer, electrical behaviour and energy production in different climatic conditions, the stability of these values through time as well as module life span

The Swiss test centre, TISO, created in 1991 built on the work done in the 1980s such as, for example, the realisation of the first c-Si module connected to the European grid and in 1988 the realisation of one of the first silicon amorphous modules.

In preceding years both an outdoor and indoor structure for testing the electrical behaviour of modules were created .

Indoor tests, which began in 2000, are carried out using a pulsed solar simulator. During the course of the project the main activities have included the maintenance of ISO17025 accreditation of I-V measurements at STC of crystalline silicon modules; ISO17025 accreditation for test to determine α (Isc), β (Voc) e γ (Pm) temperature coefficients; measurement of I-V characteristics at different irradiances; inverse (from Voc to Isc) and multiflash measurements (to measure modules with capacitive cells); measurement of thin-film modules.

Outdoor tests, which began in 1993, are carried out using external stands capable of accommodating 18 pairs of modules. The aim of the test procedure developed is to verify the real power of the modules; verify whether module guarantees are respected; observe the behaviour of modules under real climatic conditions; compare the energy yield of the different types of module; and finally develop methods for forecasting energy yield.

The procedures involve an initial period of stabilisation followed by a one-year comparison of energy yield. The modules are purchased anonymously, periodically measured indoor at STC, exposed southwards tilted at 45° and connected to a maximum power point tracker – MPPT.

During the present project a new MPPT (named MPPT3000) has been developed which is able to satisfy the demands of new models on the market which have ever increasing power and voltage.

Apart from precisely maintaining a module at MPP, it allows I-V characterisation and direct measurement of temperature and irradiation without need of another datalogger to be carried out. The MPPT which has been developed is particularly suitable for research purposes and it has therefore been possible to sell it to a number of universities, research centres and companies.

The new equipment has allowed outdoor comparisons with the tenth test cycle to be continued.

With the data acquired in the test cycle it has been possible to further refine the method for forecasting annual energy yield. It is a simplified method involving the power matrix of the PV module in relation to irradiation and temperature and a matrix of climatic events in a certain location.

When realising PV plants in an urban context power, energy production and cost are not necessarily the only criteria to be considered. Architectural and aesthetic factors are sometimes predominant in the final choice and sometimes clash with the demands of plants solely designed for energy production

Integrating a photovoltaic element into the envelope of a building is becoming an increasingly important factor for the acceptance of photovoltaic technology in an urban context. The integration solutions proposed must be simple and reliable but must also satisfy non-technical criteria such as colour, shape, lines, and application methods etc and respect the typical functions of a building element (impermeability, safety, insulation, transmissivity etc).

In order to confront the difficulties there are in including these non-technical aspects, PV engineers, architects, builders, PV module and building material manufacturers, stakeholders etc were invited to workshops to identify the main obstacles to integration. A site was therefore created (www.bipv.ch) to satisfy, at least in part, the demands of architects which came out of these meetings.

The PV module's functionality as a building element does not always match up to what it has substituted. The feasibility of some tests on aspects such as thermal behaviour (U-value and g-value) and impact resistance of PV elements integrated into synthetic roofing have been assessed. Finally the absorption/shielding properties of the non-ionising radiation (NIR) of the various types of modules (wafer or thin film) were analysed.

Figure 1: the ISAAC-TISO outdoor test facility.

1 INDOOR MEASUREMENTS

1.1 Introduction

Indoor measurements under standard conditions with a solar simulator allow comparison to a degree of precision almost impossible to achieve in outdoor conditions. They can be carried out at any moment, without needing to wait for ideal climatic conditions. There are two types of solar simulator: the flash simulator and steady state simulator.

Since 2000 the ISAAC-TISO Institute, has operated a pulsed solar simulator for the measurement of the performance of PV modules. The whole **IV measurement system**, called Pasan IIIa, is manufactured by Belval, a Swiss company specialised in solar simulators for PV applications. The simulator classified as 'class A' simulator, is composed of a single Xenon lamp 8m away from the test area, an electronic load (Belval BV66) and a data acquisition unit and software from the same manufacturer.

The standard test procedure applied by the laboratory for the **measurement of STC power** consists in the mounting and connection of an encapsulated primary reference cell near to the PV module and within the class A simulator uniformity area. The module rack insures the co-planarity of the reference device with the test device. The PV module is connected as close as possible to the output of the module with a 4-wire cable. A temperature sensor is placed on the back of the module and the reference device and the whole room is acclimatised to approximately 25°C. The IV-measurement is performed when the module and reference device temperature is stable and around 25°C ± 0.5°C. The lamp power is adjusted to 1000W/m² ± 10W/m².

To maintain a sufficiently high degree of precision and to guarantee that measurements through time are reproducible, constantly verifying the performance of the simulator and relating it to the old and new characteristics of the photovoltaic technologies present on the market has become necessary.

Apart from services for third parties and international projects and the testing of modules, indoor measurements have been characterised by the following activities:

I1) Maintenance of accreditation for I-V @STC tests.
I2) Accreditation of tests to determine the temperature coefficients α (I_{sc}), β (V_{oc}) e γ (P_M)
I3) Measurement of I-V characteristics at various irradiations.
I4) Inverse and multiflash I-V measurement.
I5) Thin film module I-V measurement.

For correct measurement of PV modules, it is necessary to remember that indoor measurements are limited by the following factors

1) The light spectrum of the Xenon lamp does not correspond perfectly with the AM1.5. spectrum at standard conditions
2) The spectral response of the reference cells do not correspond to that of the PV module under examination
3)The scanning speed of the I-V characteristic is higher in impulse simulators and this can create problems with certain modules, particularly with some from the new generation.
4) Standard conditions do not reflect real outdoor conditions.

The solar simulator used by ISAAC has a very short irradiance plateau (1.2-2ms) in which the IV-measurement is executed (irradiance variations ≤ ±1%). Also the newer Pasan simulator types, like for example the Pasan IIIb, disposes of longer plateaus of up to 10ms. As is well-known, very short sweep times can lead to measurement artefacts within capacitive modules, which can be only avoided by alternative measurement procedures. Today certain modules need up to 250 ms for a complete IV sweep. To solve this problem the ISAAC institute has applied a **multi-flash measurement** approach in which, at each single flash, a constant bias is applied instead of a voltage ramp. A single IV pair is selected at each measurement after the current reaches its stability. A minimum of 15 points with a good distribution around P_{max} are needed for the interpolation of the whole IV-curve and its parameters. For modules without sweep speed dependencies, a single 2ms IV-sweep from Isc to Voc is run instead (the so called "direct measurement").

For those modules, where no spectrally matched reference device is available, the mismatch factor has to be determined. Today ISAAC is only able to correct the data if a spectral response curve of the module to be characterised is delivered together with the device. A new system for the **measurement of the spectral response** will probably be introduced at ISAAC within a future project which allows a full in-house calibration of single junction modules to be performed.

In order to run **temperature coefficient measurements** a thermostatic chamber is used to stabilise the module at the desired temperature. A uniform temperature over the whole module area is therefore very important. The module is irradiated through the glass door of the thermal box, leading to an irradiance level of around 850W/m² on module level. The IV-characteristic of the module is repeated every 5°C, from 25°C up to 65°C. The standard coefficients are determined at 800W/m², but coefficients at lower irradiances can be measured as well.

IV-curve **measurements at different irradiances** are generally performed, from 200 to 1000W/m². The irradiance is regulated by the flash generator power. This could lead, especially at low irradiances, to changes in the spectrum which would influence the measurement accuracy for these modules for which no spectrally matched reference device is available.

The ISAAC-TISO is accredited (ISO 17025) by the Swiss Accreditation Service (No. STS 309) for the measurements of crystalline silicon PV modules at Standard Test Conditions (IEC 60904-1) and for the measurement of the temperature coefficients according to the required IEC regulations. The quality system comprises various systematic checks for **system quality and measurement accuracy** through, for example, regular calibrations of the electronic load, the temperature sensors and reference cells, as well as the testing of the stability of the whole system through weekly repeated measurements of 3 different reference modules with different reference devices.

During the course of the project the number of annual I-V characteristic measurements went from 1,500 flashes in 2003 to 4,900 flashes in 2006 (2004: 2,100 flashes; 2005: 2,600 flashes). Between 2000, the year of purchase of the solar simulator, and 2006 17,500 flashes were carried out.

The measurements were not only carried out for research projects (ISAAC-TISO Test Centre, European and other projects) and for services for third parties, but also for maintenance measurements, particularly for accreditation preparation and maintenance (repeatability measurements, Round Robin Tests, accreditation maintenance, initial tests with the new thermostatic chamber, multi-flash measurements).

1.2 ISO 17025 Certification

ISO 17025 is an International Standard (published by the International Organization for Standardization) that specifies the general requirements to be qualified to carry out tests and/or calibrations. There are 15 management requirements and 10 technical requirements. These requirements outline what a laboratory must do to become accredited.

The measurements carried out at ISAAC on c-si PV modules at STC have been ISO 17025 accredited since 2001. Measurement certification also formally guarantees that measurement services or comparison measurements in research projects are carried out in a technically exemplary manner thus guaranteeing the customer quality results.

The management requirements for the accreditation are carried out jointly with the Laboratorio Tecnico Sperimentale (LTS).

The maintenance of ISO 17025 certification requires constant checking of the measurement specifications and the precision and efficiency of the equipment. This is carried out through weekly repeatability measurements of I-V characteristics at STC of three reference modules.

Each year calibration of the measurement equipment (electronic load and reference cells) is carried out. Reference cell calibration – the most important element in the system – takes place every year both at the ESTO-JRC Laboratory and at the PTB (Physicalisch-Technische Bundesanstalt) in Germany.

1.3 Annual Audits

For accreditation maintenance, annual audits carried out by the Swiss Accreditation Service (METAS) are planned during which system processes are verified, the methods and operation of the controls are checked and any new tests are accredited.

Every 5 years the whole accreditation process must be renewed.

During the present project two audits were carried out, one of which was for the complete renewal of the accreditation, namely:

- 20/04/2004 audit (verification of the management of the system)
- 10/11/2005 audit (accreditation renewal for the whole of the institute and accreditation for the temperature coefficient determination test)

The next audit took place at the beginning of 2007. ISAAC successfully passed all audits

1.4 Repeatability I-V Measurements at STC

To verify overall stability of the solar simulator through time periodic measurements of the I-V characteristic are carried out on 3 PV reference systems.

Values for Repeatability Limit (average standard deviation):	
P_{max}:	± 1.1%
I_{sc}:	± 0.8%
V_{oc}:	± 0.8%

Figure 2: Tolerated Values for Repeatability Limit

The tolerated values for repeatability limit do not refer to percentage variations but to the average standard deviations of the results obtained.

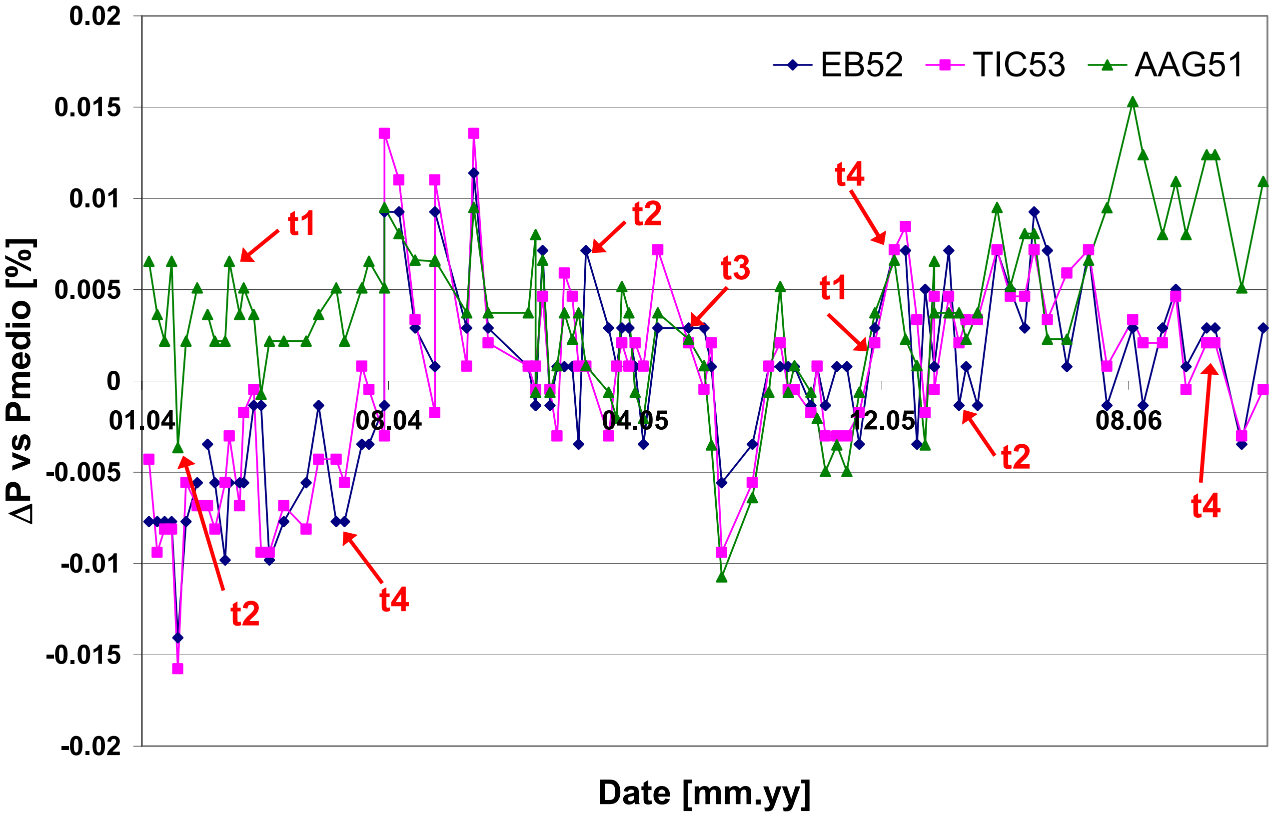


Figure 3: Repeatability measurements with the ISAAC-TISO Solar Simulator. Percentage variation (with respect to the average) of the power of the three reference modules.

Figure 3 contains the percentage variation of the reference modules in which:

- t1 refers to the substitution of the lamp
- t2 corresponds to callibration of the simulator (current channel verification, voltage and irradiation and resistance used for Krochmann reference cells). During callibration in February 2004 the 300V voltage channel and the temperature channel were adjusted.
- t3 refers to a maintenance intervention as a result of a breakdown (substitution of a power supply card)
- t4 corresponds to the callibration dates for the reference cells (see 'Reference Cells' chapter).

The power variations measured are found within the tolerated repeatability limits of ±**1.1%** and calculated using average standard deviation. In future it will be necessary to decide whether to add a reference module with a surface area closer to the modules currently on the market.

1.5 Round Robin test

In September 2002 the '"International PV Module Measurement Intercomparison" organized by the National Renewable Energy Laboratory (NREL, Colorado, USA) began.

The current-voltage characteristics for 6 pairs of different types of modules (1 sc-Si and 5 thin film) and a concentration module were measured indoor at STC.

The following laboratories took part in the international round robin:

1. National Renewable Energy Laboratories - NREL (USA),
2. Sandia National Labs (USA),
3. Photovoltaic TEsting Laboratori Arizona State University (USA),
4. Florida Solar Energy Center (USA),
5. European Solar Test Installation - ESTI (JRC, Ispra, Italia),
6. ISAAC-TISO (CH),
7. Fraunhofer Institut - ISE (Freiburg, D),
8. TÜV (Berlin, D),
9. Tianjin Institute of Power Sources (China),
10. National Institute of Advanced Industrial Science and Technology – AIST (J).

The second international round robin test concluded with the publication of the results (see conference article) during the 4th world photovoltaics conference (Hawaii, May 2006).

7 types of modules ((sc-Si, Thin film Si, a-Si/a-Si, a-Si/a-Si/a-Si, CdTe, CIS e concentrator) were measured by 10 accredited laboratories around the world.

Although our Institute took measurements for all types of modules only the ISO17025 accredited measurements, those for crystalline modules, were made public.

A comparison of our measurement results with the averaged results for all the laboratories show the following results:

- $I_{sc:}$ -1.8%
- P_m: -0.6%
- FF: +0.3%

The open circuit voltage (Voc) is slightly higher (1-2%), as also shown by a further comparison with other laboratories within the European 6FP 'Performance' project. The problem was found in the hardware of the measurement system. Subsequent modifications have resolved the situation furher improving measurement precision

1.6 Reference Cells

The reference cell is one of the most important elements in the measurement system.

Primary callibration of the reference cells takes place every year both at the ESTI-JRC in Ispra (I) and at the PTB (Physicalisch-Technische Bundesanstalt,) in Germany with verification of the spectral response of the cell included.

The difference between the two reference values was **0.25%** which is within the measurement error of the respective systems.

Callibrations

- ESTI-JRC ⇒ 123.2 mV with error ±2.2% (±2,7 mV);
- PTB ⇒ 123.5 mV with error ±0.5% (±0.6 mV).

For accrediation of the current-voltage measurement for photovoltaic modules the measurements carried out at the PTB (Physikalisch-Technische Bundesanstalt, (PTB Braunschweig), Germany) are used. Measurement error is less than that of ESTI-JRC and allows a lower final measurement error. The primary reference cells are calibrated according to one of the methods in the IEC 60904-4 (draft).

In order to guarantee continuous operation and availability of the solar simulator for certified measurements, ISAAC has purchased and had calibrated a second reference cell (a PRC Krochmann like the first). The two cells are calibrated alternatively so that each are adjusted every two years.

A filtered crystalline reference cell has also been acquired from Belval (where ISAAC purchased the simulator in 2000). The spectral response of this reference cell is similar to a-Si and CdTe modules (see Figure 4). Errors on measurement of I-V characteristics can therefore be further reduced.

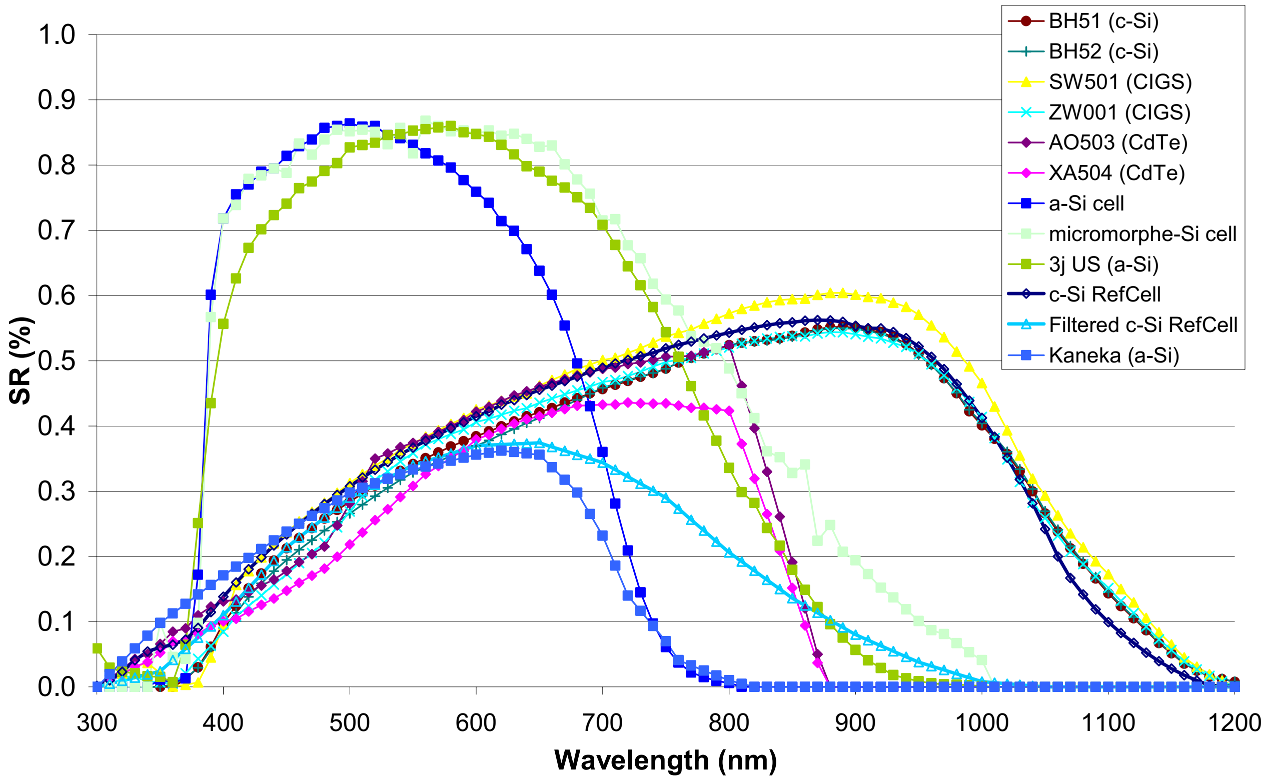


Figure 4: Spectral Responses of ISAAC Reference Cells and Examples of Tested Modules.

1.7 Measurement Uncertainty

In an accredited measurement system (ISO 17025 as far as ISAAC is concerned) defining measurement uncertainty is of great importance and it is therefore indispensable to define an error calculation procedure. The procedure has as reference the ISO 5725 International norm “Accuracy (trueness and precision) of measurement method and result”, which defines the principles and methods for determining accuracy. In practice, in calculating the uncertainty of a measurment method all the components of a system (data acquisition, reference cell, temperature sensors etc.) which could alter the results (Isc, Voc, Pmax) are taken into consideration.

During the audit for renewing accreditation (November 2005) the procedure was slightly modified and, as a result, the uncertainties were modified as follows:

c-Si PV module I-V measurement uncertainties :
current (I): ± 1.8%
voltage (V): ± 1.0%
power (Pmax): ± 2.0%

In order to also certify the measurement for the determination of the temperature coefficients of photovoltaic modules (see chapter ‘Determination of temperature coefficients’) error calculation procedure was developed for this test (see Annex 1 and Annex 2). The uncertainties are expressed as follows:

Measurement Uncertainties for the Determination of Temperature Coefficients of c-Si PV Modules:
current (α): xxx ± 187 [ppm/°C]
voltage (β): yyy ± 213 [ppm/°C]
power (γ): zzz ± 267 [ppm/°C]

1.8 Determination of Temperature Coefficients

After irradiation, the working temperature is the parameter with the greatest influence on the energy yield of PV module. For a reliable forecast of energy yield it is therefore necessary the module temperature coefficients, which can be determined indoors.

In addition to the measurement of the current-voltage characteristic at STC (25°C e 1000 W/m²), a system for electrical characterisation of photovoltaic modules at different temperatures (Isc (α), Voc (β) e Pm temperature coefficients) has been in operation since 2003. In order to achieve this a thermostatic chamber was purchased and developed by the Institute, which has a front glass for carrying out I-V measurements at different temperatures, guaranteeing the stability and uniformity of the temperature of the photovoltaic equipment.

A series of test measurements were carried out, especially for determining the reference cell position (inside or outside the chamber). To assure a better irradiance uniformity it was decided to put the reference cells inside the chamber: knowing its α coefficient (0.0278 mA/°C) it is possible to calculate reference cell sensitivity at different temperatures.

During the heating phase, module temperature varies in a non-uniform way. Module temperature uniformity during measurement cloearly has an effect on final result precision. It was therefore necessary to quantify and evaluate the incidence of temperature variation and temperature gradients in the module.

Three PT1000 temperature sensors were applied to the back surface of a photovoltaic device (132cm x 100 cm) at three different points: the top left-hand corner (A), the middle (B) and the bottom right-hand corner (C) (see Figure 5). The device was installed inside a thermostatic chamber and the three sensors were connected to a datalogger to record temperature values every two minutes. The measurement was carried out heating the module from 25°C and gradually increasing the temperature in jumps of 5°C until 60°C .

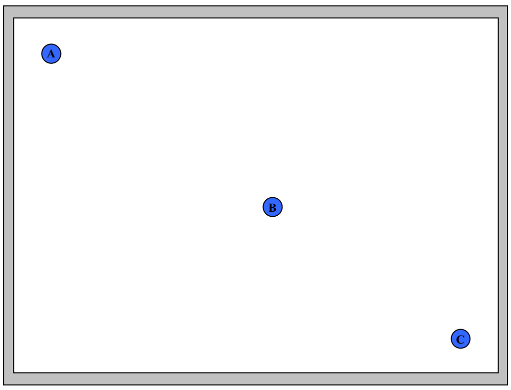


Figure 5: position of temperature sensors on the back surface of the module in order to verify temperature uniformity inside the thermostatic chamber.

The data obtained showed there was a variation of temperature uniformity which increased from 0.2°C (at 25°C) to 1.7°C (at 60°C).

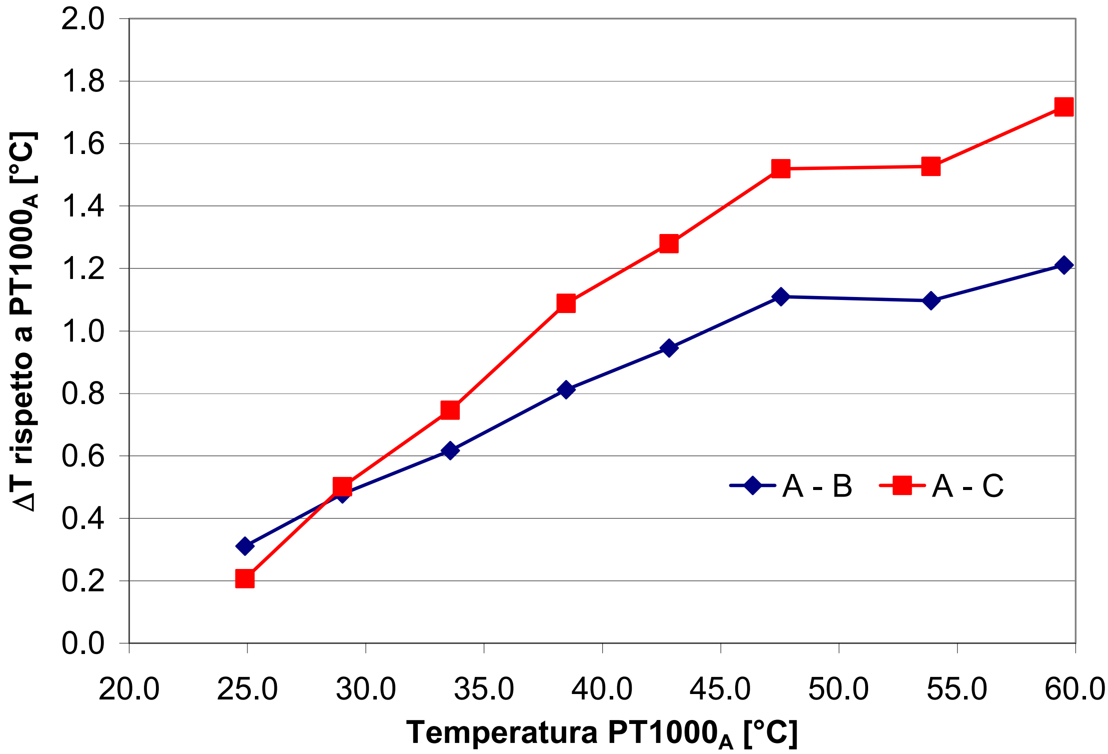


Figure 6: temperature uniformity of a module during heating

Having verified the reliability of the system a standard procedure was defined for determining Isc current (α), Voc voltage (β) e Pm power temperature coefficients (γ).

In the procedure the I-V characteristic is measured heating the PV modules at intervals of 5°C beginning at a temperature of 25°C up to a maximum temperature of 60°C. The test is always carried out during heating. Before each I-V measurement a few minutes are allowed to ensure temperature stabilisation.

At the end of the test the coefficients are determined through interpolation of the values obtained from the measurements at different temperatures as shown in Figure 7, Figure 8 and Figure 9.

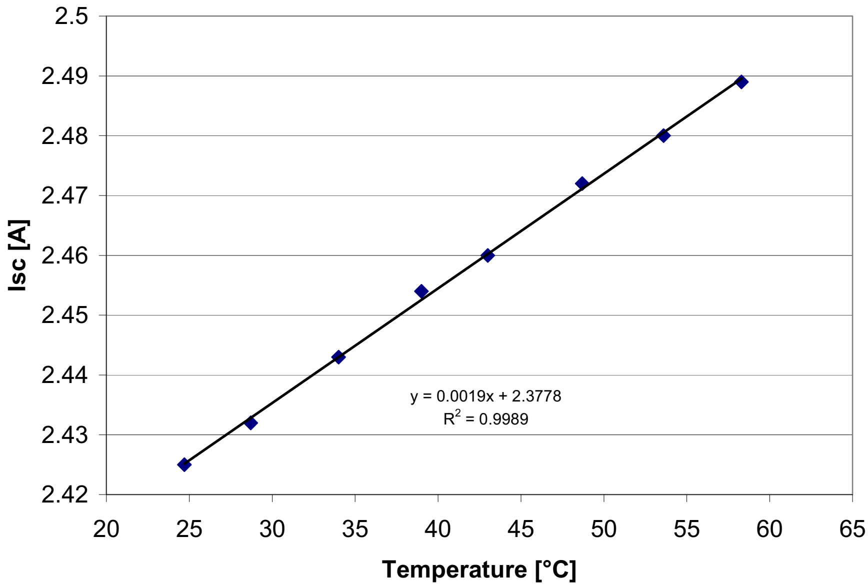


Figure 7: example of I_{sc} performance as a function of temperature (coefficient of determination α)

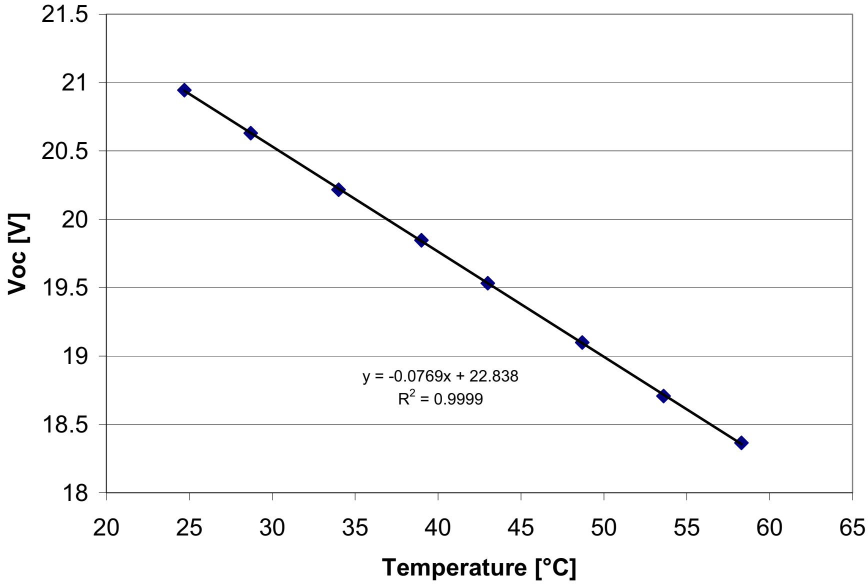


Figure 8: example of I_{sc} performance as a function of temperature (coefficient of determination β)

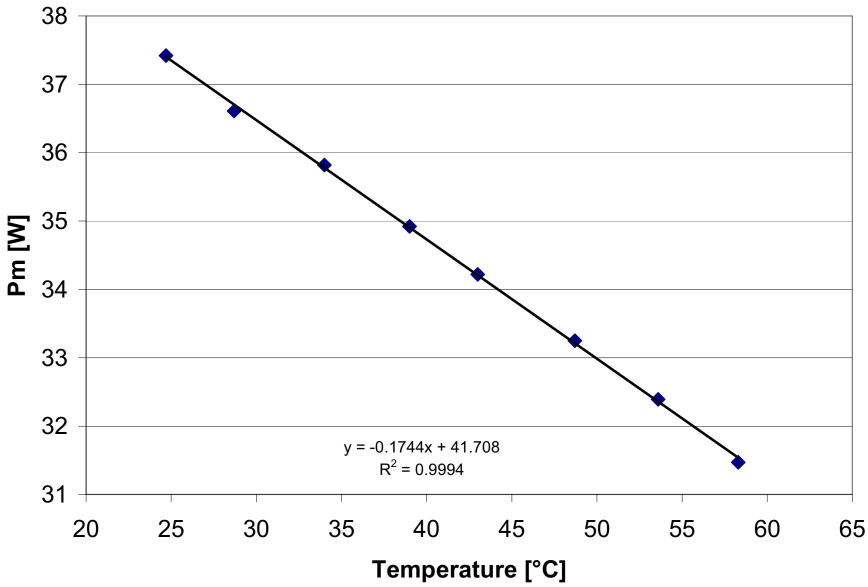


Figure 9: example of I_{sc} performance as a function of temperature (coefficient of determination γ)

Detailed procedures for carrying out the tests (see annex 3) and for the uncertainty calculation of the results (see 'Uncertainty measurements and annex 4) were prepared in order for accreditation of these measures, according to the ISO 17025 norm, during the sixth quality audit carried out in November 2005. Confirmation of the accreditation was made official in June 2006.

Thus far the temperature coefficients of 27 module types from different technologies have been determined, as summarised in Table 1.

Tipo di modulo	Tecnologia	Valori @ 25°C & 800 W/m²			Coefficienti di temperatura @ 800 W/m²		
		Isc [A]	Voc [V]	P [W]	α (ppm/°C)	β (ppm/°C)	γ (ppm/°C)
					± 187	± 213	± 267
ASE 100-GT-FT	mc-Si	2.46	42.24	77.0	894	-3464	-4099
Kyocera LA361K51S	mc-Si	2.43	20.92	37.3	790	-3674	-4671
Kyocera LA361K51S	mc-Si	2.48	21.10	38.2	823	-3618	-4474
MHH plus 180	mc-Si	7.62	24.57	138.6	207	-3280	-4474
Kyocera KC125GHT-2	mc-Si	6.24	22.02	100.3	502	-3256	-4438
Mitsubishi PV-MF130EA2LF	mc-Si	5.87	24.70	106.0	510	-3456	-4541
RWE ASE-165-GT-FT/MC	mc-Si	3.87	43.93	126.8	599	-3277	-4072
IBC 215	mc-Si	6.06	36.80	167.8	584	-3398	-4256
MHH plus 220	mc-Si	6.07	36.70	161.8	574	-3358	-4550
Solar World SW165	mc-Si	4.01	43.60	130.4	594	-3281	-4159
Kyocera KC60	mc-Si	2.69	21.21	43.3	483	-3528	-4417
RWE ASE-100-GT-FT	mc-Si	2.45	42.11	77.2	1166	-3382	-3771
				Medie valori	**644**	**-3414**	**-4327**
Atersa A-60	sc-Si	2.70	20.51	40.4	-82	-4029	-5646
Shell SM110	sc-Si	2.64	43.93	85.8	81	-3677	-4994
Solar Fabrik SF75	sc-Si	3.53	20.46	51.7	-58	-4002	-5799
Suntech STP160	sc-Si	3.84	44.08	127.2	237	-3395	-4601
Siemens SP75	sc-Si	3.54	21.65	56.0	143	-3659	-5042
Sharp NT-175E1	sc-Si	4.23	44.48	134.5	317	-3348	-4666
BP Solar BP7180	sc-Si	4.13	43.78	139.0	497	-3401	-4366
Sunpower STM210F	sc-Si	4.50	47.28	164.2	127	-2879	-4186
RA-NRG RA180	sc-Si	4.07	42.84	123.9	181	-3516	-5034
				Medie valori	**160**	**-3545**	**-4926**
Solarex MST43MV	a-Si Double-junction	0.67	101.6	38.2	657	-3887	-3069
Uni-Solar US32	a-Si Triple-junction	1.77	22.62	22.2	1416	-4235	-1571
First Solar FS50	CdTe	0.80	78.98	35.2	543	-1760	-2016
Würth WS11007	CIS	1.61	50.44	50.9	-41	-2758	-2635
Sanyo HIP-1850NE1	HIT	4.24	44.56	143.9	323	-2806	-3233
Uni-Solar US64	a-Si Triple-junction	3.51	22.94	46.5	1349	-4082	-2275
				Medie valori	**708**	**-3255**	**-2467**

Table 1: temperature coefficients and electrical characteristics at 25°C and 800 W/m² of different types of modules determined using the new ISO 17025 certified measurement at ISAAC.

From Table 1 it is noticeable how the temperature coefficients within the same technology family clearly differ among themselves, in particular the γ power coefficient, where the voltage and current coefficients combine to make it more marked.
In the multi-crystalline silicon modules the differences reach 0.09%/°c while for mono-crystalline silicon modules the differences can reach 0.11%/°C.
The lowest coefficient is that of the UniSolar US32 (a-Si) module at 0.1571%/°C followed by the First Solar FS60 (CdTe) module at -0.2016%/°C.

The HIP-185 module is the exception among crystalline-based modules at -0.3233%/°C. probably due to the unusual c-Si and a-Si combination in HIT (Heterojunction with Intrinsic Thin-layer) technology.

The energy yield for modules with lower temperature coefficients are among the highest (see First Solar and Sanyo-HIT in chapter 2.6). Extending incentives in the countries of southern Europe, where there is greater potential for insolation than in northern Europe, will especially favour those modules with better temperature behaviour. The notable temperature differences will create significant discrepancies in energy yield among the various technologies. The quality/price ratio will increasingly not be determined by the price/power ratio but rather by the ratio between price and energy yield for certain climate and building situations.

1.9 I-V characteristics at different irradiances

The power in the solar simulator can be modified. This allows variation in the level of irradiation and therefore the current-voltage measurements can be carried out at irradiances different from 1000 W/m². Minimum irradiation for measurement was 200 W/m², a limit below there is a risk significant spectrum variations may occur. Normally measurements start at 200 W/m² and continue at regular intervals of 200 W/m² (and in some cases 100 W/m²) up to 1000 W/ m².

From the measurements carried out on 18 modules (crystalline and thin-film,) linear trends were observed not only for the Isc but also for the Pm e Voc electrical parameters (see Figure 10); it can therefore be assumed that the light spectrum of the xenon lamp does not undergo any significant modifications up to 200 W/m².

However the real spectrum at different irradiances must be verified through regular specific measurements in order to guarantee a measurement which is reproducible though time.

Electrical characterisation of modules at different irradiances is the next test for which ISAAC hopes to obtain the accreditation (2008).

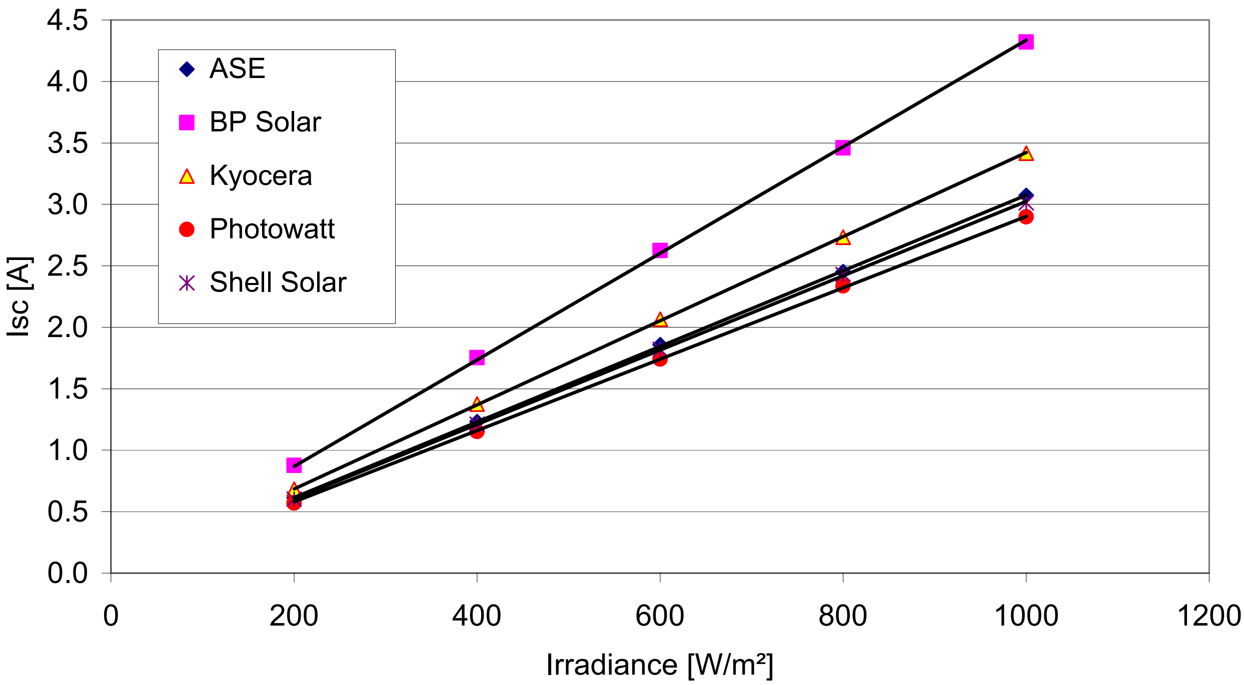


Figure 10: Typical example of Isc variation in some c-Si PV modules in relation to irradiation in the ISAAC-TISO solar simulator.

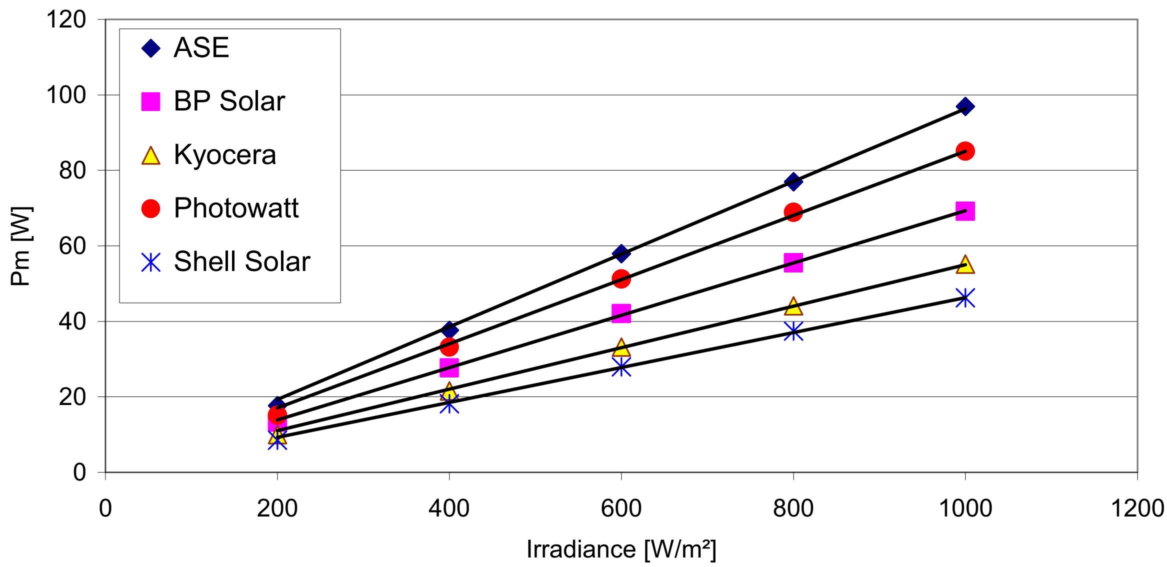


Figure 11: Typical example of Pm variation in some c-Si PV modules in relation to irradiation in the ISAAC-TISO solar simulator.

1.10 I-V measurements for modules with high cell capacitance

As is well-known very short sweep times can lead to measurement artefacts within capacitive modules, which can only be avoided by alternative measurement procedures. Today certain modules need up to 250 ms for a complete I-V sweep.

To solve this problem the ISAAC institute applied a **multi-flash measurement** approach in which, at each single flash, a constant bias is applied instead of a voltage ramp. A single IV pair is selected at each measurement after the current reaches its stability. A minimum of 15 points with a good distribution around P_{max} are needed for the interpolation of the whole IV-curve and its parameters. For modules without sweep speed dependencies, a single 2ms IV-sweep from Isc to Voc is run instead (the so called "direct measurement").

The possibility of finding PV modules with high cell capacitances and high series resistances and obtaining, with a pulsed sun simulator, bad results from single sweep IV measurements, led the ISAAC to perform multi-flash measurements on all new PV module types.

Regarding service measurements, notable differences were found in the modules Atersa A-120 P5 (mean $\Delta Pm_{multi\text{-}direct}$ = 5.3%) and Webel WS115 (mean $\Delta Pm_{multi\text{-}direct}$ = 4.8%).

Sanyo HIP-J54BE2 modules (with cells made of one c-Si layer and a very thin a-Si film) presented a considerable capacitive effect (mean $\Delta Pm_{multi\text{-}direct}$ = 12.0%).

As demonstrated by a round robin test (see EU 6FP "PERFORMANCE" project), the multiflash approach leads to very good results compared to those obtained with much more expensive steady state simulators. However a very careful selection of the IV pairs is essential. The main criteria for the data selection is the reaching of stability of both, voltage and current, within the irradiance plateau. To limit the time effort of a multiflash measurement, the number of flashes has to be reduced to a minimum. For this a good distribution and interpolation of the single IV points is very important.

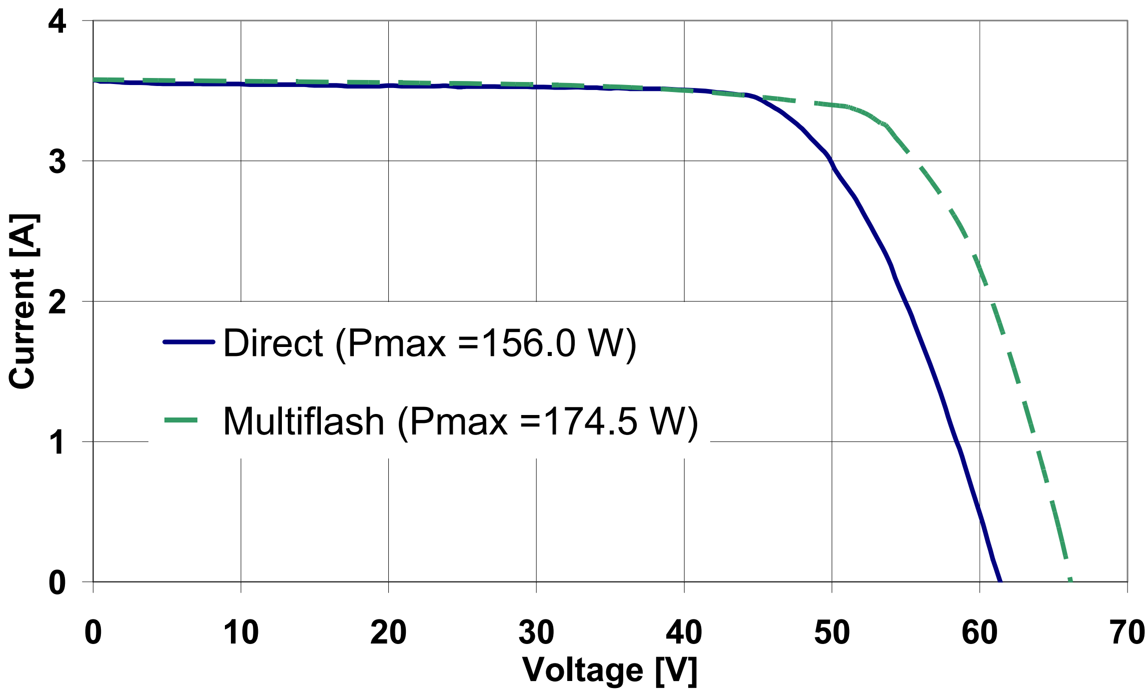


Figure 12: I-V characteristic of Sanyo HIP-J54BE2 module in direct and multiflash (dashed line) measurements.

1.11 Thin film measurement – spectral mismatch

In order to measure the absolute value @ STC of thin-film technologies it is necessary to calculate the spectral mismatch factor considering 4 parameters:

1. tested specimen spectral responses;
2. reference cell spectral responses;
3. solar simulator flash lamp spectrum;
4. standard AM1.5 spectrum.

The correction tool is applied to all thin-film technologies tested during the test cycles. This lead to an increased prediction accuracy at Standard Test Conditions. The spectrum of the xenon lamp of the ISAAC solar simulator was also measured during the EU PERFORMANCE (TÜV June 2007). For comparison purposes, the measurement was repeated on our simulator using equipment from BELVAL, solar simulator manufacturers. Preliminary analyses of the results are currently being performed.

In the corrections applied, the spectrum measurement determined by the manufacturer of the xenon lamp was used. It is however necessary to remember that the spectrum varies according to the power applied and with a decrease in power in particular an increase of the infrared component is normally expected. Use of filtered reference cell further improves the result of the measurement.

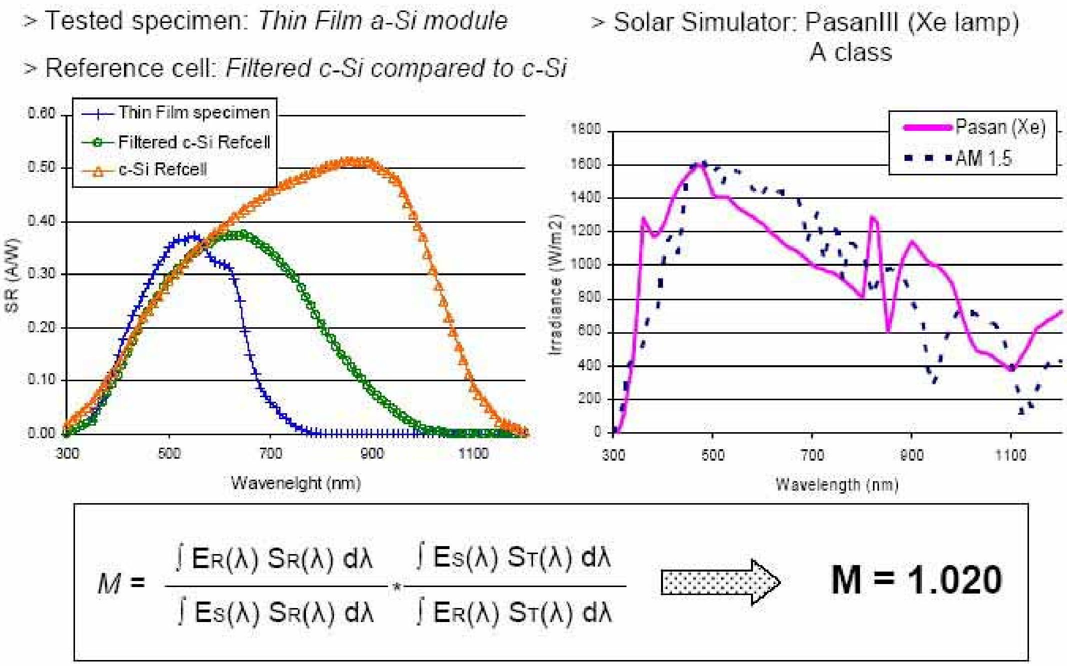


Figure 13: Spectral response of an a-Si single-junction module and the two reference cells (filtered and non-filtered), spectrum of the Xe-lamp and of the AM1.5 reference.

In Figure 14 an example of IV curve spectral mismatch correction procedure for a thin-film a-Si single junction specimen is shown.

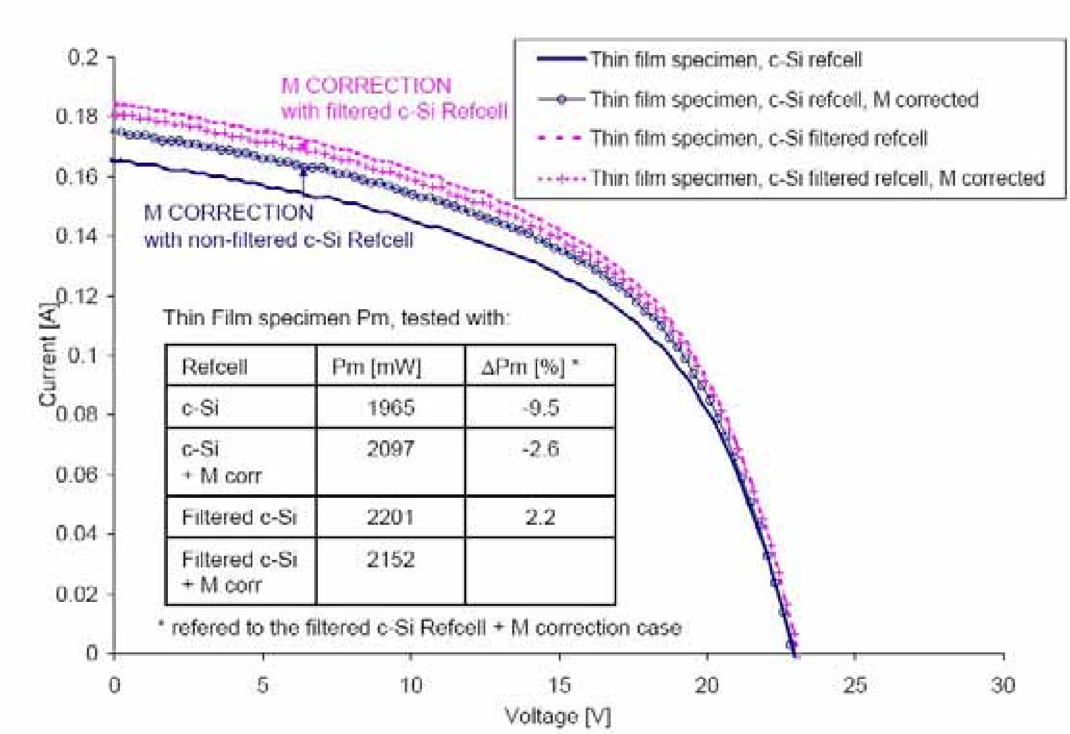
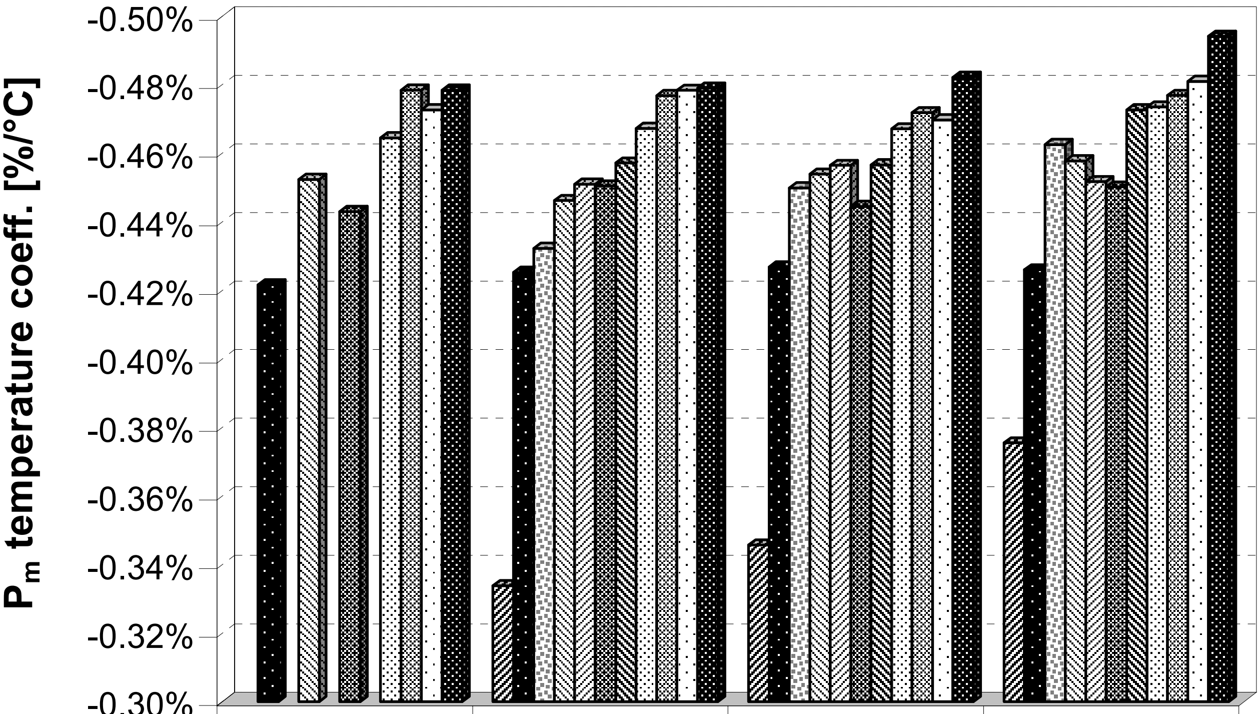


Figure 14: I-V curve of an a-Si single-junction module measured with and without a c-Si reference cell, with and without spectral correction.

1.12 Indoor matrix measurements $P_m(G,T)$

The execution of measurements at different irradiances at various temperatures allowed data collection for indoor determination of the module matrix, here carried out on all the cycle 10 reference modules. In practice, following the procedure for determining temperature coefficients (gradual heating of the modules from 25°C to 60°C, at 5°C intervals) 3 or 4 I-V characterisations at different irradiations (usually 300, 600,, 800 and 900 W/m²) were carried out for every planned temperature step.

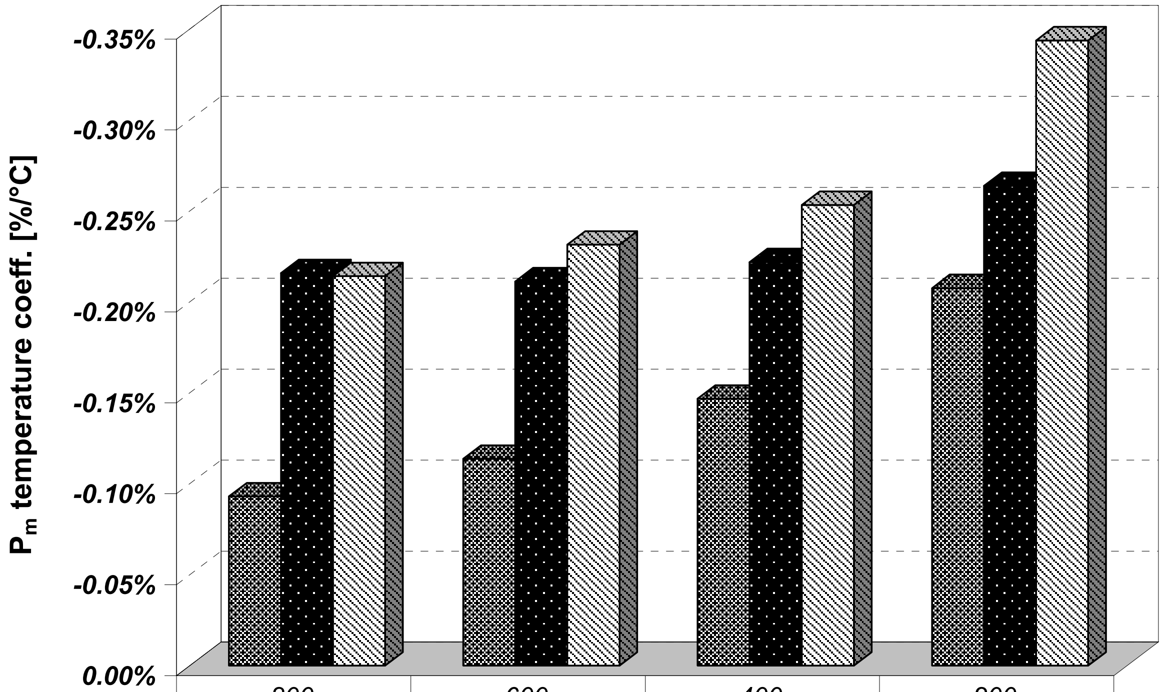
The following Figures (Figure 15 to Figure 18) show the inter-comparison of the parameters extracted from the indoor matrices of the 14 different reference modules. The extracted parameters are, the temperature coefficients of the maximum power Pm at different irradiances γ(G) and the performance ratio PR versus irradiance at 25°C ($PR=(P_{meas}/P_{stc})*(G_{meas}/G_{stc})$).



	900	800	600	300
HIP		-0.334%	-0.346%	-0.375%
ASE	-0.422%	-0.425%	-0.427%	-0.426%
STM		-0.432%	-0.450%	-0.463%
SW	-0.452%	-0.446%	-0.454%	-0.458%
STP		-0.451%	-0.456%	-0.452%
IBC	-0.443%	-0.450%	-0.444%	-0.450%
NT		-0.457%	-0.457%	-0.473%
MF	-0.465%	-0.467%	-0.467%	-0.474%
MHH	-0.478%	-0.477%	-0.472%	-0.477%
BP	-0.473%	-0.478%	-0.470%	-0.481%
KC	-0.478%	-0.479%	-0.482%	-0.494%

Figure 15: Maximum power temperature coefficients of all c-Si modules measured at 300, 600, 800 and 900 W/m².

Figure 15 shows the temperature coefficients of all c-Si modules of cycle 10. Due to the window of the thermal chamber and the reduction of the lamp power caused by the large number of flashes (multi-flash measurements) carried out for the determination of a whole matrix of a capacitive module (see chapter 1.10), certain modules could not be measured at irradiances greater than 800W/m². The temperature coefficient of all c-Si modules, with the exception of the HIP technology, was independent of irradiance levels. The values are all in the range of the measurement uncertainty of 0.0267%. A single measurement at 800W/m² is therefore sufficient for a precise characterisation of the temperature behaviour of pure c-Si modules. The HIP module behaves, on the other hand, similarly to the thin film technologies as shown in Figure 16. The temperature coefficients of these modules are generally lower than the c-Si coefficients (see as well Table 1) and they tend to increase with decreasing irradiance (see Figure 15 for HIP and Figure 16 for all TF).



	800	600	400	200
K	-0.093%	-0.114%	-0.147%	-0.208%
FS	-0.216%	-0.211%	-0.222%	-0.264%
ES	-0.214%	-0.231%	-0.253%	-0.344%

Figure 16: Maximum power temperature coefficients of all thin film modules measured at 200, 400, 600 and 800 W/m².

Figure 17 and Figure 18 show, instead, the irradiance dependency at a constant temperature of 25°C. The range highlighted by the yellow area corresponds to the ±2.0% measurement uncertainty at 1000W/m² and 25°C. Even if for each module technology a reference cell spectrally matched as closely as possible was used, the error due to an increase in the MM error at low irradiances, due to possible changes in the spectrum of the lamp when reducing its power, can't be completely excluded, especially for the thin-film technologies. At this stage it is very difficult to separate MM errors from material related differences.

The later inter-comparisons of indoor to outdoor data will show that the differences shown here between the technologies reflects the performance under real operating conditions very well anyway. The higher the indoor measured PR at low irradiances and the lower the temperature coefficient the higher is the annual energy output in kWh/Wp real power (P3).

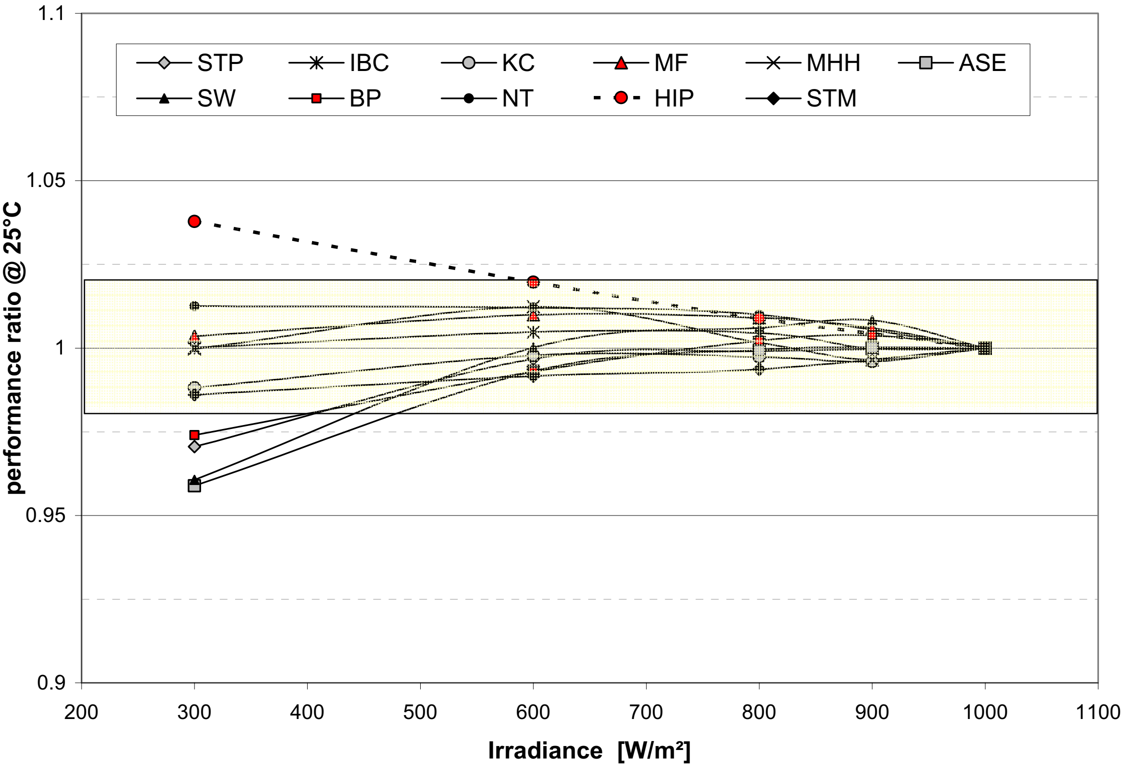


Figure 17: Performance ratio @25°C versus irradiance for all c-Si modules.

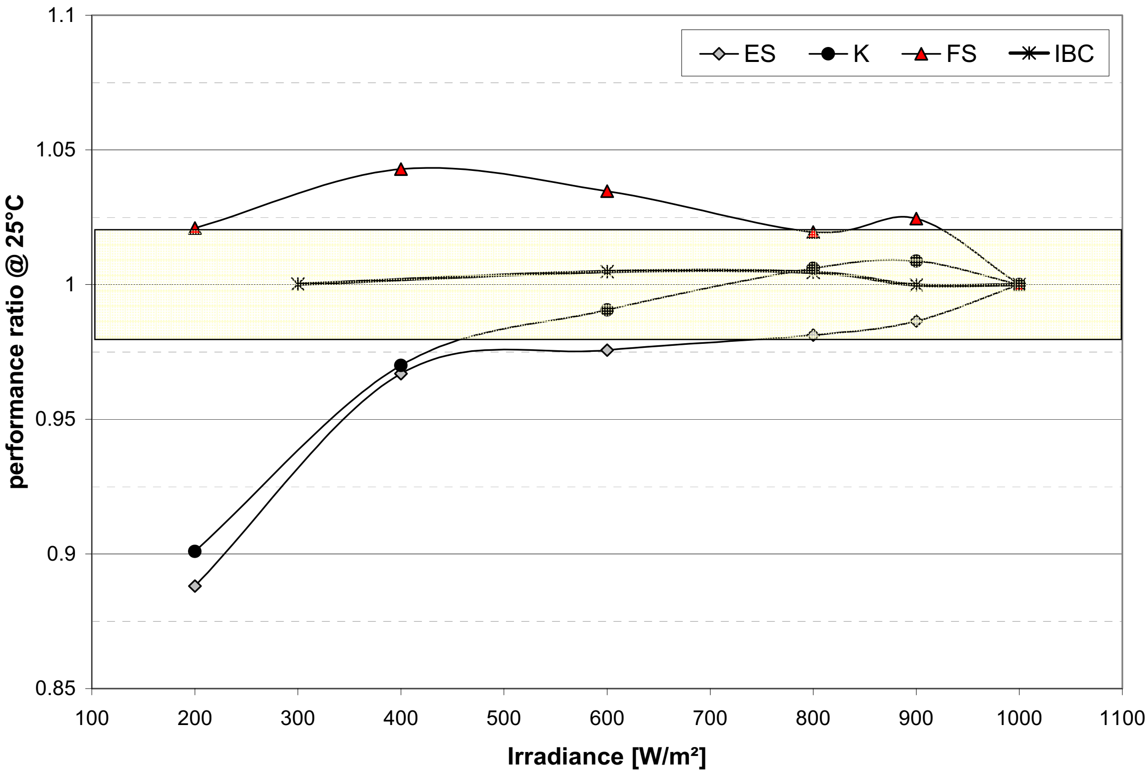


Figure 18: Performance ratio @25°C versus irradiance for all thin film modules and 1 c-Si module.

1.13 Solar simulator assessment (spectrum & uniformity)

The lamp and electronics of the solar simulator used at ISAAC-TISO (PASAN III a) generate a light impulse lasting approx. 25sms. The scan time of the I-V characteristic is however only 2ms, corresponding to the stable peak of the impulse (see Figure 19).

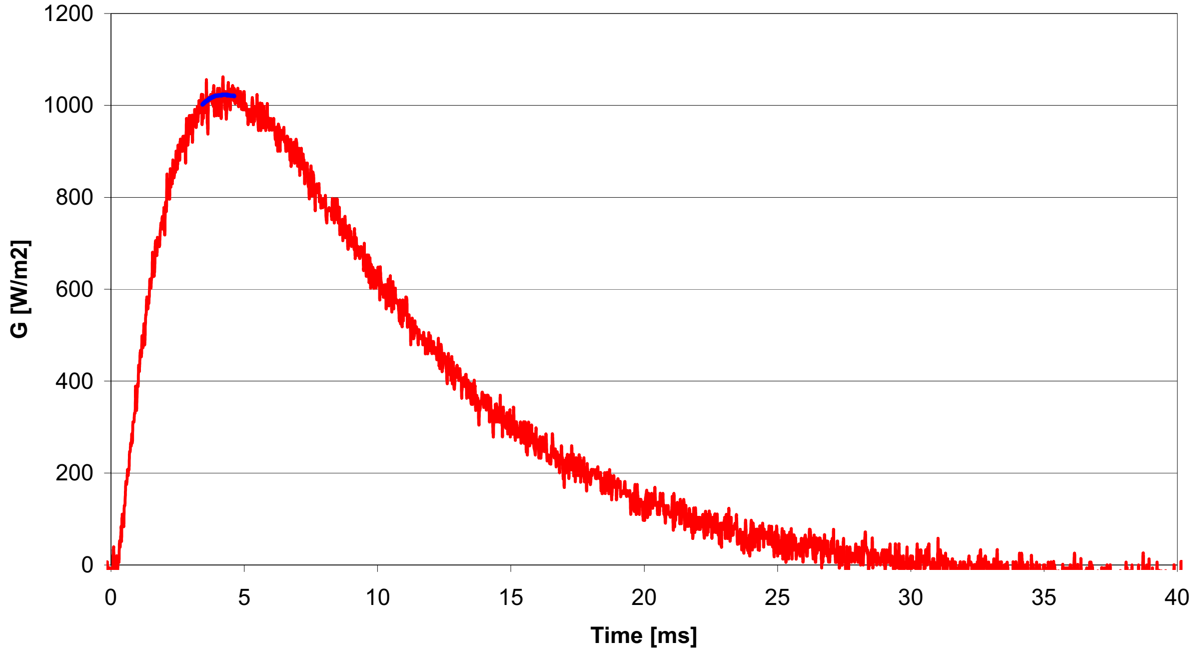


Figure 19: Irradiance flash lamp peak.

The measurement of the ISO17025 accredited I-V characteristic refers solely to crystalline silicon modules and irradiation is measured by means of a crystalline silicon reference cell. The spectral response of the two devices is similar and in this way measurement miss-match error is minimised.

In order to carry out spectral mismatch correction it is necessary to know the spectrum of the lamp. Two measurements of the spectrum were carried out. The first was done in collaboration with the producer of the PASAN solar simulator and associated with the approximate spectrum supplied by the producer of the xenon lamp. The measurement of the spectrum was carried out with integration throughout the whole period of the flash (25sms) and not only on the 2 ms of the I-V characteristic scan (see Figure 20)

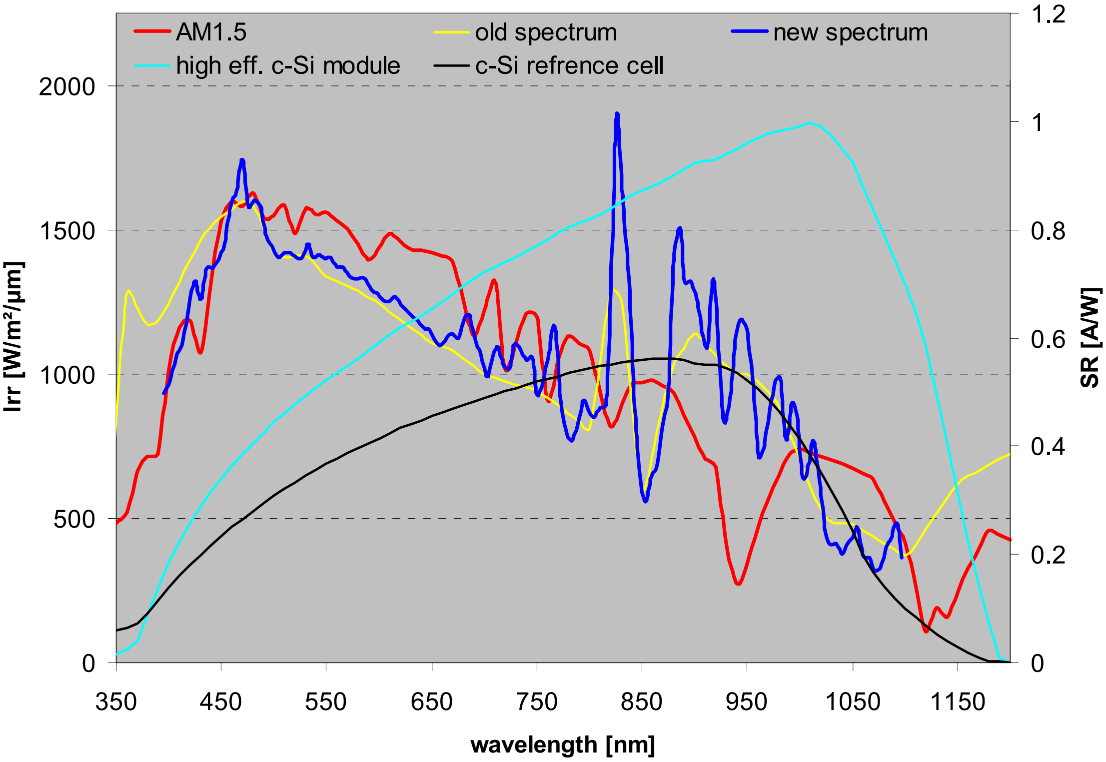


Figure 20: Spectrum Irradiance Measurement by PASAN and spectrum supplied by the producer of the xenon lamp

Following this, in collaboration with the EU project (FP6) called PERFORMANCE (Task 1.2) a further comparison measure of the real spectrum of the lamp was carried out. From the results shown in Figure 21, there is a difference, in particular in the infrared. With respect to the AM1.5 standard spectrum and the IEC 60904 norm, the simulator can be placed in the Class A category.

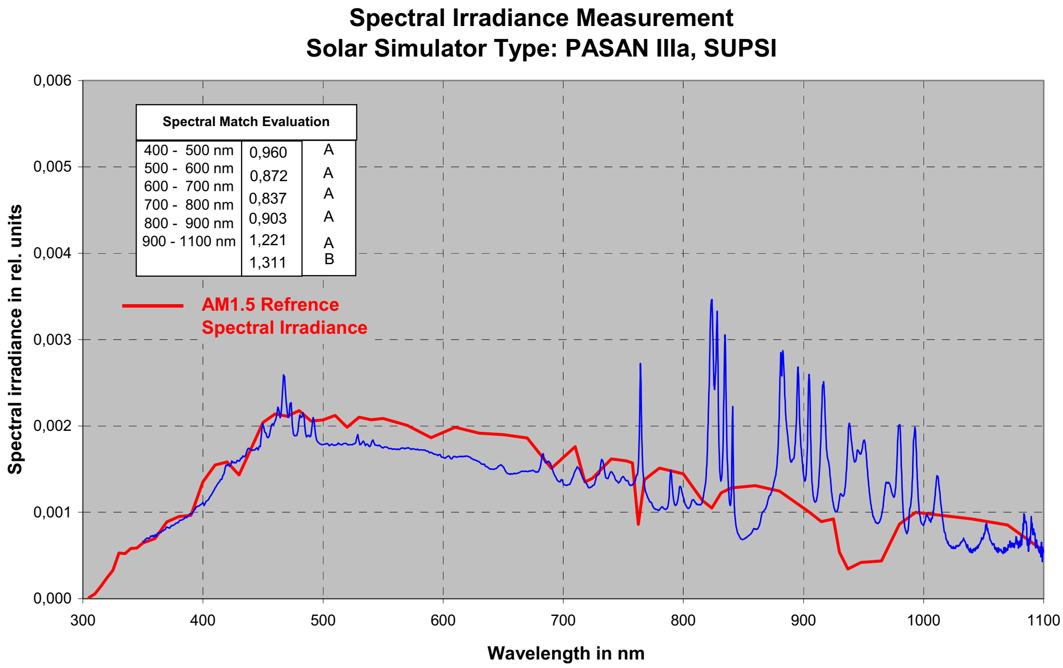
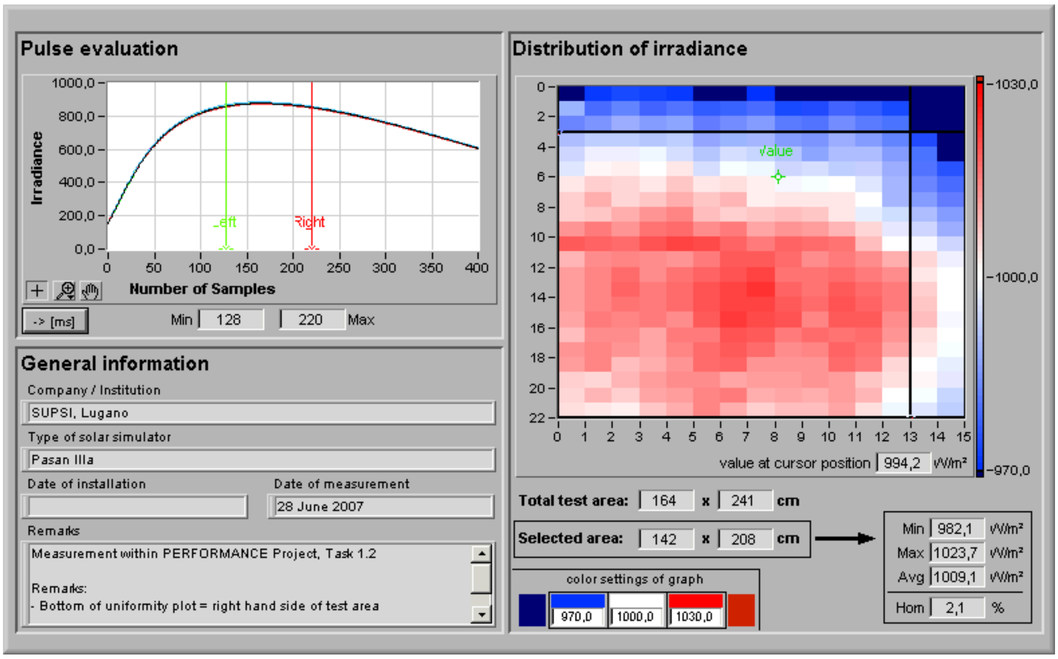


Figure 21: Spectrum Irradiance Measurement



Results: Non-uniformity of irradiance (Class A test area) 142 x 208

Figure 22: Non-uniformity of irradiance (Class A test area) 142 x 208.

Detailed uniformity measurement (see Figure 22) shows Class A uniformità within an area of 142 x 208 cm. However, the area is not centred and as a result the lamp structure position has had to be corrected.

2 OUTDOOR MEDIUM-TERM MEASUREMENTS

2.1 Abstract

The ISAAC-TISO centre carries out systematic outdoor tests, under real operating conditions, on the most important modules currently on the market. Up to 18 types of module for each test cycle are purchased anonymously. The modules are exposed for 15 months. I-V measurements @STC are periodically performed. For each tests cycle the modules are fixed to an open-rack structure tilted at 45° and 7° south of azimuth. Each module is equipped with a Maximum Power Point Tracker adapted to its voltage and current range for greater accuracy measurements.

2.2 Introduction

Figure 23: View of the ISAAC-TISO outdoor test facility (module of cycle 10).

Medium-term measurements allow both the energy production of the modules and the data declared by the manufacturers to be verified as well as supplying precise indications on their behaviour under real operating conditions, on degradation through time and thus guarantee module quality on the market. Simultaneous exposure of the PV modules also allows direct comparison between the various technologies available on the market .

The test procedure developed during preceeding projects at the 'Cenrale di collaudo' (Test Centre) has been modified and extended to take into account both the various characteristics of the different technologies available on the market and the new information the market now demands.

In particular the test procedures allow:

- Verification of the electrical parameters of the modules, as declared by the manufacturer, to be continued.
- Initial degradation of the modules present on the market to be quantified.
- Verification of the electrical stability of the modules under examination.
- The study of the behaviour of the modules under real operating conditions
- The energy production of the technologies tested to be quantified and compared
- Simplified forecasting methods for energy yield to be determined and verified

An important aim of medium-term measurement is *energy yield* and how to forecast it under different climatic conditions.

The collaborative projects embarked on in previous years has shown that the matrix method, developed during the preceding project on the basis of data from medium-term measurements, is a valid and effective method for energy yield forecasting of crystalline-silicon module yield. Its precision is ±2%.

2.3 Test Procedure – test cycles

The test procedure started in 1993 was modified in 2000 with the introduction of a measurement for the current-voltage characteristic at STC every 3 months instead of every 6 months. Nevertheless, in the present project there was a wish to furher modify the test procedure by on the one hand reducing indoor measurements on stabilized c-Si modules while on the other hand introducing a third module for the realisation of specific measurements

Two different procedures have been studied for **crystalline** silicon (see Figure 24) and **thin-film** (see Figure 25) technologies. For both procedures, two samples of each type of module are exposed under real operating conditions and continuously monitored. Indoor performance measurements are periodically carried out.

The third sample of thin film modules will be light soaked until power stabilization. For the third sample, other outdoor and indoor measurements, like temperature coefficients, spectral response and characterization at different irradiances, are foreseen.

Crystalline procedure:

After the initial performance measurements to verify the power declared by manufacturers (PI.1 ⇨ Pa), the crystalline silicon modules will be subjected to a light soaking of about 40 kWh/m² (LS) and then indoor measured again (PI.2 ⇨ P0).

A multi-flash measurement (CI) and hysteresis test (CO) has been introduced to verify the presence of distortions due to high cell capacitances. Every type of module with measurement problems are then measured always using multiflash.

A spectral response measurement (SR-Spectral Response)is forseen for each type of module. Nevertheless for cycle 10 it was not possible to carry out SR measurements at the JRC because of a change of direction in the scientific work of that institute.

In future equipment with a filter measurement for SR characterisation of PV modules will be introduced for this purpose.

Thin Film procedure:

After the initial performance measurements to verify the power declared by manufacturers (PI.1 ⇨ Pa), the thin-film modules are not subjected to controlled light soaking since initial degradation mechanisms are slower. This is the reason why an initial 3 month stabilisation period was introduced.

Spectral mismatch correction will be applied to all thin-film technologies tested during the coming test cycle as well as for indoor and outdoor measurement. For the measurements, a filtered cell with a similar SR to thin-film modules is used in order to reduce deviation SR mismatch correction of the three thin-film modules is carried out using a module SR supplied by the manufacturer (Unisolar and Kaneka), while for First Solar modules a measurement carried out at JRC Ispra on the same type of modules was used.

During cycle 10 the test procedures were not fully carried out because it was not possible to carry out the spectral response measurement at JRC.

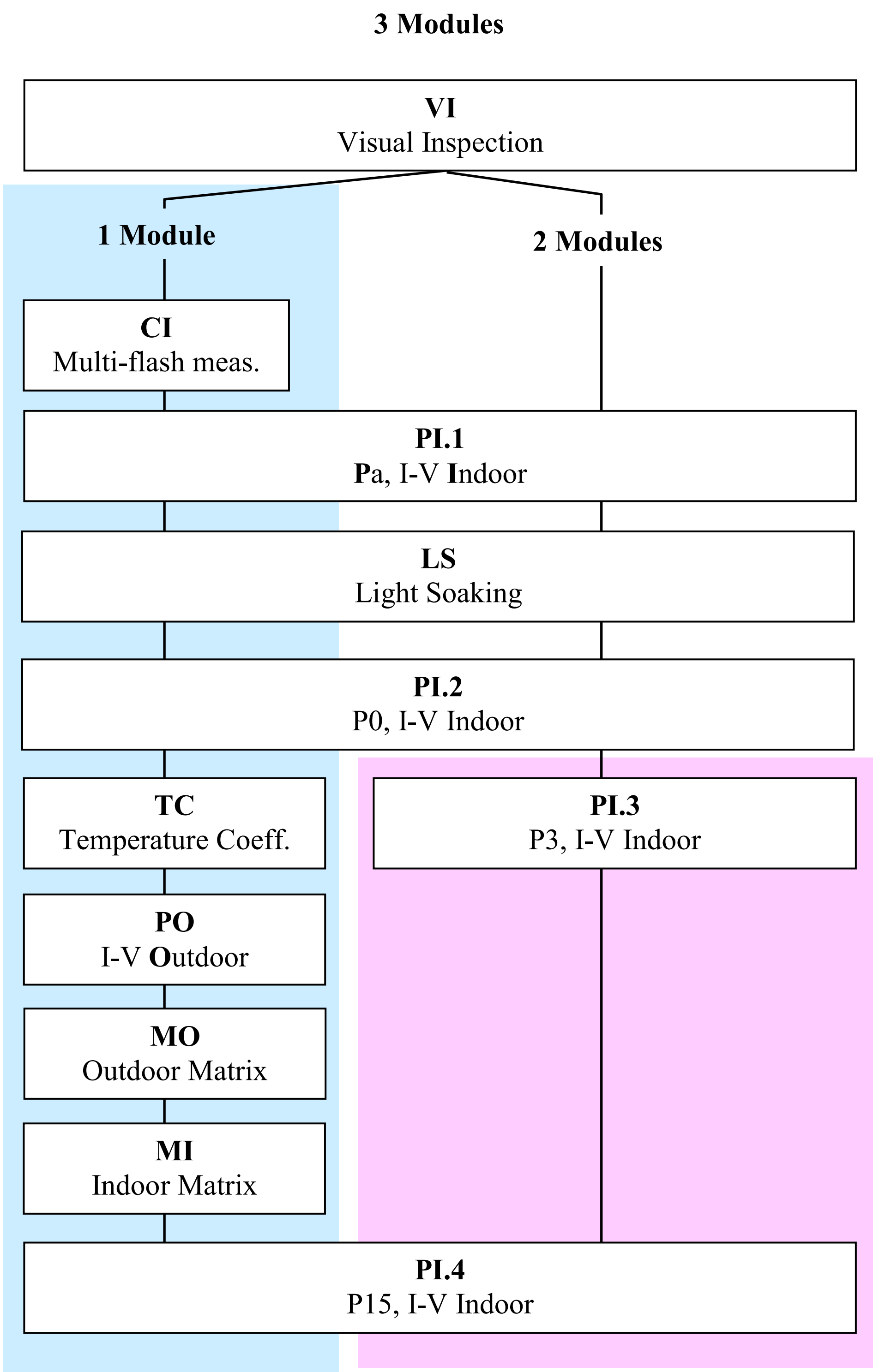


Figure 24: Crystalline silicon modules ISAAC test procedure (cycle 10). (in blue: reference module; in red: outdoor exposition)

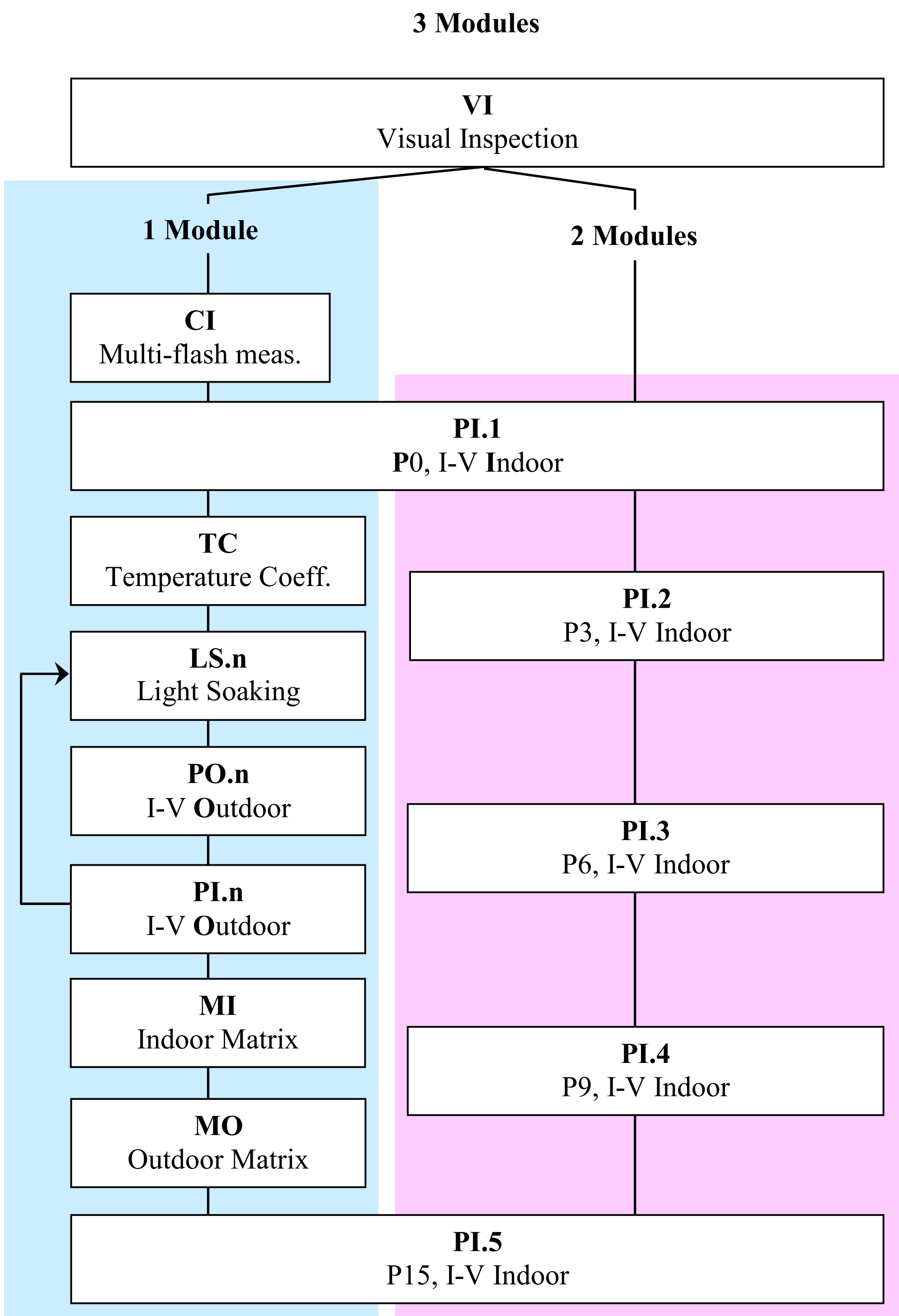


Figure 25: Thin-Film modules ISAAC test procedure (cycle 10). (in blue: reference module; in red: outdoor exposition)

2.4 Choice and Purchase of Modules to be Tested (cycle 10)

In the present test procedure:

- The modules are bought **anonymously**
- Up to 18 different types of module is possible for each cycle
- **Three** models are bought for each type of module

For each test cycle up to 18 different types of photovoltaic modules are chosen usually from different manufacturers. However, market development which favours increasingly larger modules limits the number of modules which can be installed on the present stands. During cycle 10, just 14 different types of modules (28 in all) found space on the stands, despite the availability of electronic equipment.
The choice of modules to be tested is made on the basis of the following criteria:

- Presence on the Swiss and/or European market
- Diffusion in the markets of reference
- Interesting technologies which penetrate the market rapidly
- New technologies which are already mature or at an advanced stage of industrialisation

The purchase of **three modules** for each type occurs anonymously so as to avoid receiving purpose-built modules or the best available. The modules come from retailers from all over Europe. Anonymous purchase guarantees impartiality when comparing modules.

However, the results published in this report are not meant to be a statistical analysis of the characteristics of the modules produced by the manufacturers, but are just a small sample of what the manufacturers have put on the market. It is therefore possible modules of the same type and from the same manufacturer present different characteristics with respect to the values published here. Moreover notable differences were found between module types with the same name, in that they are built with different cells or are treated differently

During the present project a test cycle (**cycle 10**) was carried out on 14 PV modules. In fact in the first phase of the project, after the end of **cycle 9** it was necessary to develop and substitute the old MPP trackers (see chapter 2.8). This task lasted longer than forecast and did not allow the realisation of further cycles.

Fourteen different modules were chosen in an attempt to include the major part of available technologies: 7 mc-Si, 3 sc-Si, 1 HIT, 2 a-Si and 1 CdTe (see Table 2).

Exposure of the modules under real environmental conditions of test cycle 10 began in May 2006 and ended in June 2007.

N°	Manufacturer	Module type	Cell Type	Pmax [W]	Isc [A]	Voc [V]	Im [A]	Vm [V]	FF (%)	Manufacturer warranty limit		
				[W]	[A]	[V]	[A]	[V]	[-]	$Pw_{10years}$	$Pw_{20years}$	Pmin
1	RWE SHOTT	ASE-165-GT-FT	MAIN mc-Si	165	5.18	43.8	4.58	36.0	72.7%	NA	NA	±4%
3	IBC Solar	IBC-215S Megaline	mc-Si	215	7.75	36.8	7.17	30.0	75.4%	90 (12y)	80 (25y)	±2.5%
4	Kyocera	KC125GHT-2	mc-Si	125	8.00	21.7	7.20	17.4	72.2%	90 (12y)	80 (25y)	+ 10 / - 5%
5	Solarwatt	MHHplus220	mc-Si	210	7.60	36.4	6.86	30.6	75.9%	90 (12y)	80 (25y)	±3%
6	Mitsubishi	PV-MF130EA2LF	mc-Si	130	7.39	24.2	6.79	19.2	72.9%	NA	NA	+ 10 / - 5%
7	Solar World	SW165	mc-Si	165	5.10	43.9	4.60	35.5	72.9%	91 (10y)	81 (25y)	±3%
8	Suntech	STP150-24	mc-Si	150	5.00	42.0	4.52	33.2	71.5%	90 (12y)	80 (25y)	N/A
2	BP Solar	BP7180	sc-Si	180	5.40	44.8	5.00	36.2	74.8%	90 (12y)	80 (25y)	+ 2.5 / - 0%
9	Sharp	NT-175E1	sc-Si	175	5.40	44.4	4.95	35.4	73.1%	NA	NA	±5%
10	Sunpower	STM210 F	sc-Si	210	5.70	47.8	5.25	40	77.1%	--	80 (25y)	+ 3 / - 0%
11	Sanyo	HIP180NE1	HIT	180	5.49	45.5	4.93	36.5	72.0%	--	80 (20y)	+ 10 / - 5%
12	Kaneka	K60	a-Si	60	1.19	92.0	0.90	67.0	55.1%	90 (12y)	80 (25y)	+ 10 / - 5%
13	UniSolar	ES-62T	a-Si	62	5.1	21.0	4.10	15.0	57.4%	NDC	--	±5%
14	First Solar	FS-60	CdTe	60.0	1.14	90.00	0.96	63.00	58.9%	90 (10y)	80 (25y)	±5%

Table 2: 14 module types of test cycle 10 (NA: Not Available; NDC: not Defined Correctly – 20 years on power output).

Taking into consideration the criteria mentioned, a module of Chinese origin (Suntech), a HIT (Sanyo) module and 3 thin-film modules were chosen for cycle 10.

The First Solar module cells are Cadmium Telluride (CdTe) and are particularly widespread in big installations in Germany, thanks in particular to their low price. The voltage is low compared to other modules (700Vdc). First Solar is by far the largest producer of CdTe modules (2005: 20MWp; 2006: 50MWp). First Solar has a CdTe module recycling programme where the Cd is separated from the glass support.

The Sanyo modules use HIT (**H**eterojunction with **I**ntrinsic **T**hin layer) technology based on a thin wafer of monocrystalline silicon surrounded by an ultra-thin film of amorphous silicon. These modules are characterised by high efficiency and very low temperature coefficients if compared with c.Si modules.

The Sunpower modules have A-300 cells with high performance EWT (Emitter Wrap Through) back- contact.

The high efficiency of SunPower’s A-300 solar cell is obtained in part by covering its front surface with a proprietary coating which prevents the loss of the charge carriers generated by sunlight. Nevertheless this creates a problem called ‘surface polarisation’ which risks limiting output power. The module must therefore have the positive pole connected to earth and the frame

The BP7180 modules have BP Solar Saturn 7 cells. However, from information received it transpires that this cell series lacks Anti Reflecting Coating (ARC). Despite the change in cell type, the module name still remains the same. As a result there are modules on the market with the same name but with different performances.

2.5 Power Measurements

The measurement of I-V characteristics and therefore of Maximum Power Pm, of the photovoltaic modules is carried out at standard conditions (STC) of irradiation at 1000W/m2 and module temperature at 25°C, in the solar simulator of ISAAC.

Indoor measurements allow verification of manufacturer declared power and respect of guarantee limits as well as determination of eventual degradation of PV elements.

2.5.1 Manufacturer definitions on power and warranty

Over the past few years, module manufacturers have redefined power and warranty limits [1].

Usually, apart from Nominal Power (Pn), warranty limits were expressed as a percentage and in years.

With the realisation that crystalline silicon modules undergo initial degradation, production tolerances (± t) have been introduced in the manufacturers' power declarations for the modules and consequently a minimum power at purchase has been defined:

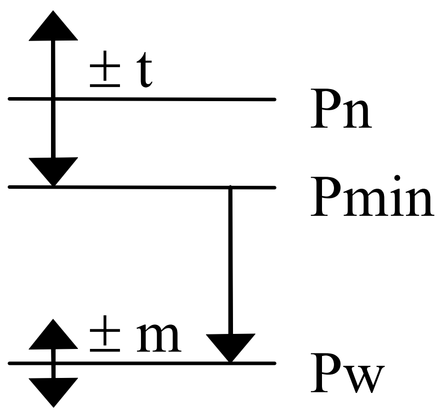
$$P_{\min} = P_n \pm t_p$$ **Equation 1**

where:
- *Pn* is the nominal power of the module [W].
- *tp* is the production tolerances, in [%] or [W].

If before, the warranties were given referring to nominal power Pn, now manufacturers increasingly use minimum power Pmin. This means that if a 200W module has a production tolerance of t=±10W and a warranty of w=±20% in 20 years with respect to Pmin, real guaranteed power will be:

$$Pw = \left(P_n - t_p\right) - w - m$$ **Equation 2**

where ±m is measurement tolerance (for example 3%). The real power of the module could be as low as 147.5W without a claim against the guarantee.



Where:

Pn :	nominal power.
Pmin:	minimum power.
Pw:	limit of the warranty power output.
± tp:	production tolerance.
± m:	measurement tolerance.

Figure 26 Relationship between the declared power parameters of the manufacturer

2.5.2 Warranties and values comparison (cycle 10)

The difference between declared and real values (measured at STC), before and after stabilisation of power, should coincide with the guarantees of production tolerance (tp) and long duration power (w) supplied by the manufacturer

Table 3 shows guarantees for production tolerance and the (first) long duration power guarantee comparing them with initial power and stabilised power after 15 months of exposure.

Type of measurement	MODULE	Pn [W]	*tp (tolerance) [%] / [%]*	Pa [W]	(Pa-Pn)/Pn (%)	*w (warranty) [%] (years)*	P15 [W]	(P15-Pn)/Pn (%)
Direct (c-Si RC)	Miitsubishi PV-MF130EA2LF	130	+ 10 / - 5%	129.4	-0.5%	NA	128.3	-0.7%
	Suntech STP150-24	150	± 3%	150.4	0.2%	90 (12y)	148.0	-1.5%
	Kyocera KC125GHT-2	125	+ 10 / - 5%	122.0	-2.4%	90 (12y)	121.1	-3.1%
	RWE ASE-165-GT-FT	165	± 4%	159.0	-3.6%	NA	154.9	-6.1%
	Solarwatt MHHplus220	210	± 3%	198.9	-5.3%	90 (12y)	192.8	-8.2%
	IBC-215S Megaline	215	± 2.5%	205.1	-4.6%	90 (12y)	209.8	-2.4%
	Solar World SW165	165	± 3%	161.7	-2.0%	90 (10y)	159.4	-3.4%
	BP Solar BP7180	180	- 0 / + 2.5%	171.8	-4.6%	90 (12y)	170.2	-5.5%
Multiflash	Sharp NT-175E1	175	± 5%	174.0	-0.6%	NA	171.2	-2.2%
	Sanyo HIP180NE1	180	+ 10 / - 5%	180.4	0.2%	80 (20y)	176.3	-2.1%
	Sunpower STM210 F	210	- 0 / + 3%	204.6	-2.6%	80 (25y)	199.8	-5.1%
Direct (filtered c-Si RC)	First Solar FS-60	60	± 5%	60.2	0.4%	90 (10y)	57.9	-3.5%
	Kaneka K60	60	+ 10 / - 5%	84.0	39.9%	90 (12y)	54.6	-9.0%
	UniSolar ES-62T	62	± 5%	64.3	3.6%	(10y)	53.4	-13.8%

Table 3 Warranties and differences between initial power (Pa), stabilised power (P15) vs. nominal power (Pn), sorted by type of measurement (i.e. direct, multiflash or direct with spectral matched reference cell). In green: mc-Si; in blue: sc-Si; in pink: thin-film modules.

Initial real power should be found in the range of power defined by nominal power plus or minus the production tolerance. Ideally, it would be more correct if the manufacturer defined production tolerance at stabilised power after initial exposure as is done with a-Si modules. In fact, initial degradation in a-Si modules is important and a-Si manufacturers define nominal power as stabilised power. The slight initial degradation [2] “Osaka”, of c-Si modules, still little known, has not obliged manufacturers to move towards a clear definition of power. It is nevertheless described in the EN50380 norm.

For this reason a comparison between nominal power and power at purchase and not initial stabilised power (P0) has been chosen.

All the characteristics were measured indoor at the ISAAC solar simulator.

Remarks regarding measurement of some types of modules are described below:

- Electrical characterization of Sanyo HIP180NE1 modules - with HIT solar cells, Sharp NT-175E1 and Sunpower STM210F are made by means of multiflash method due to the presence of capacitance effects;
- Measurements on amorphous silicon devices are performed with filtered reference cell (nominal power Pn refers to stabilized power);
- For Thin-Film samples the mismatch correction has been applied.

In three types of module (Solarwatt MHHplus200; IBC-215S Megaline; BP7180) power at purchase is lower than the value defined by production tolerance. Nevertheless, guaranteed final power (w) is respected for all modules under examination (final column, Table 3).

	(Pa-Pn)/Pn (%)	(P15-Pn)/Pn (%)
mc-Si	-2.6%	-3.6%
sc-Si	-1.9%	-3.7%

Table 4: Mean difference of power at purchase and stabilised power with respect to nominal power for mc-Si and sc-Si modules

On average with respect to nominal power the difference between power at purchase in ci-Si modules is lower by -2,3% (mc-Si: -2.6%; sc-Si: -1.9%), while with respect to stabilised power (P15) it is on average lower by -3.7% (mc-Si: -3.6%; sc-Si: -3.7%) – Table 3 and Table 4.

On average the power at purchase of c-Si modules is -2.3% that of nominal power (Pn).

Initial power of the a-Si Kaneka is greater by **+40%**. If on the one hand this might seem positive, on the other hand in the planning stage of a plant it is necessary to take this extra power into account for correct sizing of the components.

However, power at purchase of the (Unisolar) ES-62T modules is much lower for this type of module considering the first initial degradation. In fact stabilised power (P15) is found at -13.8% with respect to the level of nominal power Pn. Nevertheless, from the module's datasheets only the years of guarantee (10 years and 20 years on the new datasheets) and not the power limits are clearly defined and so it is therefore not possible to determine whether the module is still within guarantee limits.

Declared power is therefore not the only determining parameter for the choice of a module, **the guarantee limits** and **production tolerance** being just as important.

Currently, although well-known, initial degradation of ci-Si modules is rarely considered in defining production tolerance (or initial minimum power), while for thin-film modules both nominal power and minimum power are defined at stabilised conditions of power. This means that at purchase and after just a few days of exposure initial power P0 is below production tolerance limits for the next 20 years, while still within guarantee limits.

2.5.3 Initial degradation of c-Si modules

From the current-voltage characteristic measurements and therefore from maximum power measured during the (P_0, P_3, P_6, P_9, P_{12}, P_{15}) test cycle it is possible to verify:

- **initial degradation:** degradation in the first hours of exposure (≥20kWh/m^2 of insolation) at Voc.
- **first 3 month degradation:** degradation in the first 3 months at MPP.
- **secondary** and **annual degradation:** degradation during the stabilised period every 3 months and after one year.

❖ the respect of **warranty** through comparison of the **stabilised (P15) measured values** with those guaranteed by the manufacturers

This last aspect must not be confused with the previous ones. The first three points are of a technological nature, while the last one refers to marketing aspects.

In crystalline silicon module an initial degradation of power occurs when they are exposed to real operating conditions.

Almost all standard c-Si PV modules tested in cycle 5 to 10 showed a degradation in performance when exposed for the first time to sun light. Such power degradation occurs during the first hours of exposure (H=2.5 kWh/m2) and ranges normally between 0 and 5 %

In order to avoid initial degradation effects influencing the determination of module energy yield, the test procedure of the ISAAC-TISO laboratory, was modified in 2001 adding a period of light soaking of 20kWh/m^2 followed by 3 months of stabilisation. The initial degradation of ci-Si modules is shown in Table 5 in the column comparing power at purchase and power after a 20kWh/m2 "(P0-Pa)/Pa" exposure.

			Degrado, dipendente dalla tecnologia			
Type of measurement	**MODULE**	**P15 [W]**	**(P0-Pa)/Pa (%)**	**(P3-Pa)/Pa (%)**	**(P15-Pa)/Pa (%)**	**(P15-P3)/P3 (%)**
Direct (c-Si RC)	Miitsubishi PV-MF130EA2LF	128.3	-2.2%	-0.3%	-0.8%	-0.6%
	Suntech STP150-24	148.0	-1.2%	-0.6%	-1.6%	-1.0%
	Kyocera KC125GHT-2	121.1	-1.6%	-1.1%	-2.2%	-1.1%
	RWE ASE-165-GT-FT	154.9	-2.7%	-2.7%	-4.1%	-1.5%
	Solarwatt MHHplus220	192.8	-2.9%	-4.1%	-4.6%	-0.5%
	IBC-215S Megaline	209.8	0.6%	0.4%	-0.3%	-0.7%
	Solar World SW165	159.4	-0.1%	-0.4%	-2.1%	-1.7%
	BP Solar BP7180	170.2	-1.6%	-1.3%	-2.6%	-1.4%
Multiflash	Sharp NT-175E1	171.2	-1.0%	-0.1%	-1.6%	-1.5%
	Sanyo HIP180NE1	176.3	0.3%	-0.3%	-2.2%	-2.0%
	Sunpower STM210 F	199.8	0.2%	-1.0%	-2.3%	-1.4%
Direct (filtered c-Si RC)	First Solar FS-60	57.9		-7.2%	-9.0%	-1.9%
	Kaneka K60	54.6		-27.2%	-33.6%	-8.8%
	UniSolar ES-62T	53.4		-11.1%	-15.4%	-4.8%

Table 5: Degradation of cycle 10 modules, after exposure to real climatic conditions (mean value of two modules; for FS-60 value of 1 module).

Initial degradation [(P0-Pa)/Pa] in power of the c-Si modules is found to be on average at -1.1%, ranging from +0.6% to -2.9%. The ± 1 % values are found within the repeatability tolerance limit of the measurements (see 1.4)

The performance loss is mainly due to degradation of the short circuit current Isc. Considering the measurement precision, for degradations up to -5%, a linear relation between power and Isc degradation can be observed. Also in cycle 10, where the c-Si modules underwent initial degradation in power it was mainly in Isc, as previously shown in [1].

Prior sunlight exposure, storage time and subsequent pre-degradation of the modules purchased is not known, so the initial power Pa measured at ISAAC-TISO could correspond to the power of already degraded c-Si modules.

2.5.4 Power degradation after 1 years of exposure (c-Si)

During the first year of outdoor exposure under real climatic conditions and after the initial degradation, [(P15-P3)/P3], the weathered modules show a further average degradation of -1.2%, ranging from -0.5% to -2.0%. The relative average degradation of the short circuit current was -0.8% (ranging from -0.0% to -1.4%) and that of the open circuit voltage was -0.4% (ranging from +0.3% to -0.7%).

The reproducibility limit of the measurements does not allow a real degradation in Isc or Voc to be seen, the negative trend of Pmax being slightly larger than the measurement uncertainty.

The average degradation of mc-Si e sc-Si modules show no significant differences between them and do not permit a subdivision into two separate categories characterized by different degradation behaviors.

Overall, from purchase of the modules to one year of outdoor exposure [(P15-Pa)/Pa, the average degradation of power of the c-Si modules was -2.2% with a maximum value of -4.6%. This result shows that, on average, initial and medium-term degradation of crystalline silicon modules is limited. However, in certain cases, a maximum degradation of nearly 5% can occur

2.5.5 Initial and mid-term degradation in thin film modules

Initial degradation of thin film modules depends on various factors. In particolar, the behaviour of amorphous silicon modules (Kaneka Z60 and UniSolar ES-62T) is greatly affected by insolation and temperature. In the table only the values of one of the First Solar modules (Cd-Te) are shown due to a breakdown in one of the two modules.

Indoor measurements of thin film modules were carried out with a filtered reference cell which best corresponds to the Spectral Response of these thin film modules. The test procedures for thin film modules only foresee an initial 3 months of stabilisation (light soaking).

During this period the degradation of the First Solar module was -7.2% (Pm). Isc degradation was nil (0.0%) while Voc degradation was -4.0%.

In the Unisolar modules, initial degradation was-11.1% (Pm) and the following year it was -4.8%. This last value must, however, be considered in relation to climate conditions preceding the measurement. In particular, initial reduction in Isc was -1.0%, in Voci it was -3,4% while most of the degradation occured in FF (-7.2%). During the course of the year additional reduction [(P15-P3)/P3] was -4.8%, with most occuring in FF (-3.1%).

The degradation of power measured indoors of the Kaneka K60 module was more significant. Initially Pm reduction was -27.2% ((∆Isc: -1.7%; ∆Voc: -8.0%; ∆FF: -19.2%), while during the rest of the year the total degradation was -8.8% (∆Isc: -2.4%; ∆Voc: -2.4%; ∆FF: -4.5%).

2.6 Outdoor Performance inter-comparison

2.6.1 Approach

In April 2006 a new test cycle with 28 modules (14 different types and 2 modules of each) started. The first goal was to identify the module technologies with the highest energy output. After 1 year of outdoor exposure the energy output of the different modules were compared to each other and analysed in detail to identify the strengths and weaknesses of each technology. The results presented here covers the period from 1 of May 2006 to 30 April 2007. The results are representative for Lugano and open-rack mounted modules. Only a detailed analysis can give some more information on how the modules will perform under different operating conditions.

Additional to the energy output (E) in kWh/Wp the Performance Ratio (PR) of each module is also calculated and compared to each other. The PR is here defined as the DC energy produced by the module divided by the incoming solar energy and the module power under Standard test conditions (PR = ∑Wh / Pstc / ∑insolation). The modules are all mounted on the same rack and see the same irradiance. The incident irradiance is measured by two pyranometers positioned on each site of the test area. The measurements are executed simultaneously. The STC power taken for the calculation of the performance ratio or the kWh/Wp differs depending on which power is considered, the name plate value (nominal power) or the value measured at ISAAC. As shown in chapter 2.5.2 ,the nominal power (Pn), as declared by the manufacturer, hardly ever corresponds to the real stabilised power due to:

1) manufacturing process related power differences,
2) declaration strategies,
3) measurement uncertainties,
4) initial degradation effects and
5) the Staebler Wronsky effect in (only for amorphous silicon modules).

For the evaluation of the energy output, our laboratory generally differentiates between two points of views. The first is more consumer oriented, as it looks at the energy output in relation to the nominal STC power and the second one is a purely technological inter-comparison, where the real stabilised STC power measured by a accredited laboratory is used as reference, in this case our own test results (see Table 2). The first approach, shown in Figure 27, gives an idea of the annual performance of a module per acquired Watt peak or invested CHF and the second one an idea of the product quality (Figure 28 - Figure 30).

For the second one, the purely scientific approach, the P3 power measured after 3 months (20th June 2006) of outdoor exposure was used as reference. Three different situations are here analysed: 1) one year data (Figure 28), 2) all clear sky days with G_{diff}/G_{glob}<25% and 3) only cloudy days with G_{diff}/G_{glob} in between 50% and 85% (Figure 30). Days with diffuse light fractions of more than 90% have been totally neglected, due to the higher measurement uncertainties. The figures are described in more detail in the following paragraph.

2.6.2 kWh inter-comparison

For all 4 figures the energy output in kWh/Wp refers to the best one of the test cycle. For reasons of simplicity the average of the two modules is shown here. The grey bars corresponds to the respective difference between the two modules. All crystalline silicon technologies with declared efficiencies of less than 15% are represented within Figure 27-Figure 31 by red bars, the high efficiency modules with green bars and the thin film technologies with blue bars.

Due to the above-mentioned reasons and the different degradations occurring during the first year of exposure, the **kWh ranking with respect to nominal power Pn** (Figure 27) leads to slightly different figures compared to the one referring to the measured power P3 (Figure 28-Figure 30). During the last few years a remarkable improvement in the accuracy of power declarations of all crystalline silicon technologies could be observed (see chapter 2.5.1). This lead to increasingly smaller discrepancies between modules when comparing their energy output on the basis of its nominal power. In fact some years ago the main difference was mainly due to the high tolerance declarations (±t%), usually of ±10%. From 2000, the differences in Wh/Wp nominal power, of the crystalline silicon modules investigated by our laboratory, changed from ±10.9% to ±4.6%. As a result, also the divergence between commercial and technological comparison diminished every time. The new test cycle demonstrated an effective difference in the annual output of the c-Si modules in the range of only ±3.0% (with P3 as reference), which compared to the above- mentioned ±4.6% (with Pn as reference) leads to a very small difference of 1.6%. The differences are today so little that considering the measurement uncertainties involved it is not always possible to tell if one module produces more than the other. But due to the ongoing technological developments in the c-Si field and the other new emerging technologies a clear differentiation is still possible.

The **First Solar CdTe module** resulted in having the highest output (Wh/Wp), independent of which power value was taken as reference (Pn or P3) and of which type of days were considered (1 year data or clear sky days). Only in the case of cloudy days does it move down on the second place, but with a very small difference.

In the pure technological inter-comparison (stabilised power P3 as reference) the modules can be separated into 3 groups: **Group A** with up to 3% of difference respect to the best one, **Group B** with a difference of in between 3% and 6% and **Group C** with a difference from 6 to 10%. The module can be always correlated to the same groups independently of the 3 investigated cases (1 year, clear sky days, cloudy days).

The groups are: **Group A (FS, MHH, ES, HIP)**; **Group B (MF,KC,STM,IBC,ASE,NT)** and **Group C (SW, STP, BP, K)**. The spread in between the single groups slightly increases for variable days.

The interpretation of the **amorphous silicon technologies** within the ranking, here represented in blue, are complicated by the fact that the STC power of these technologies changes in time (degradation and recovery effects). Consequently their position in the ranking changes as well depending on the period under investigation. Especially for the **single junction technology of Kaneka,** the position changed from top in the first 5 months (see annual report 2006) to bottom after 1 year. More realistic figures are possible after the first year when the initial degradation is completed and only the seasonal variations occur. In this case a reference power corresponding either to the average minimum or maximum annual power would still need to be defined. No standard exists up to now to define this.

To show the range of order of the **kWh/Wp uncertainty,** error bars were added in Figure 27 to Figure 30. In the case of name plate power as reference the uncertainty is on the one hand due to the energy measurement itself (±1.0%) and on the other hand due to the uncertainty in power declarations (±t%). Taking instead the real power as reference, the uncertainty is the sum of the energy measurement uncertainty (±1.0%) and the ISAAC power measurement accuracy (±2% for c-Si and CdTe, not defined for a-Si). The ±1.0% of the outdoor measurement uncertainty includes the data acquisition accuracy, MPPT tracking efficiency, cable connections, differences in albedo and ventilation, and module alignment errors. All a-Si error bars are to be treated with caution due to the non-availability of the exact error in indoor performance determination.

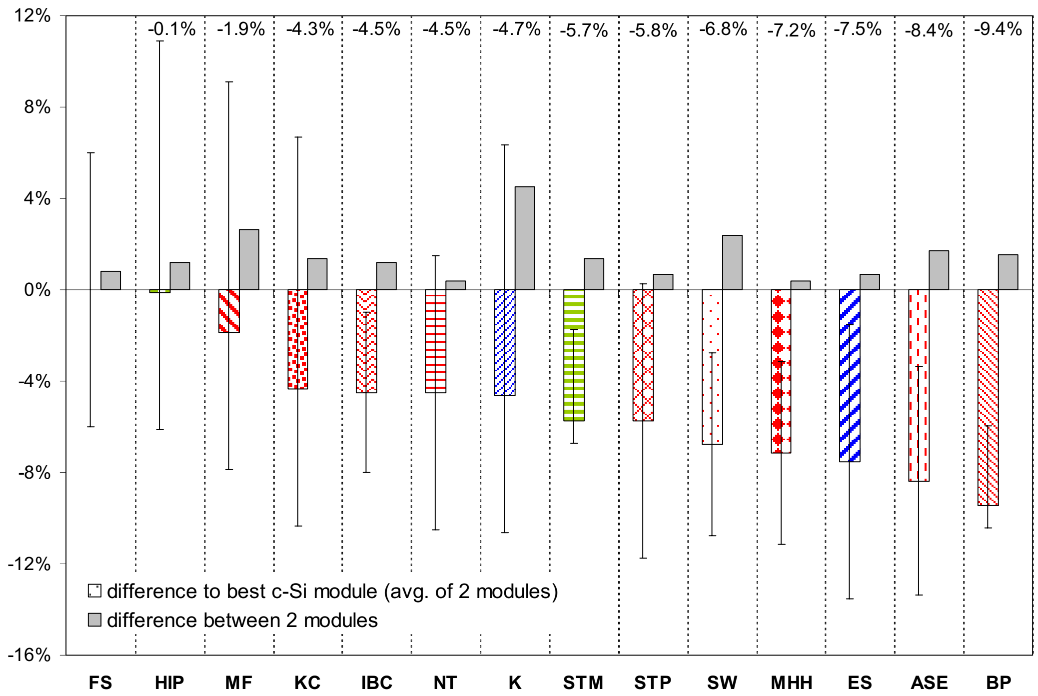


Figure 27: Difference (average of 2 modules) in annual energy production [kWh/kWp], of 14 different module types compared to the best module with nominal power Pn as reference and difference between the two modules of the same type.

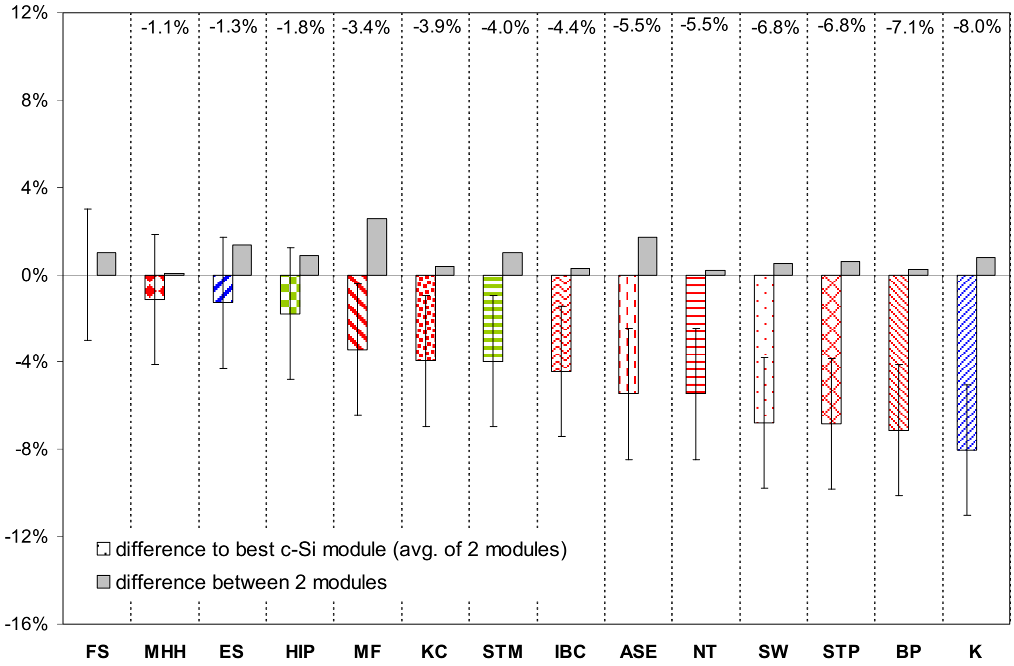


Figure 28: Difference (average of 2 modules) in annual energy production [kWh/kWp], of 14 different module types compared to the best module with real power P3 as reference and difference between the two modules of the same type.

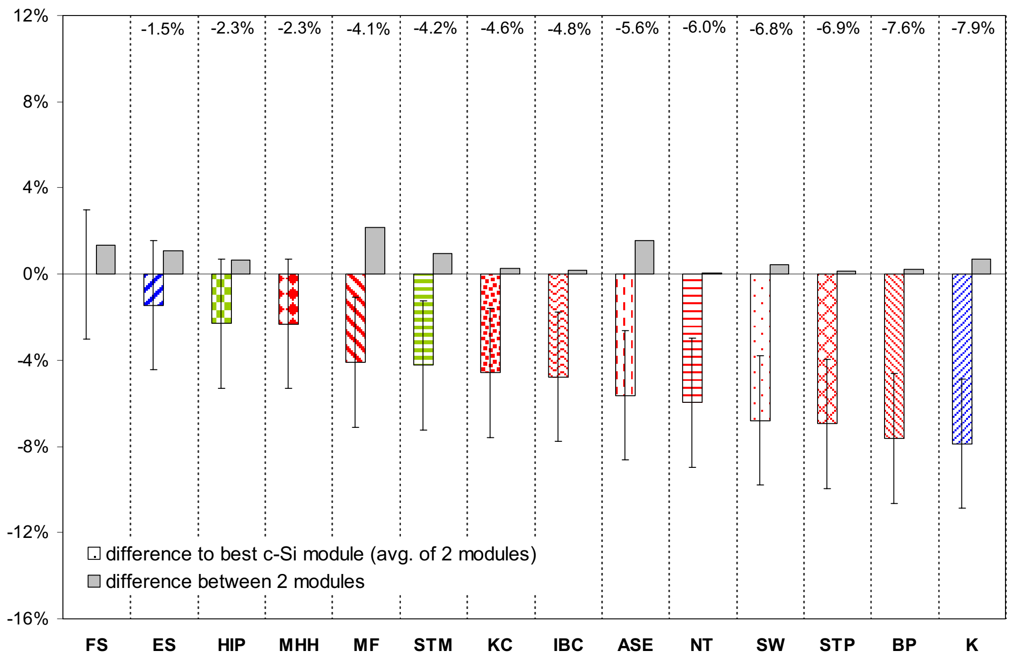


Figure 29: Difference (average of 2 modules) in the energy output on clear sky days [kWh/kWp] with a diffuse light fraction of less than 25% (129 days), of 14 different module types compared to the best module with real power P3 as reference and difference between the two modules of the same type.

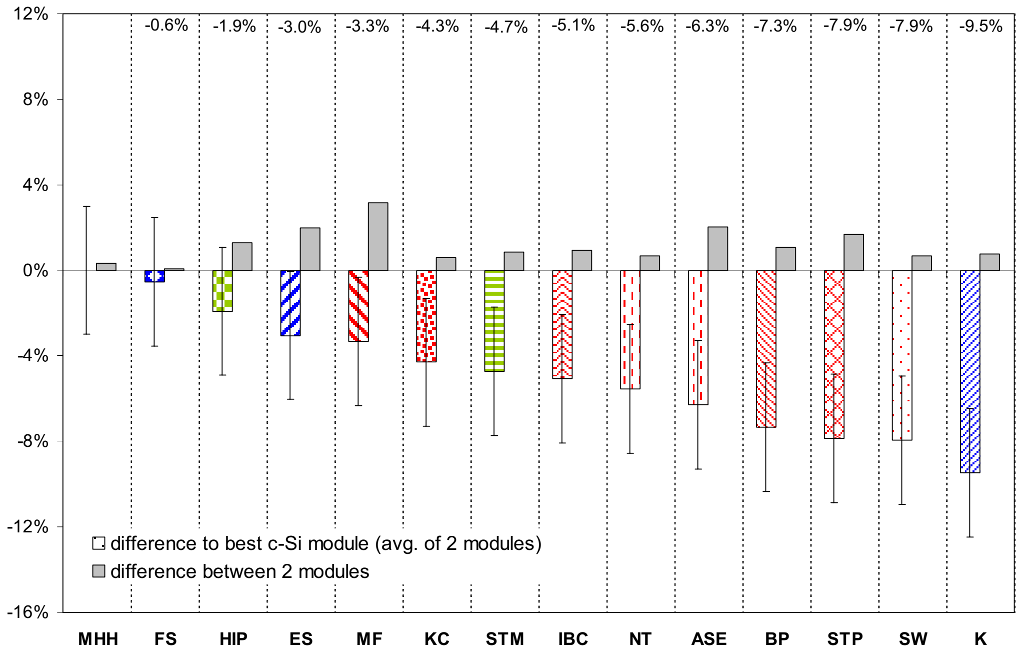


Figure 30: Difference (average of 2 modules) in the energy output on cloudy days [kWh/kWp] with a diffuse light fraction between 50% and 85% (59 days), of 14 different module types compared to the best module with real power P3 as reference and difference between the two modules of the same type.

In the last graph (Figure 31) the energy output has been compared with respect to the STC module efficiency declared by the manufacturers instead of the STC power. It is clearly visible that the higher the efficiency is the higher is the kWh/m² output as well, but that they are not directly proportional. This means that an optimisation of the modules with respect to their STC efficiency is not the only relevant parameter. This is especially clear for the thin film technologies which have an output not so far away from the lower c-Si technologies.

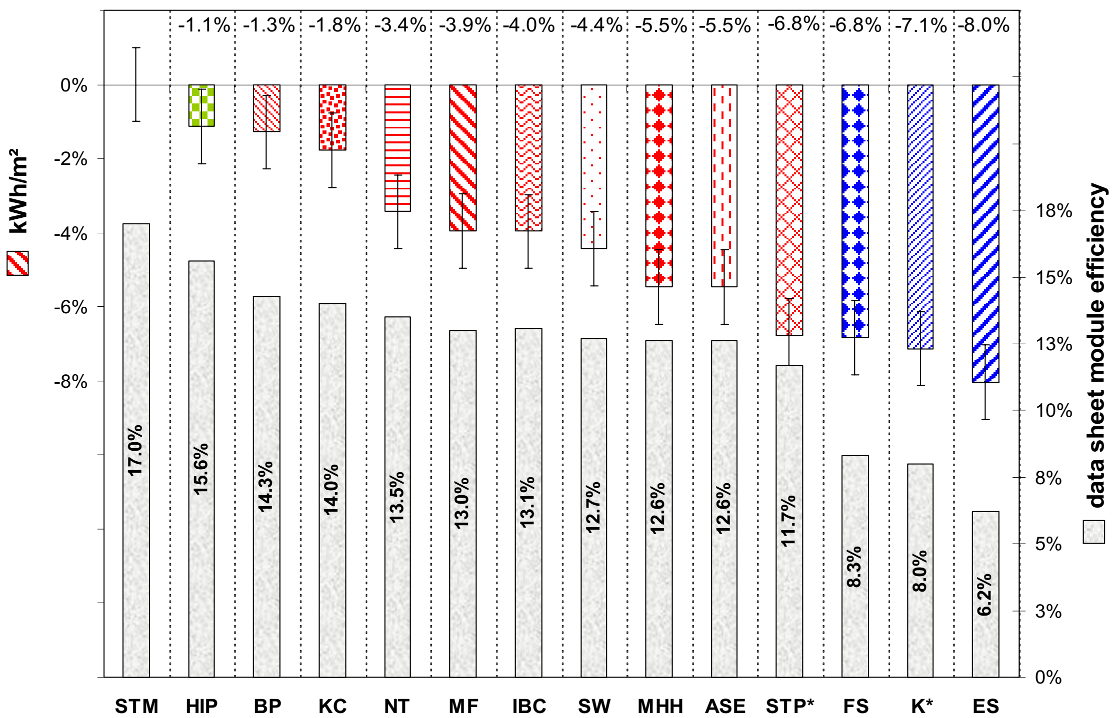


Figure 31: Difference (average of 2 modules) of annual energy output per square meter [kWh/m²] of 14 different module types compared to the best module together with their declared module efficiency.

* No data sheet value available, the measured one was taken instead.

2.6.3 Daily performance ratio inter-comparison (referred to P3)

The PR comparison consists of (1) the plot of daily PR versus time (Figure 32-Figure 36) and (2) the plot of the average daily PR under different types of environmental conditions like daily insolation, average module temperature and average diffuse light fraction (Figure 37-Figure 39). For each environmental condition the number of days for which these conditions occur are drawn as well.

1. **Standard c-Si technologies** (average PR 0.91-0.95)
   Typical PR trend inverse to module temperature (see Figure 32). The power temperature coefficient goes from -0.41 to -0.47%/°C.
2. **HIP180NE1** (HIT cells) (average PR 0.96)
   Overall higher performance ratio (see Figure 33). The lower temperature coefficients compared to standard c-Si modules 0.32%/°C leads to reduced temperature losses at high temperatures and consequently at high irradiances. One of the two modules (HIP02) seems to degrade slightly (see Figure 34). This degradation couldn't be observed within the indoor STC measurements.
3. **STM210F** (Sunpower back-contact cells) (average PR 0.94)
   The modules have an overall high performance, but a higher output would be expected considering the very high efficiencies declared by the manufacturer (see Figure 33). Compared to the other technologies, the two Sunpower modules show a higher instability in PR, with sometimes one performing better than the other. This effect could be associated to some technology related effects called "surface polarization". The high efficiency of SunPower's A-300 solar cell is obtained in part by covering its front surface with a coating which prevents the loss of the charge carriers generated by sunlight. But this layer performs much like a transistor that is turned off, preventing current flow. In the particular case of polarisation of the surface, the "transistor" effectively turns on, allowing charge carriers to recombine at the front surface thus reducing the output current of the cell. The manufacturer claims that, like a transistor, this effect can be fully reversed and current returned to the original level. Some simple tests were performed towards the end of the test cycle to verify possible malfunctions caused by this, but no improvements could be observed even after more than 1 week of proper grounding as described within the mentioned references.
4. **MHHplus220** (Sunways cells) (average PR 0.97)
   Despite the relatively high temperature coefficient of 0.47%/°C, the module performs very well (see Figure 33). A higher PR at low irradiances and low temperatures is observed for this kind of modules. A better performance at high incident angles or high diffuse fraction seems to be responsible for this (see Figure 37 to Figure 39).
5. **FS60** (CdTe cells) (average PR 0.98)
   The Firstsolar technology is the module with the highest average PR (see Figure 35). It has a low temperature coefficient close to that of the a-Si technologies 0.2%/°C, but compared to the a-Si the STC power is much more stable except for a pronounced initial degradation not shown in the figures (see power tables of chapter. Compared to the c-Si and a-Si technologies the PR changes much less over the year. A slight degradation over time seems to be visible, but longer monitoring periods would be needed to prove it.
6. **ES62T** (triple junction a-Si technology) (average PR 0.96)
   Typical a-Si trend with a minimum in winter and recovery in summer due to the combination of the typical Staebler-Wronsky effect and the low temperature coefficient (see Figure 35). Compared to the single junction a-Si technology of Kaneka the initial degradation is almost terminated within the first month and is less pronounced.
7. **K60** (single junction a-Si technology) (average PR 0.88)
   The single junction technologies show a very strong initial degradation (see figure 10) which is dominant with respect to the seasonal variations. The initial degradation not being totally concluded, the K60 has not been shown further in Figure 35 and Figure 37 - Figure 39. An inter-comparison with the other modules is almost impossible.

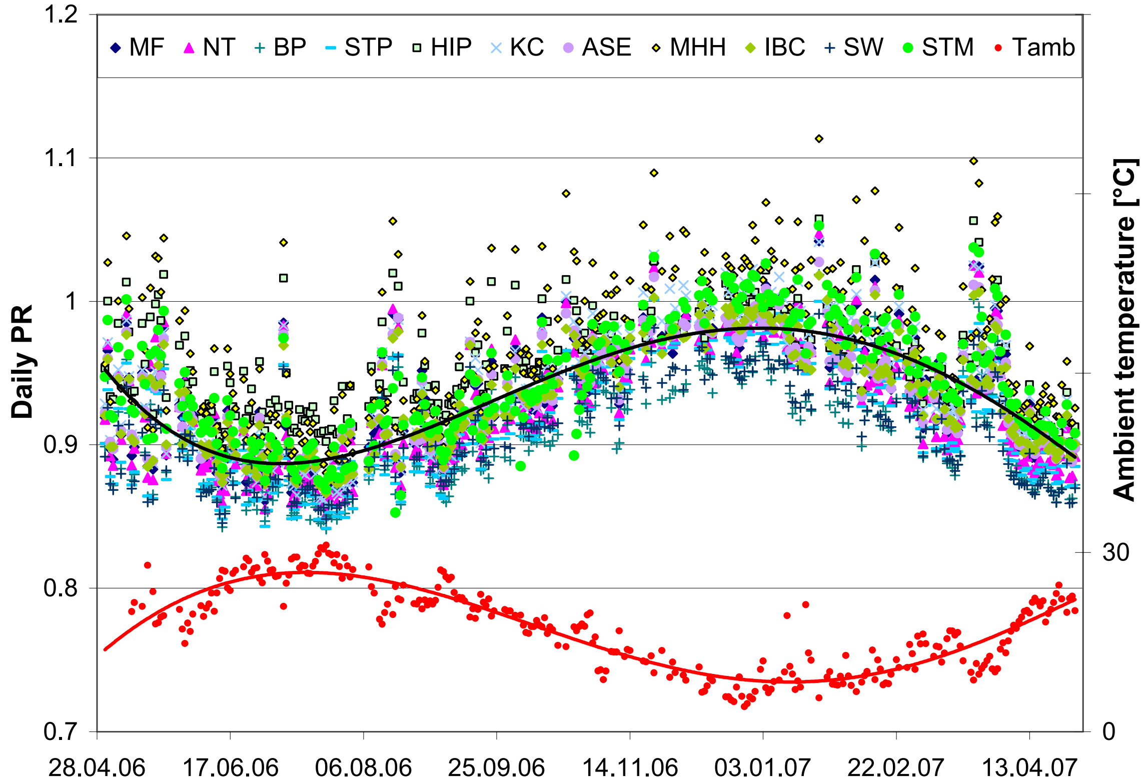


Figure 32: Daily performance ratio of all c-Si modules over the first year of outdoor exposure. The black line is the fit of one of the average modules used as reference (c-Si ref) for the comparison with the other technologies.

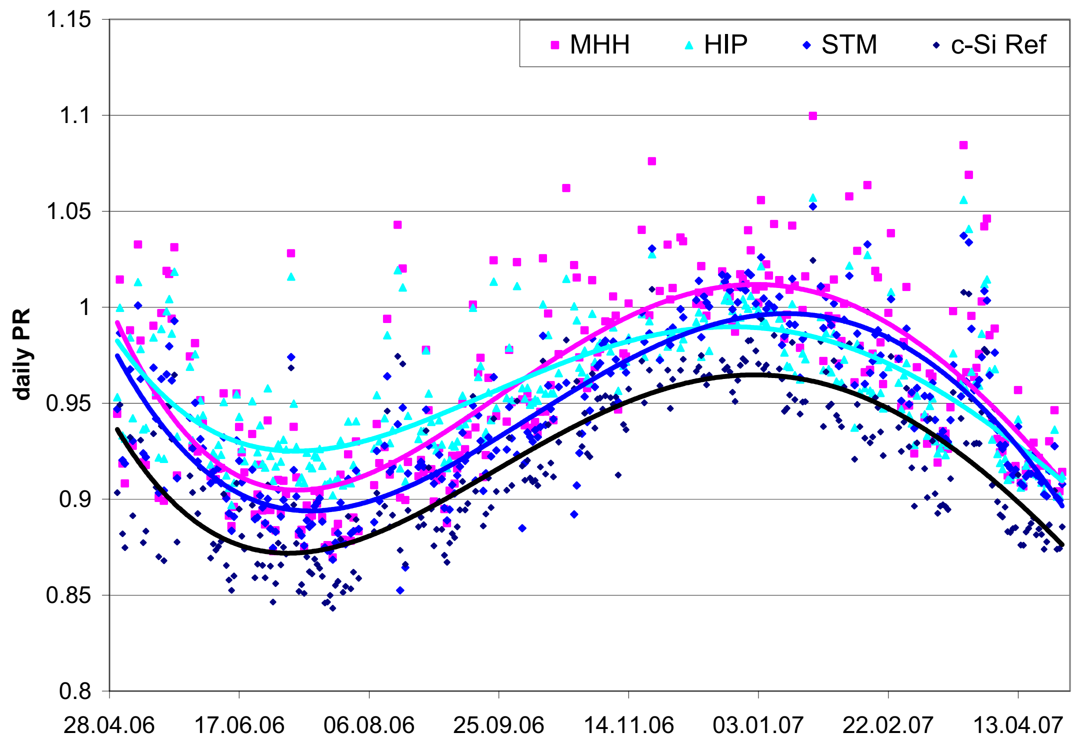


Figure 33: Daily performance ratio of the 3 best performing c-Si modules over the first year of outdoor exposure together with the c-Si reference.

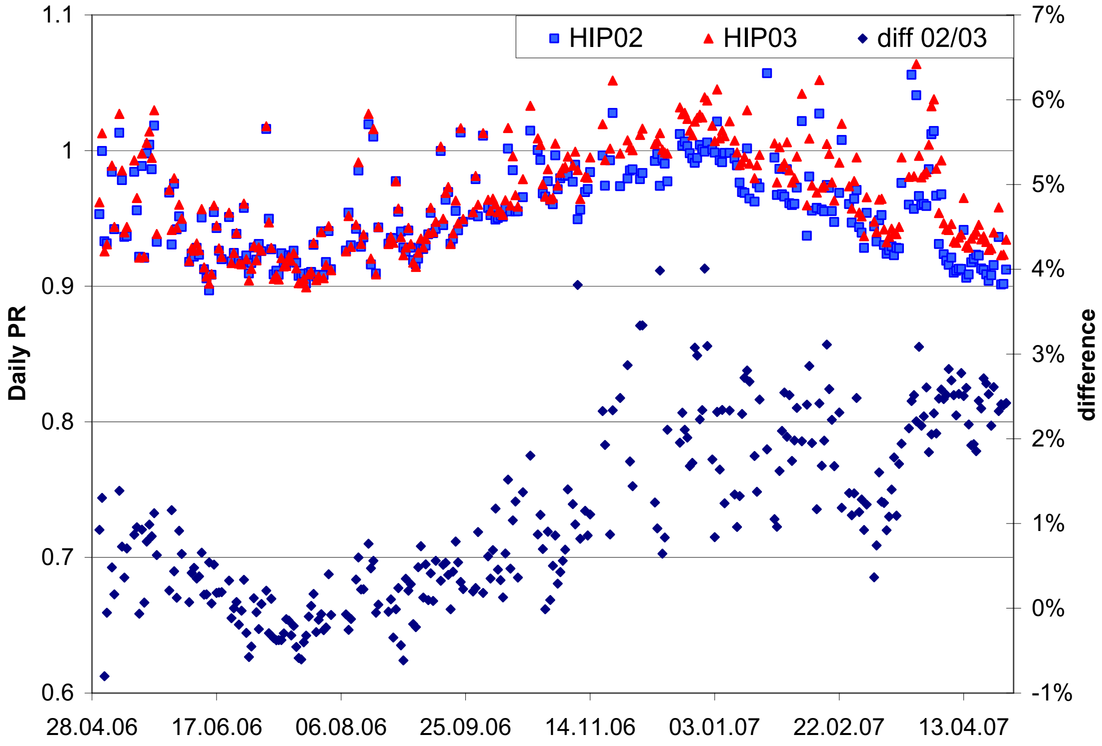


Figure 34: Daily performance ratio of the two HIP modules and the difference in between the two [%] during the first year of outdoor exposure.

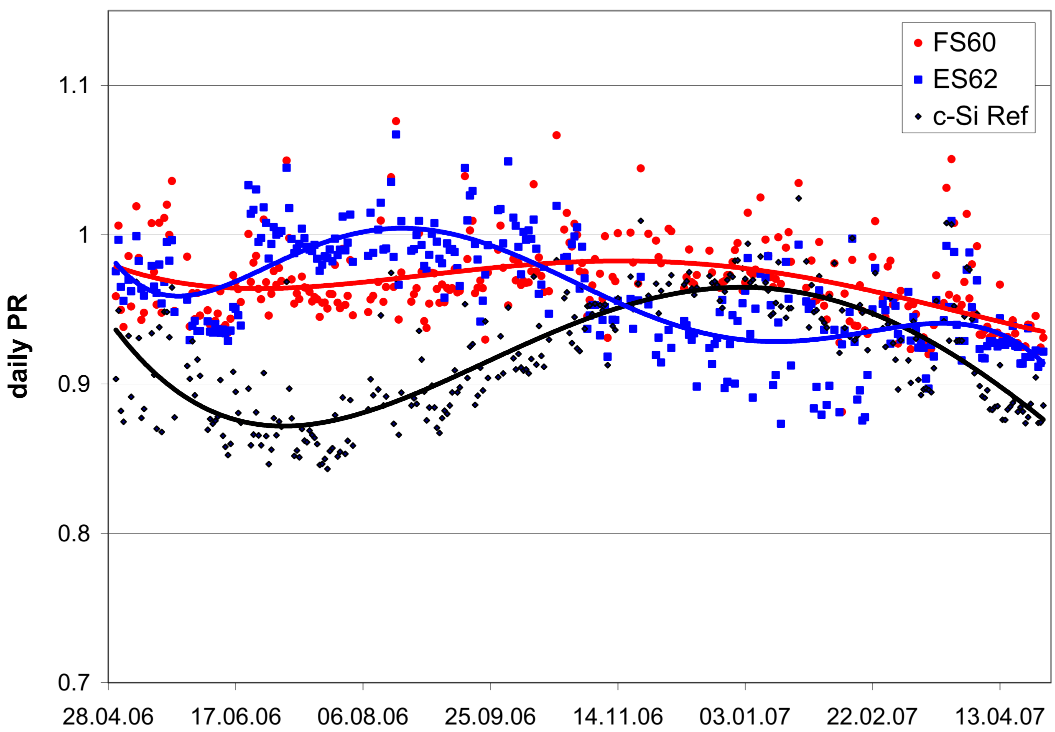


Figure 35: Daily performance ratio of all thin film technologies over the first year of outdoor exposure together with the c-Si reference.

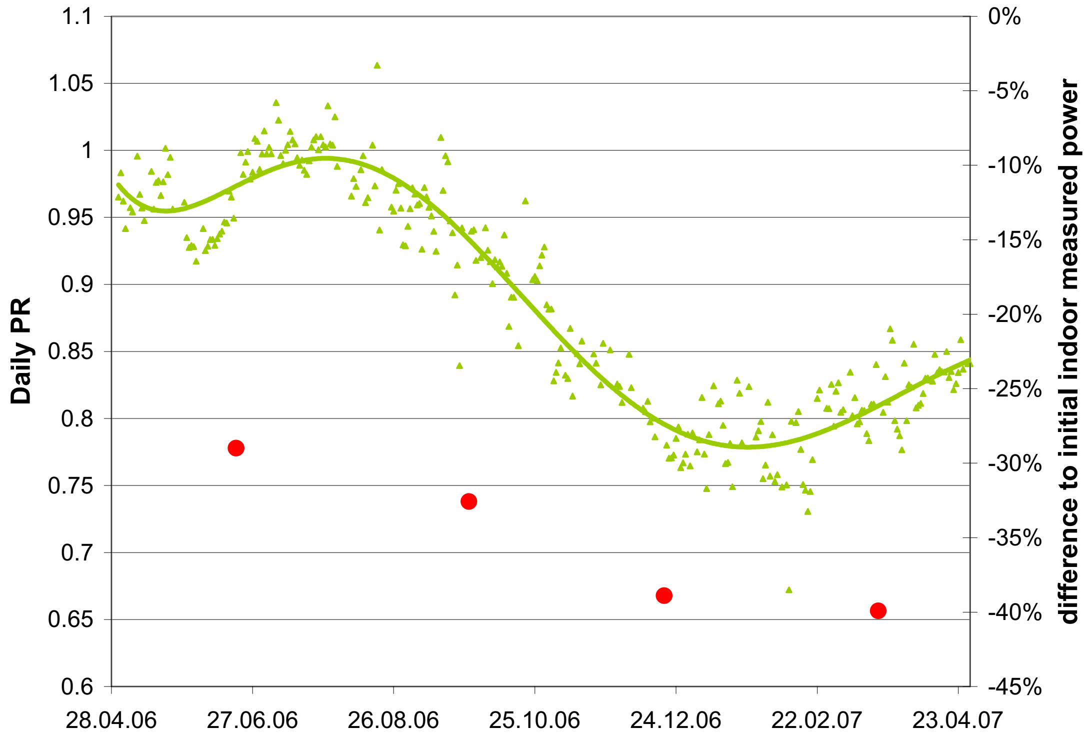


Figure 36: Daily performance ratio of the single junction a-Si module over the first year of outdoor exposure together with the indoor measured peak power (red dots). The first power measurement is the one used for the calculation of PR.

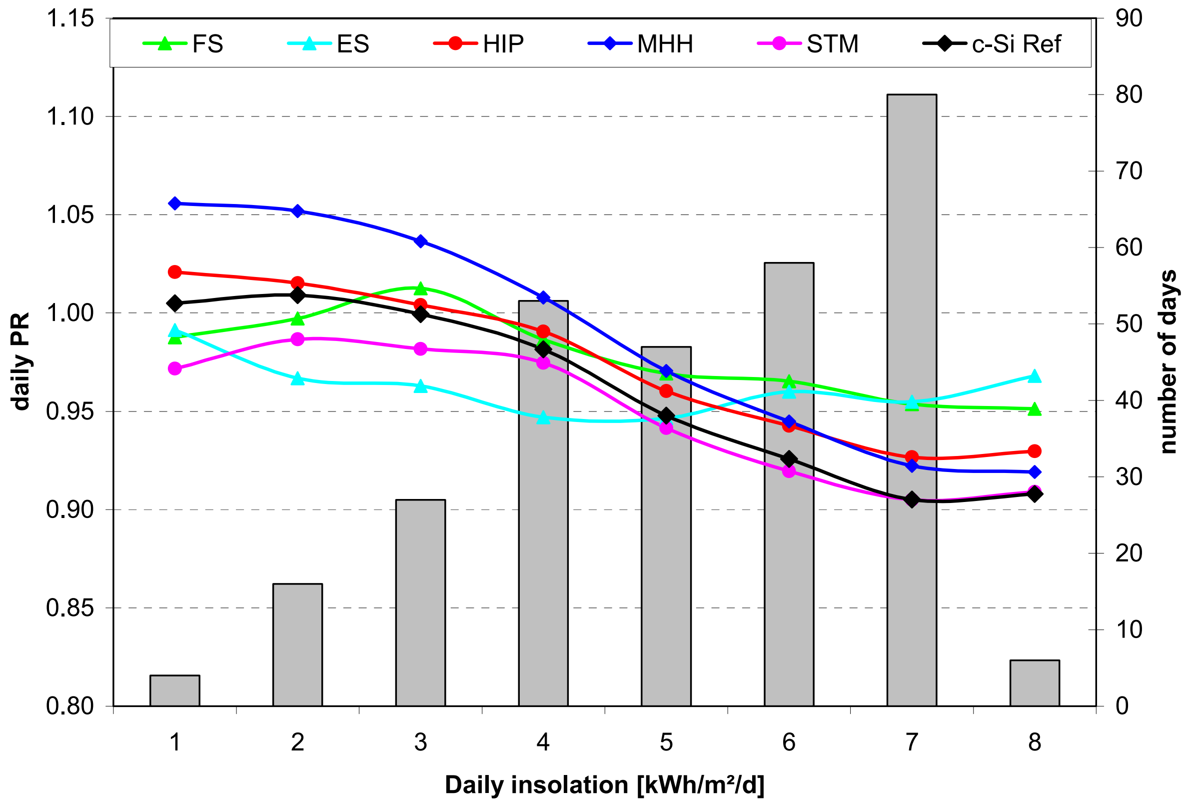


Figure 37: Daily average performance ratio versus daily in-plane insolation of all TF modules, the three best c-Si modules and the c-Si reference module, representative for c-Si modules with standard behaviour and with an average performance considering a whole year.

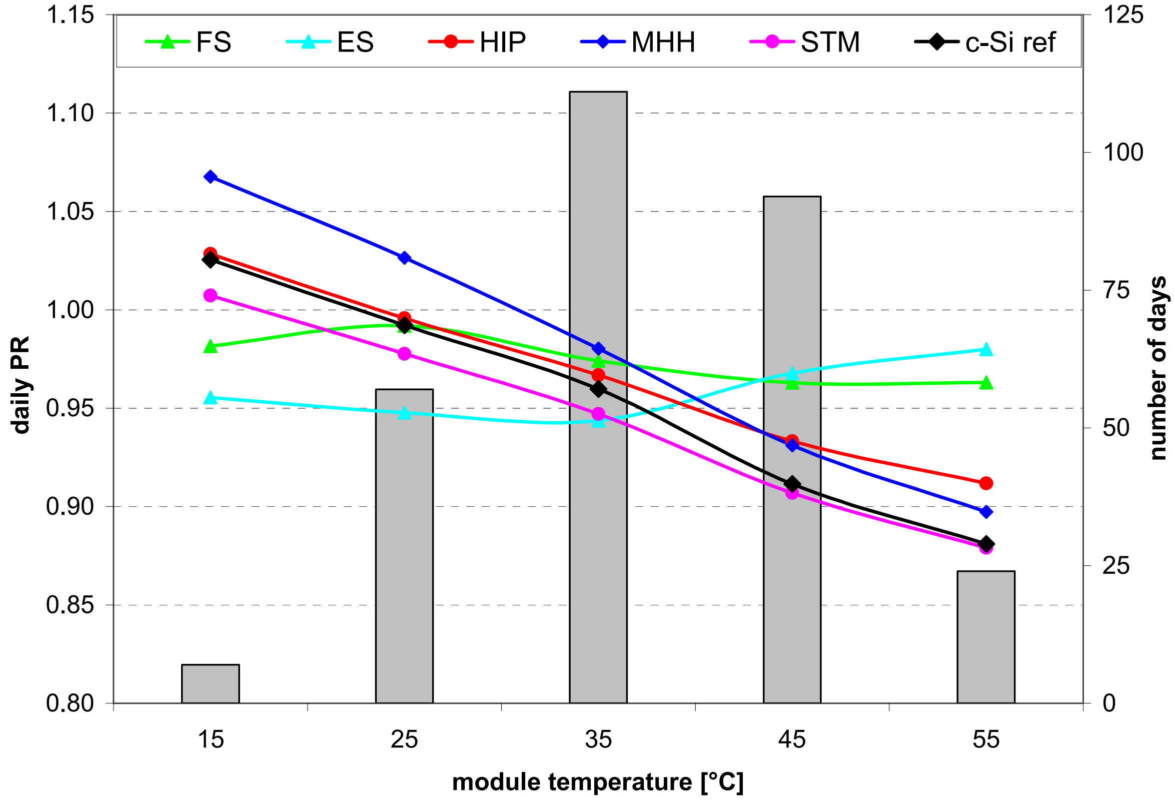


Figure 38: Daily average performance ratio versus average module temperature of all TF modules, the three best c-Si modules and the c-Si reference module, representative for c-Si modules with standard behaviour and with an average performance.

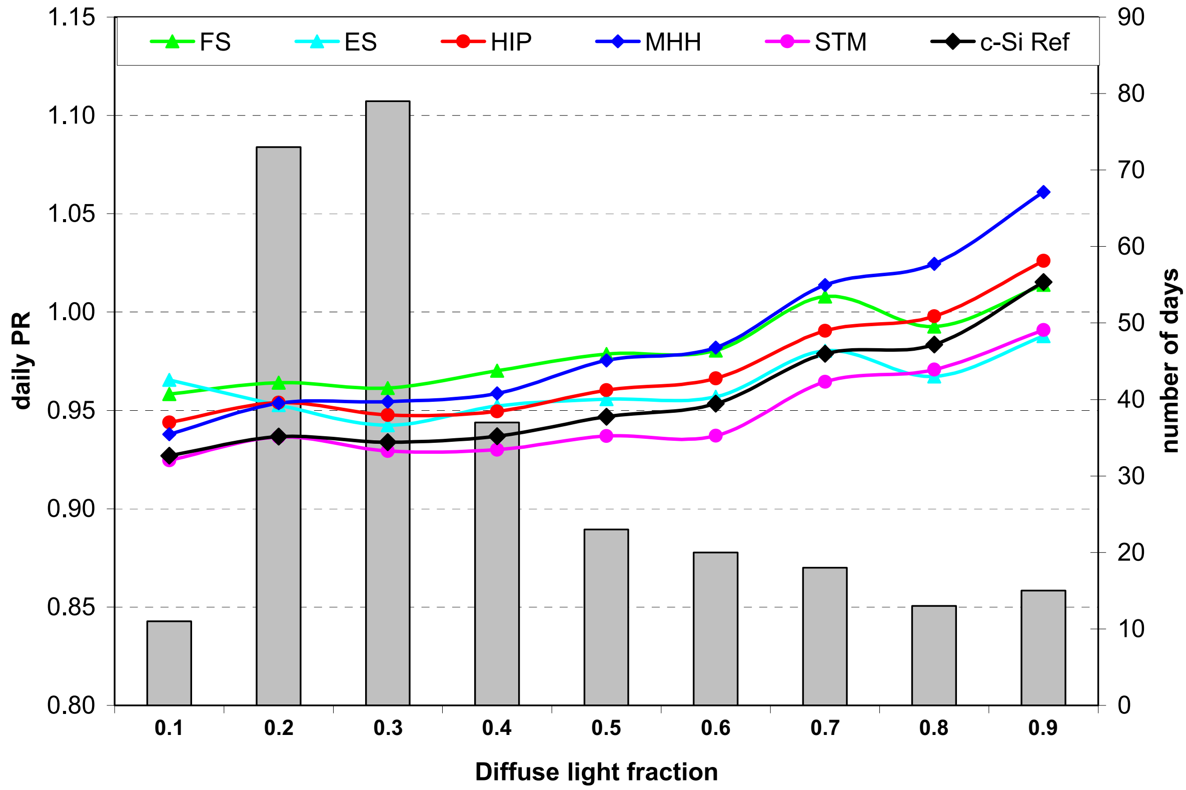


Figure 39: Daily average performance ratio versus average diffuse irradiance fraction of all TF modules, the three best c-Si modules and the c-Si reference module, representative for c-Si modules with standard behaviour and with an average performance.

2.7 Energy Rating Prediction with the Matrix method

2.7.1 Objectives

To be able to predict the energy of a module you need different information about the module, which can be either measured indoor or outdoors. The tests on the reference module concentrate therefore on short-term indoor and/or outdoor characterisation methods for the determination of the module performance at different temperatures and irradiance levels. The obtained power matrix $P_m(G_i,T_{amb})$, is the primary input parameter of the Matrix Method. In the past this power matrix was directly extracted from the long-term measurements of the test cycle modules. Even if leading to very good energy predictions, as shown in the TISO activity report for the period 2000-2003, such extensive measurement is not feasible for a standard energy rating procedure. Since there is still no standard measurement procedure for energy rating itself available, different methods had to be compared to each other with the aim of identifying the one which leads to the best energy prediction in the shortest time. To not interrupt the monitoring of the two original modules the third module, named reference module, was acquired and tested without being exposed outdoors except for the purpose of the measurements themselves and for an initial outdoor exposure of approximately 20kWh/m², necessary to stabilise the module. The test results of the reference module are used here to predict the energy of the other two modules.

Regarding the meteorological input parameter of the site for which the energy has to be predicted, the idea is to limit the number of input parameters to a minimum and more precisely to the irradiance of a broad band pyranometer and the ambient temperature. The reason for this is that these two parameters are easily available for almost all locations, which is not often the case for other meteorological parameters.

At this stage no spectral, angle of incidence or coverage effects are explicitly considered within the simulations. The assumption made here is that they make either a small contribution to the total energy output or that they average out over the year. One of the aims of this work is to identify the accuracy to be expected in the case of optimally oriented modules and to quantify the major error expected for the different thin-film technologies. A future energy prediction method for building integrated modules especially if of a-Si technology will of course need the introduction of some of the up-to-now neglected effects.

The final objective here is to develop an energy rating method which reduces the number and complexity of the required tests and input parameters to a minimum, but still leads to a prediction accuracy which is in the range of measurement accuracy.

2.7.2 The Matrix Method

The Matrix Method already described in detail within the last activity report for the period 2000-2003 [Ref] uses a performance surface (power matrix) as a function of in-plane irradiance G_i and back of module temperature T_{bom} and links this to the irradiance and ambient temperature T_{amb} data of the site for which the energy output has to be predicted. The power surface is described by the equations 1 to 3,

$$I_m = I_{m,stc} \cdot G_i/1000 \cdot [1+\alpha_{Im} \cdot (\Delta T + T_{bom} - 25)] \quad (1)$$

$$V_m = V_{m,stc} + C_0 \cdot \ln(G_i/1000) + C_1 \cdot (\ln(G_i/1000))^2 + \beta_{Vm} \cdot (\Delta T + T_{bom} - 25) \quad (2)$$

$$P_m = I_m \cdot P_m \quad (3)$$

where:
$I_{m,stc}$ maximum power point current @ STC
α temperature coefficient of Im @ 1000W/m²
ΔT temperature difference T_{cell}-T_{bom} @ 1000W/m²
$V_{m,stc}$ maximum power point voltage @ STC
C0 C1 module specific parameter
β temperature coefficient of Vm @ 1000W/m²

To be able to combine module with meteo data, the power matrix $P_m(G_i,T_{bom})$ has to be first translated to $P_m(G_i,T_{amb})$, by applying equation 4.

$$T_{bom} = (NOST - 20°) \cdot G_i/800+T_{amb} \quad (4)$$

NOST, the nominal operating specific temperature, is defined as the site and mounting specific module temperature of a module operating at maximum power point, 800 W/m² and 20°C ambient temperature.

Compared to the past the fitting procedure was automatised and integrated into a new version of the energy prediction software written in Labview. The program shown in Figure 40 has the following main features:

1. extraction of raw data for the matrix generation independent from the input format.
2. visualisation, filtering and saving of the different measured matrices in dependence of irradiance and module or ambient temperature (Im, Vm, Pm, E and Meteo) together with their standard deviations (Figure 41).
3. fitting to equations 1 and 2 and extraction of the parameters $I_{m,stc}$, $V_{m,stc}$, α, β, C0 and C1 and the respective fitting error curves.
4. extraction of the NOST value.
5. execution of energy predictions and inter-comparison to real data.
6. detailed error analysis by plotting the energy prediction error against irradiance, temperature, angle of incidence or air mass.

The matrix method is currently under evaluation within the research project 'Performance', where various round robins (RR) are under execution to compare and improve existing energy rating approaches. The results of the first RR were presented at the 22nd European PV Solar Energy Conference (Milano, 2007).

The validation executed here wants instead to further validate the method on a large number of different modules and identify the best way to determine the input parameters.

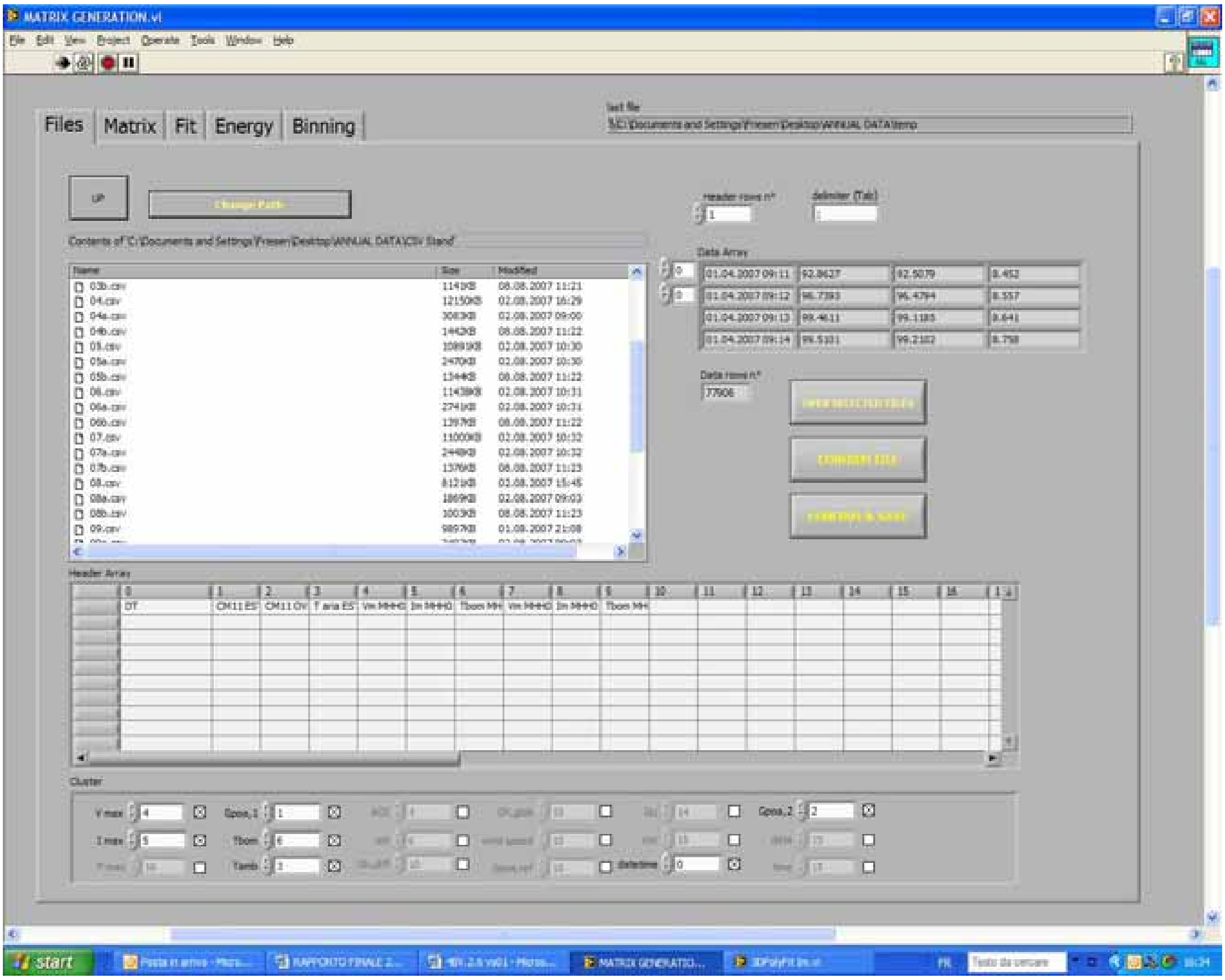


Figure 40: Main window of the new energy rating prediction software.

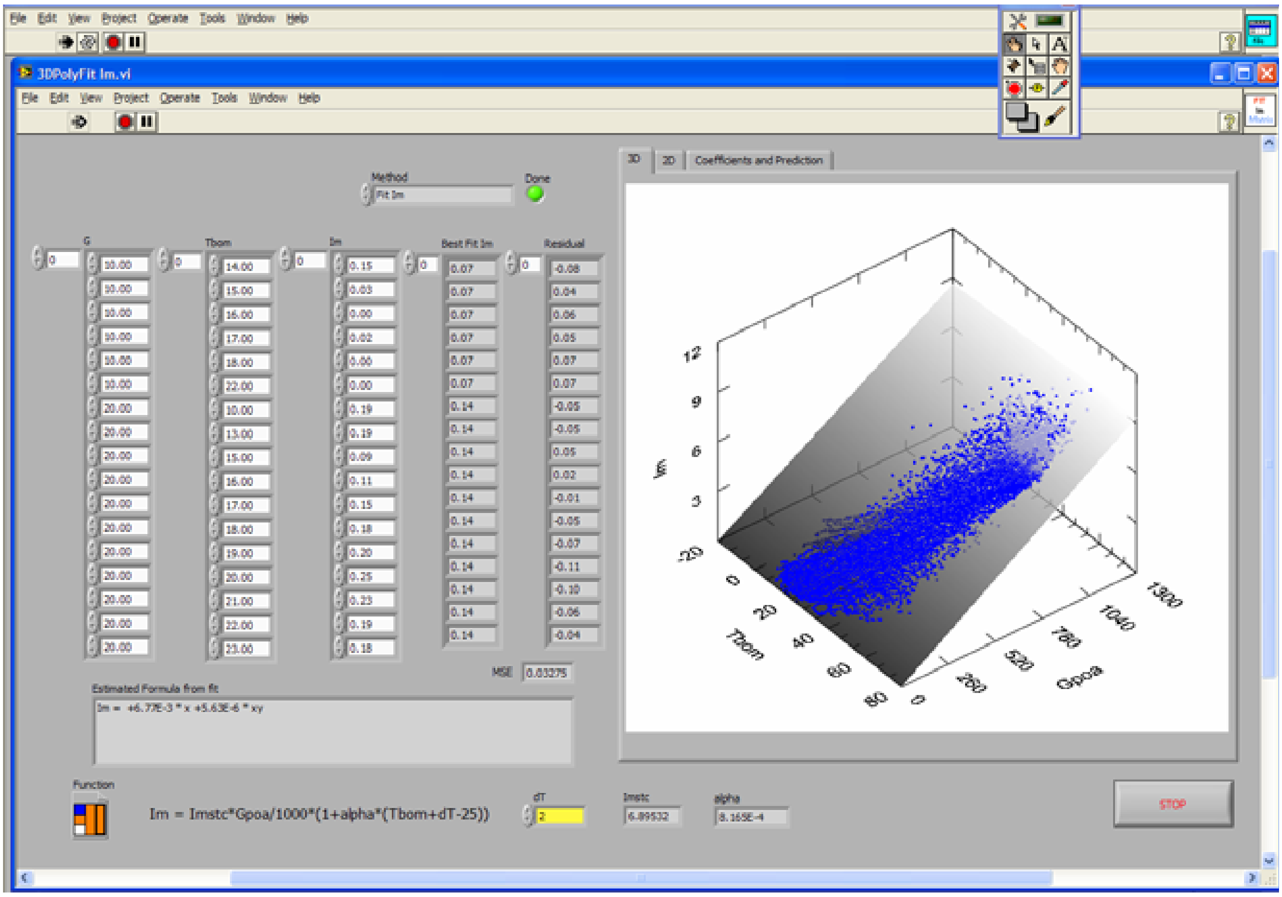


Figure 41: Sub-panel for the fit of the maximum power point current matrix.

2.7.3 Energy Rating (ER) Measurements

2.7.3.a Determination of the Power Matrix

The Power Matrix is either measured indoors (see chapter 1.12), or outdoors on the sun-tracker (see chapter 2.7) or by extracting the power matrix from the long term data of the energy rating stand.

The parameters $I_{m,stc}$, $V_{m,stc}$, α, β, C0 and C1 needed for the final power matrix are then obtained by fitting the measured maximum power point current (Im) and voltage (Vm) values to the two equations 1 and 2 by using the new software. In the case of indoor data the data are directly fitted and the ΔT value is assumed to be equal to zero, due to the thermal stability of the module. In case of outdoor data an initial binning and averaging of the raw data into irradiance bins of 10 W/m² and temperature bins of 1 °C. is made and ΔT is fixed at 2°C.

On the sun-tracker the power matrix is measured in 1 minute intervals. A maximum of 1 or 2 clear sky days are used to determine the power matrix. The matrix is created by using both irradiance measured by a pyranometer and by a c-Si reference cell. The module is either tracked or fixed on the same position of the tests stand.

2.7.3.b NOST Measurements

The NOST value, as described by equation 4, is extracted from short or long term outdoor data by plotting the module and ambient temperature difference against irradiance, and by determining the slope of the linear fit. The figure shows an example of a NOST value extracted from a set of 1 year data and the following table shows the respective NOST values of all 14 modules.

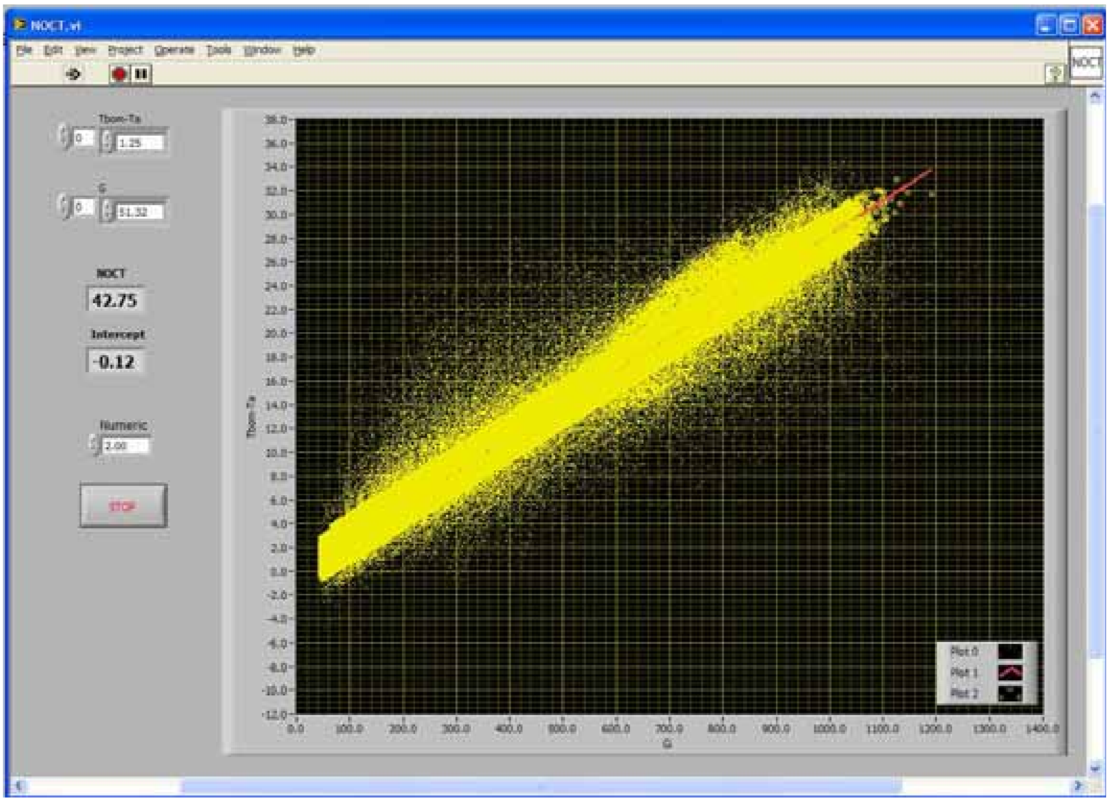


Figure 42: NOST determination.

	NOST [°C]
RWE ASE-165-GT-FT	41.9
Kyocera KC125GHT-2	41.9
Kaneka K60	41.9
IBC-215S Megaline	42.1
Suntech STP150-24	42.4
Sanyo HIP180NE1	42.7
Sunpower STM210 F	42.7
Solarwatt MHHplus220	42.8
First Solar FS-60	43.3
Miitsubishi PV-MF130EA2LF	43.4
UniSolar ES-62T	43.8
Sharp NT-175E1	43.8
BP Solar BP7180	44.3
Solar World SW165	45.1

Table 1: List of modules and NOST values in order of magnitude.

2.7.3.b Inter-comparison of different ER measurement approaches

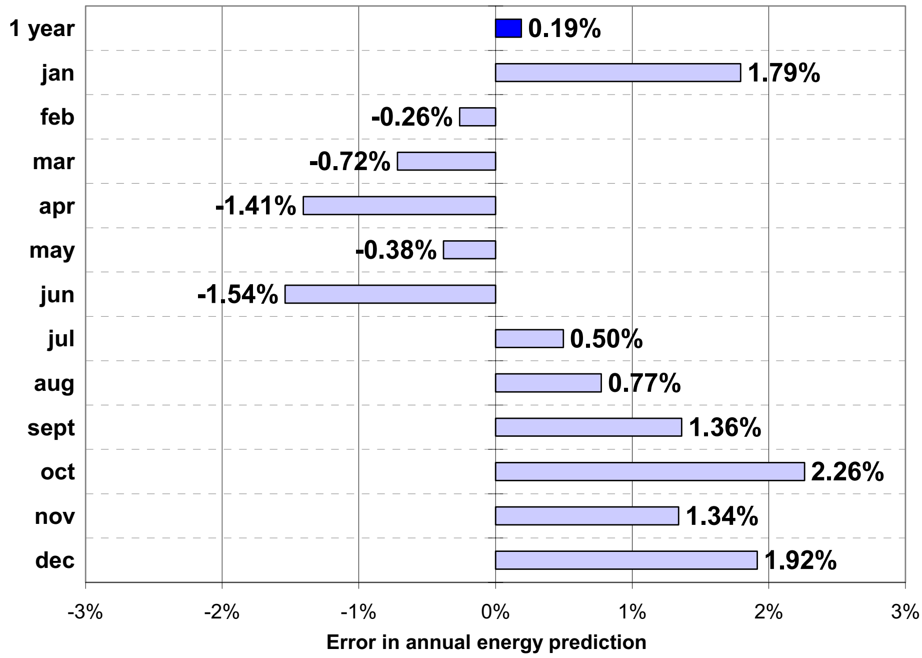


Figure 43: Error in annual energy prediction of a ASE modules obtained from simulations with a power matrix extracted from the energy rating stand (annual or monthly raw data + pyranometer irradiance).

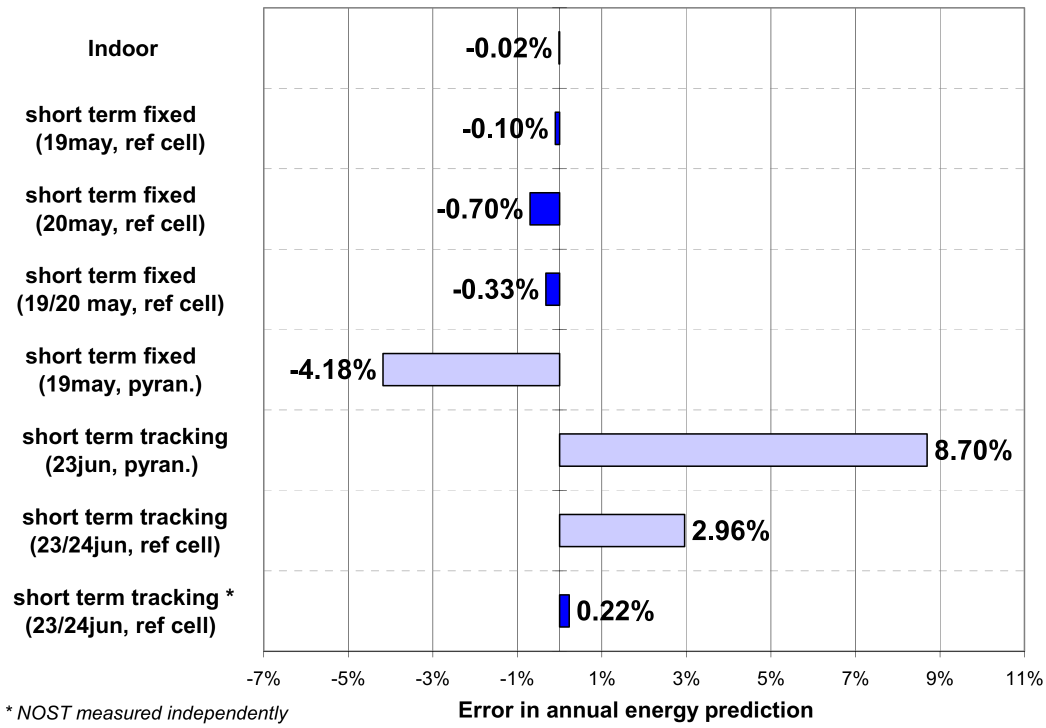


Figure 44: Error in annual energy prediction of a ASE module obtained from simulations with a power matrix extracted from different short measurement campaigns with the reference module.

Same results for KC!

2.7.4 Energy Rating Prediction Results

The ER method with the highest reproducibility and accuracy for all modules was the indoor approach. For this reason the final validation of the method was made on all modules by applying the above-defined procedure. For all test modules, except for the Kaneka modules which were still not stabilised, the error remained in the range of ±3%.

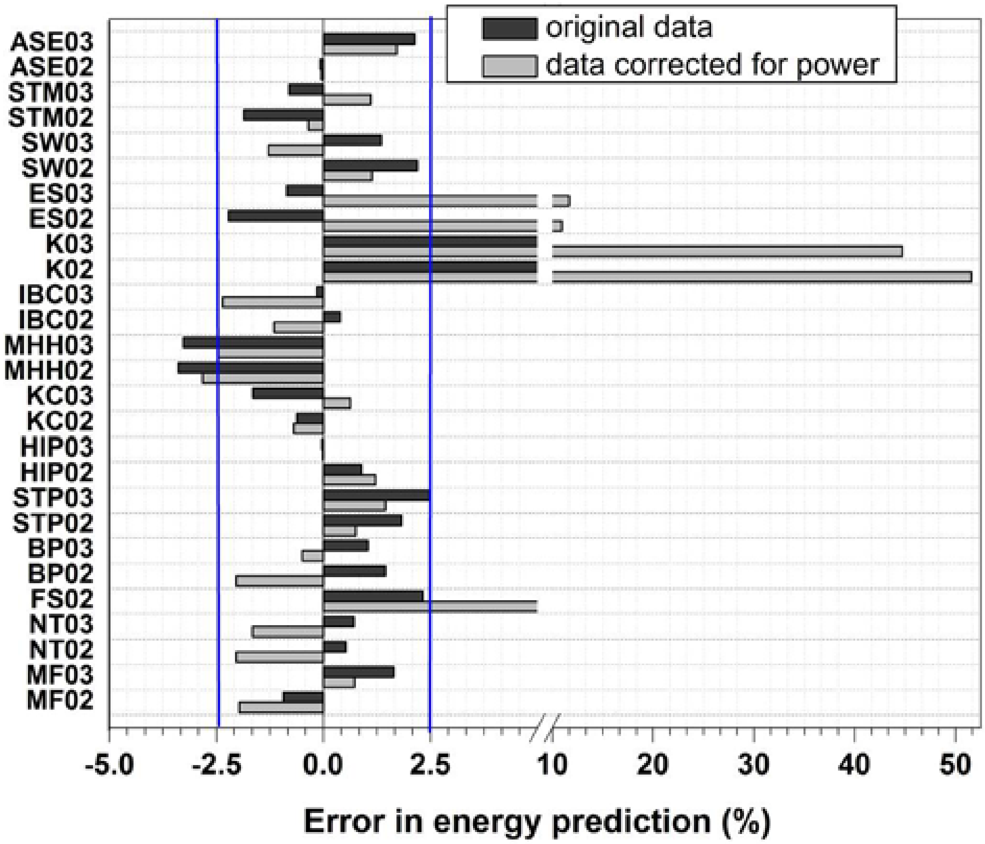


Figure 45: Error in annual energy prediction of all modules obtained with the indoor measured power matrices of the reference modules (original data). Since the stabilised power of the reference modules and the outdoor monitored modules were not identical a correction for STC power is made (data corrected for power).

	Vm	beta	Co	C1	Im	alpha
MF01	19.3	-0.0857	-0.27	-0.36	6.8	-1.83E-04
NT01	35.3	-0.1675	-2.12	-1.96	4.8	-3.73E-05
FS01	68.8	-0.171	-2.66	-1.61	0.9	3.74E-04
BP01	35.6	-0.1657	-0.21	-0.58	4.7	-5.37E-05
STP01	34.2	-0.1569	-0.31	-0.80	4.3	-2.20E-05
HIP01	36.4	-0.1321	-1.29	-0.84	5.0	2.39E-04
KC01	17.4	-0.082	-0.16	-0.33	7.1	-1.05E-04
MHH01	28.4	-0.1321	-1.96	-1.48	6.9	-3.19E-04
IBC01	29.5	-0.1278	-0.22	-0.24	7.0	-1.48E-04
K01	77.5	-0.1967	-2.64	-2.46	1.1	1.19E-03
ES01	16.7	-0.0576	0.33	-0.23	3.9	1.08E-03
SW01	35.1	-0.1588	-0.57	-1.04	4.6	-1.26E-04
STM01	39.5	-0.1809	-1.52	-1.57	5.2	-1.21E-04
ASE01	35.6	-0.1486	0.11	-0.68	4.4	-5.09E-05

Table 6: Fit parameter extracted from indoor data

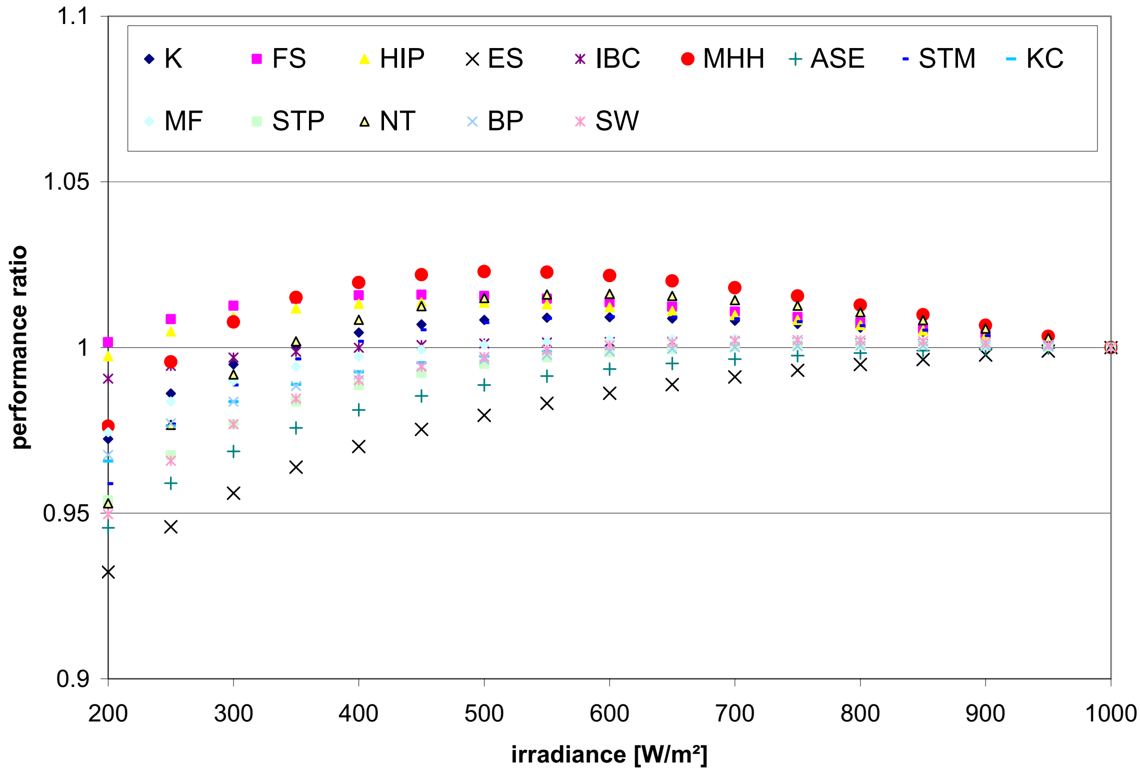


Figure 46: Performance ratio @25°C in dependence of irradiance for all modules calculated with fit parameters of Table 6**.**

A superimposition of the single indoor matrices with the respective measured outdoor matrices, not shown here, demonstrated that they are in fact very close to each other for almost all modules (±2%). This explains why the energy predictions through indoor measured power matrices leads to such good results. To further reduce the error the other effects such as spectral and angle of incidence effects to the simulations probably need to be added, but the characterisation methods have to be validated in the same way to be sure that the increase in the complexity of the module characterisation at the end does not lead to an increase in the final error. A probably more important aspect to investigate is the influence of the stability of the module. The initial degradation, the long term degradation or other degradation/recovery effects like for example the well known Staebler-Wronsky effect will be important for a good energy prediction.

It can be concluded that the differences in the indoor power matrix of single modules or alternatively a combination of the temperature coefficients and the performance ratio curves, explain already a large part of the differences under real operating conditions. A low temperature coefficient by itself does not guarantee a high energy output, a good PR over the whole range of occurring irradiances is also relevant.

2.8 Development of a new maximum power point tracker (MPPT)

The old electronic devices used for medium term photovoltaic module tests had been operating for 9 years under intense working, real environmental and meteorological conditions. In order to maintain a high reliability and to fulfil the new requirements of the PV module market and research, it was decided to develop and realize a brand new device.

New features were included in this new device for PV module testing, named “MPPT 3000”, and moreover all main parameter ranges were extended. Among these new features, there is the on-line scan of the I-V characteristic and the possibility to measure, independently from data loggers or external peripherals, the main meteorological parameters.

Since the beginning of tests appropriate equipment was developed so as to make modules work at their maximum power point (MPP) conditions and moreover to get the value of the produced energy.

Three generations of "MPPTs" have since then been developed. The first Maximum Power Point Tracker equipment for module tests had very simple functions and low ranges of current and voltage input parameters according to module range at this time. The maximum input current was 2 A, the max voltage was 25 V and the max connectable power could not exceed 50 W. All electronics were based on analog circuits and had an electromechanical energy counter. These devices had actually been developed for G4000 and a-Si but also adapted for stands tests. They were put into operation for the first time in 1989.

The second generation MPPT had a new electronics concept, extended ranges and analog non-isolated output for remote data logging. The maximum input current had been raised up to 10 A , the max voltage up to 100V and the max connectable power up to 150 W. The electronic control part was made digital by using a PIC MicroChip microcontroller. That allowed us to include further useful features such as a power PWM control, a digital energy counter and a digital display. The power part was based on a buck-boost power DC/DC converter working at about 80 kHz. The Im and Vm values were also set as analog output to be used for example by remote data loggers. These second generation MPPT's were basically developed and adapted for the medium-term outdoor module tests and were put into full operation in 1996.

The MPPT 3000 is a multifunction testing device for photovoltaic modules. A photovoltaic module, when connected to the MPPT 3000, is set to work in an MPP tracking mode. The MPPT 3000 also allows a customized I-V Tracer function. It is possible to connect RTD temperature sensors, pyranometers or other external sensors. Interaction with the MPPT is possible directly using its LCD and buttons or through a simple graphical user interface. The PV module energy is dissipated using an external resistor load with heat sink that must be always connected.

- accurate MPP tracking: maximum 0.5 % error on P_{MPP} tracking
- wide voltage and current scalable ranges: up to 200V / 20A / max 250W
- optoisolated analog auxiliary outputs in order to measure, using an external measurement system, the PV module working condition and the auxiliary sensors
- built-in independent data logging: internal data storage allowing the use of the MPPT as datalogger
- transportable, compact, wide operating ambient temperature range (from -20°C to +40 °C)
- galvanically isolated RS-485 interface: dialog between PC master and one or more MPPTs
- I-V Tracer : use of the MPPT3000 as settable IV Tracer
- simultaneous Im and Vm measurement
- non isolated analog output (optional)
- run-time selectable ranges (automatic or manual)
- possibility to measure, thanks to an in-built micro-converter and independently from data loggers or external peripherals, the main meteorological parameters (T, G, …) by means of auxiliary sensors.
- user friendly management software
- IP 20 case

Figure 47: MPPT 3000, a multifunction device for testing photovoltaic modules

Typical applications:

This electrical equipment is extremely useful for anyone who needs to accurately test photovoltaic modules such as school laboratories, module manufacturers or module providers, testing laboratories and so on.

Typical applications are:

- sc-Si, mc-Si, a-Si, thin-film accurate module testing
- I-V characterization
- Energy production test and comparison at outdoor real conditions
- Meteorological measurements during module test
- Comparison of an existing PV plant behaviour with respect to a reference PV module under test using the MPPT3000.

2.8.1 Development of the new MPPT3000

The power circuit is consists a Cûk-coupled inductor DC-DC converter working at a 78 kHz PWM command signal. The configuration and features of the elements involved in a Cûk converter have the advantage of strongly reducing high current peaks through capacitors and also reducing dynamics currents through inductors. All this leads to a strong decrease in electrical disturbance and should increase element lifetime duration. Moreover, to reduce power losses the latest generation of MOS-FETs with very low R_{DS}(on) has been used. Particular attention has been given to the precision of Im and Vm measurement and to the accuracy of the MPP search.

The MPPT is managed by a control board containing a DSP (Digital Signal Processor) that interacts with all other main circuits parts. It converts the measured signals, elaborates them, gives back appropriate PWM command signals, and communicates with other components and peripherals. The control board software update is easy because the DSP program is stored on an extractable PLCC flash memory and the micro-converter is programmable in circuit. The MPPT itself can act as a little data logger thanks to the presence of on board data flash memory. By means of a micro-converter it is possible to measure and manage, independently from external data loggers or peripherals, the main meteorological parameters (T, G, …) and to store their sampled data. All analog auxiliary output has been optoisolated.

An interesting new feature is the possibility to communicate with a master terminal by means of an integrated RS-485 port. Also the RS-485 port is galvanically isolated to protect the internal MPPT boards from external disturbances or over-voltages. Another interesting new feature is the auto-range measuring system that allows better accuracy and precision in the measures to be obtained.

A simple user interface is made by means of a 2x16 characters display, two push buttons and a scroll button for fast selection. The display is useful for showing values and parameters while selection buttons are useful for settings especially when the MPPT is not RS-485 connected to an external master terminal. The MPPTs can be used as stand alone equipment. However is better to connect them to a PC master, which, through a dedicated software, permits use of all the features in a more comfortable user friendly way.

This new MPPT 3000 comes in a nice and solid anodised aluminium case in IP23 protection grade

The first MPPT 3000's were put into operation in March 2006

This new electronic device is composed of three main different parts assembled together :

- power part and auxiliary outputs
- DSP-control board, communication and auxiliary inputs
- user interface (display and command buttons).

For easier understanding the three parts listed above will be hereafter named :

- POWER Print
- DSP Print
- Display Print

It would have been nice to feed the "measured" energy into the main electrical grid but we estimated that this task was too hard and expensive, and also not strictly what the MPPT 3000 is intended for.

Most electronic components are widely over-dimensioned. This permits the MPPT 3000 to be electronically very solid and reliable. For example, losing little resolution in measurement accuracy, we tried the MPPT 3000 in a 920 W power test.

Technical specifications:

General		
MPPT power supply	-	+24VDC / 8 W +/-10%
Operating ambient temperature	°C	from -20 to +40
Case protection grade	-	IP20
Load output resistor	Ω	from 18 to 47 (**Load must be always connected !**)
Dimensions	mm	194 x 221 x 162 without cableglands nor cables
Weight	kg	5
Photovoltaic module values		
P_{MAX} in	W	250 (continuous);
V_{MAX} @ 250W	V	150
$I_{SC\ MAX}$	A	5 / 10 / 20 (depends on the model)
$V_{m\ MIN}$	V	5
Measurements		
Voltage measurement ranges	V	200 / 100 / 50 / 25
Current measurement ranges	A	20A Model: 20 / 10 / 5 /2.5 10A Model: 10 / 5 / 2.5 /1.25 5A Model: 5 / 2.5 / 1.25 / 0.625
Accuracy	%	0.2
IV Tracer		
Scan rate	min	2 / 3 / 4 / 5 / 6
Points number	-	128 / 256 / 512
Sweep Time	s	1.0 to 3.0
IV tracing ad hoc available using the MPPT manager software.		
MPP Tracker		
Types	-	Full I-V curve search Fast MPP fine adjust
Control	-	Power and voltage
Customizable MPP adjust and Vm adjust available.		
Auxiliary opto-isolated analog outputs		
4 analog outputs (Vm, Im, 2 ext. param.)	VDC	from 0 to 10 (proportional to the default represented input ranges)
Short circuit protected outputs. High impedance load required.		
Auxiliary analog measurement inputs		
Auxiliary input 1		only RTD
Auxiliary input 2		RTD, voltage (autorange from 0..10mV to 0..1V)
Auxiliary input 3		RTD, voltage (autorange from 0..10mV to 0..1V)
Galvanically isolated RS-485 port		
Bit rate	bps	115200
Data length	bit	8
Stop bit	bit	1
Parity	-	Even
Flow control	-	None

Performance

MPP Tracking		
Static MPP tracking efficiency	%	> 99.5
Dynamic MPP tracking efficiency	%	> 98.0
IV Tracer		
IV tracing difference	%	±0.2
DC / DC conversion		
Typ. Efficiency (Pout/Pin)	%	90.0

This performance test was carried out at specific conditions, please see the specific data-book for details (see annex).

The supply and demand of photovoltaic modules is going more and more in the direction of bigger modules and that means, apart from bigger volume and weight, higher currents and voltages. Modules can easily reach 10A at Im or 50V at Vm for sc-mc-Si types and can also easily reach 90V at Vm for thin-film types.

Many modules can moreover reach nominal power rates up to 250 - 300W. All these parameters indicated to us that the second generation MPPT was no longer suitable for PV module testing. Although the second generation MPPT was sufficiently accurate it was time to also establish new accuracy rates all over the entire range of measures.

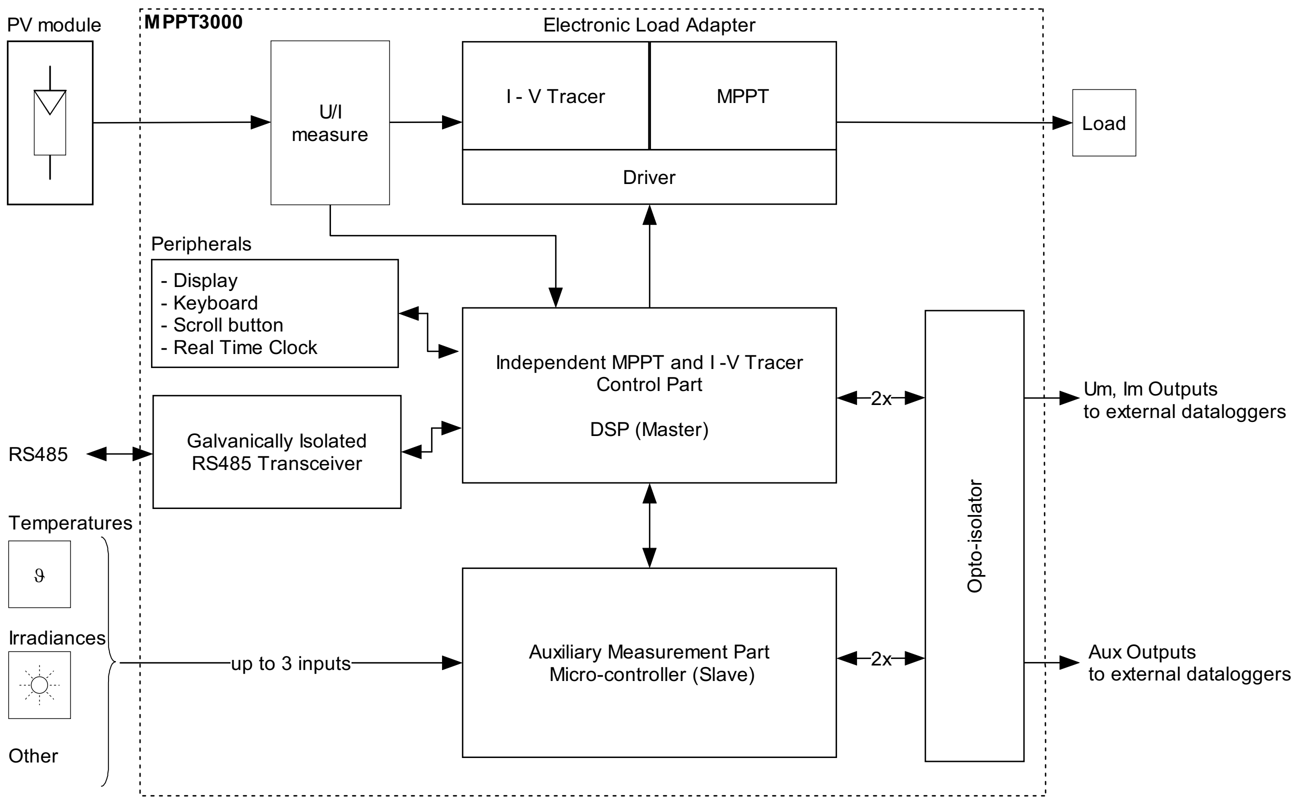


Figure 48: MPPT3000 Block diagram

Figure 48 shows the block diagram where the development started from. The device is composed of three main parts: the power board, the control board and the user interface board.

2.8.2 Power DC/DC converter part

The power circuit is consists of a modified Cûk-coupled inductor DC-DC converter working at a 78 kHz PWM command signal. The configuration and features of the elements involved in a Cûk converter have the advantage of strongly reducing high current peaks through capacitors and also to reducing dynamics currents through inductors. All this leads to a strong decrease in electrical disturbances and should increase element lifetime duration.

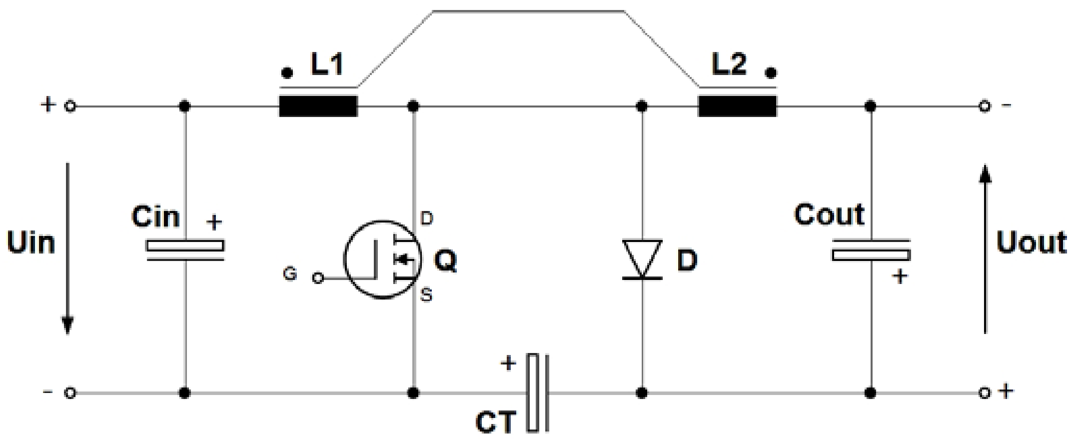


Figure 49: Modified Cûk converter, basic schematic

Measuring part:

Particular attention has been given to the precision of Im and Vm measurement. Different prototypes have been constructed and many tests have been carried out to get the best result possible. Moreover, different models of specific differential operational amplifiers have been interchanged and tested.

Measuring the current : a voltage drop on a high precision shunt resistor is pre-amplified by means of a differential instrumentation amplifier, then, depending on the selected current range, again amplified by means of a precision programmable gain amplifier.

The amplified output value will be then converted into a digital value through a 14 bit ADC converter of the DSP processor.

I-V tracer part

The I-V tracer drive signal comes from the DSP in a PWM format and then integrated and filtered to obtain a continuous drive voltage. By means of a power op amp integrator circuit, the voltage of the module Um is forced to become the same as the drive voltage. The op amp output signal directly drives a very low R_{DS}(on) power MOS-FET from short circuit to open circuit state.

2.8.3 Control Board

The main part of the control board is the processor, therefore it's important that it has all the features needed. To establish which one to use, a list of required points and features was redacted giving each point a weight in terms of importance. Particular attention was given to the MPP tracking accuracy. The following chart shows the maximum tracking error vs. voltage and current using a 10 bit PWM to drive the power part.

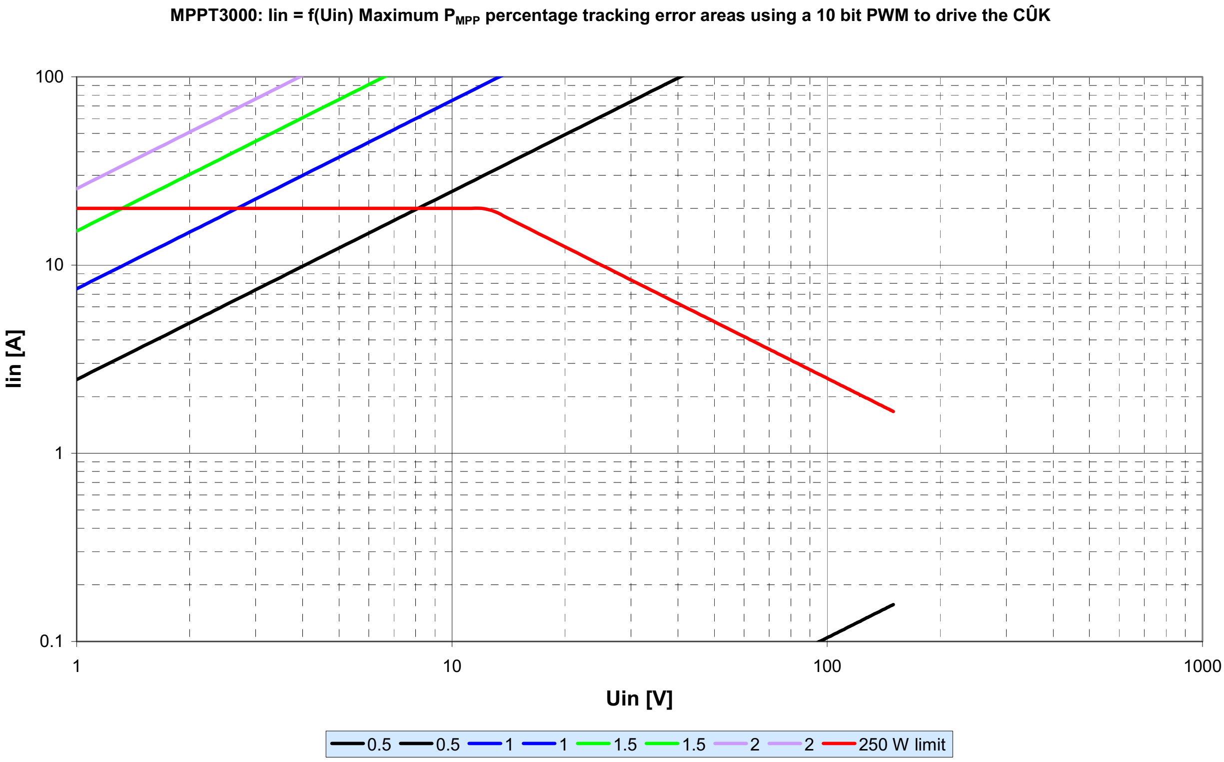


Figure 50: Iin = f(Uin) Maximum MPP percentage tracking error areas using a 10 bit PWM to drive the CÛK

It can be seen that the 0.5% MPP tracking static error limit is respected in almost every condition. An accuracy problem can occur only in extreme conditions: under 10 V with high currents and over 100 V with very low currents. In Accordance with this important requirement and other secondary needs, we decided what DSP to use. We choose the DSP after an accurate analysis of all the processors available from several manufacturers and the chosen one fits our needs best.

We bought an evaluation board that allowed us to develop the first DSP programs and helped us to project the first control board custom PCB. After that some custom hand made little boards were developed to be connected to this evaluation board in order to have a first whole control board prototype. We used also an evaluation board to develop the auxiliary measurement part.

Thanks to this multi-custom made board prototype it would be possible to realize the first one-board prototypes.

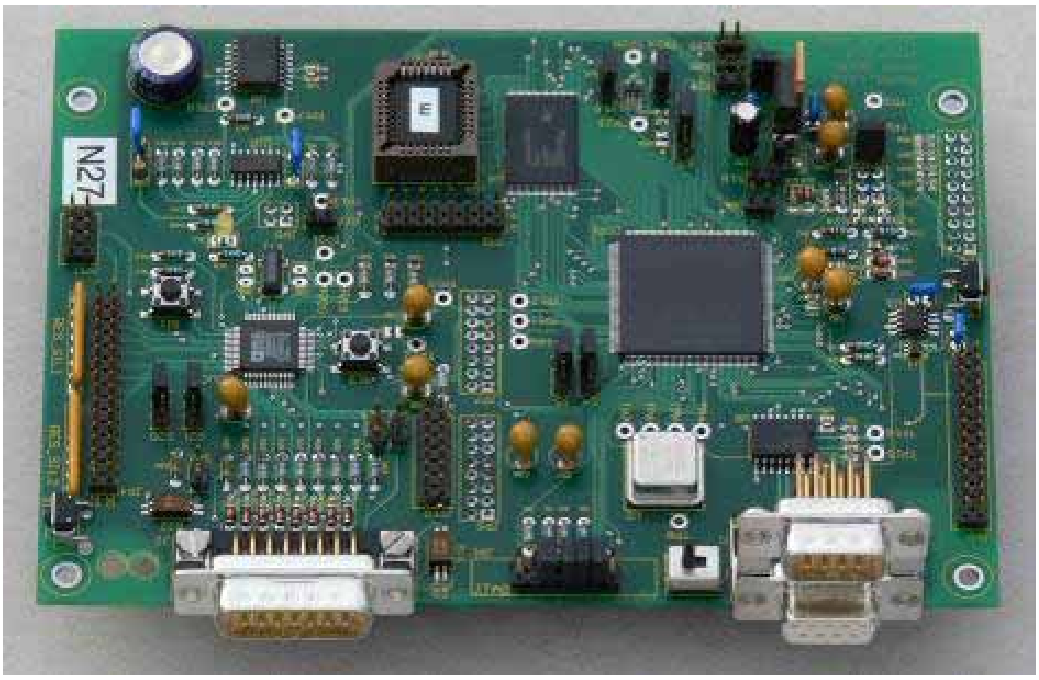


Figure 51: Control PCB, final version

The evaluation board is still used daily to develop and debug the new processor softwares and to write the flash memories that contain the most recent program version that runs on our MPPTs. Also the micro-converter evaluation board is still used to improve the auxiliary measure part software.

The next subchapters explain the main parts of this board better.

Processors:

As said, two processors are used in this board: a main DSP and an auxiliary micro-controller.

The first is a 16 bit, fixed-point, 160 MHz core DSP. It can be programmed in assembly or in C language using the development tool provided by the DSP manufacturer. The program language chosen is C except few little crucial parts where assembly is used.

The second is a 8 bit, 6 MHz micro-controller, also programmed in C for higher flexibility (SDCC: a simple but powerful freeware open source C compiler).

Galvanically isolated RS485 port:

This board has a galvanically isolated RS485 port in order to communicate with a master terminal. The RS485 standard was chosen because it is cheap, robust (suitable for outdoor use), supports long distances (up to 1200 meters), half-duplex and multi-point. The default bitrate in our MPPT3000 is 115200 bps.

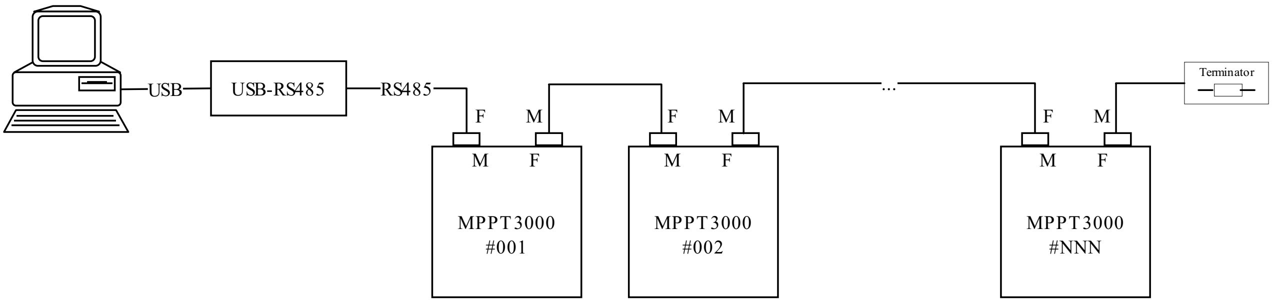


Figure 52: RS485 Network

To connect a master terminal to the RS485 network any kind of adapter can be used as long as the technical specifications are respected. A terminator resistor is required in order to minimize reflections of the signal. The terminal is a master, the MPPTs are slaves; that means that an MPPT answers only if interrogated by the master. A specific software we developed permits easy management of the MPPT network.

JTAG port

The JTAG port permits to connection of an emulator to the DSP. That's very useful during the development but the user doesn't need to access this port; that's the reason why it is not accessible from the outside.

Real time clock (RTC)

The real time clock is an integrated circuit chip that keeps track of the current date and time even when the MPPT is turned off. A backup super-capacitor provides power supply to this chip when the MPPT is not powered. The real time clock can run several days in this condition. The specific Labview software was developed to permit the synchronization of the MPPT RTC with the master terminal clock. The real time clock has a very precise square wave function and two alarms used to synchronize events inside the DSP.

Flash memories

The MPPT has two flash memories: an extractable PLCC to store the program and an SMD to store data like the calibration values, energy production history and so on.

Simultaneous current and voltage measurement

The DSP ADC has 4 pairs of analog inputs. By means of two sample&holds two measures are possible simultaneously. Thus PV module current and tension are simultaneously measured. The DSP ADC is a 14 bit pipeline flash ADC working at 20 MHz permitting the conversion of all 8 channels in less than 800 ns.

Main PWMs

Two main PWMs drive the power board. The first one is used to drive the DC-DC converter in order to move the point where it works. The second one is used to drive the IV-Tracer part in order to measure the PV module IV curve. These PWMs have a 10 bit resolution and they work at 78 kHz. More resolution would be possible provided that a lower frequency is selected. 10 bit resolution at 78 kHz is the best compromise in order to have enough accuracy and to limit the physical dimension of the power part inductors.

Auxiliary DSP PWMs

Two auxiliary PWMs are available. These auxiliary PWMs vary their duty cycle in order to represent proportionally the measured PV module voltage and current, in other words to represent the point where the PV module is working. These PWMs are later integrated by the power board obtaining a continuous voltage directly proportional to the measured PV module voltage and current. These outputs are opto-isolated.

Serial peripheral interface (SPI)

The DSP and the micro-converter are independent. This assures maximum flexibility to the control board. A processor doesn't need the presence of the other one to work. Despite this a communication between them is available through the serial peripheral interface.

Auxiliary measure inputs

The auxiliary measure part, managed by the micro-converter, has three analog inputs where it is possible to connect several sensor types.

- auxiliary input 1: only an RTD sensor can be connected
- auxiliary input 2: RTD, pyranometer, …
- auxiliary input 3: RTD, pyranometer, …

When using one or more RTDs, the micro-converter itself provides the excitation current and uses a 4-wire measurement system obtaining a very high accuracy. The auxiliary measure part flexibility is evident. Just bear in mind that a couple of jumpers and switches have to be changed inside on the control board in order to adapt the measure circuit to the external sensors as well as a few micro-converter software settings.

Internal temperature sensor

An internal temperature sensor is available permitting the monitoring of the MPPT internal temperature with an accuracy of ±2 °C from -25 °C to 100 °C. This feature can be used to avoid exceeding the operating temperature limits.

Auxiliary micro-converter PWMs

The micro-converter too has two auxiliary PWM outputs to represent some of the measured inputs. Like the other auxiliary PWM outputs, these PWMs are later integrated by the power board obtaining a continuous voltage and are opto-isolated.

2.8.4 MPPT and Stands

Every tested module is connected to an appropriate MPPT 3000 device. The MPPTs are placed in a box with the 24V power supply and signal connectors. The modules are connected as shown in the following figure:

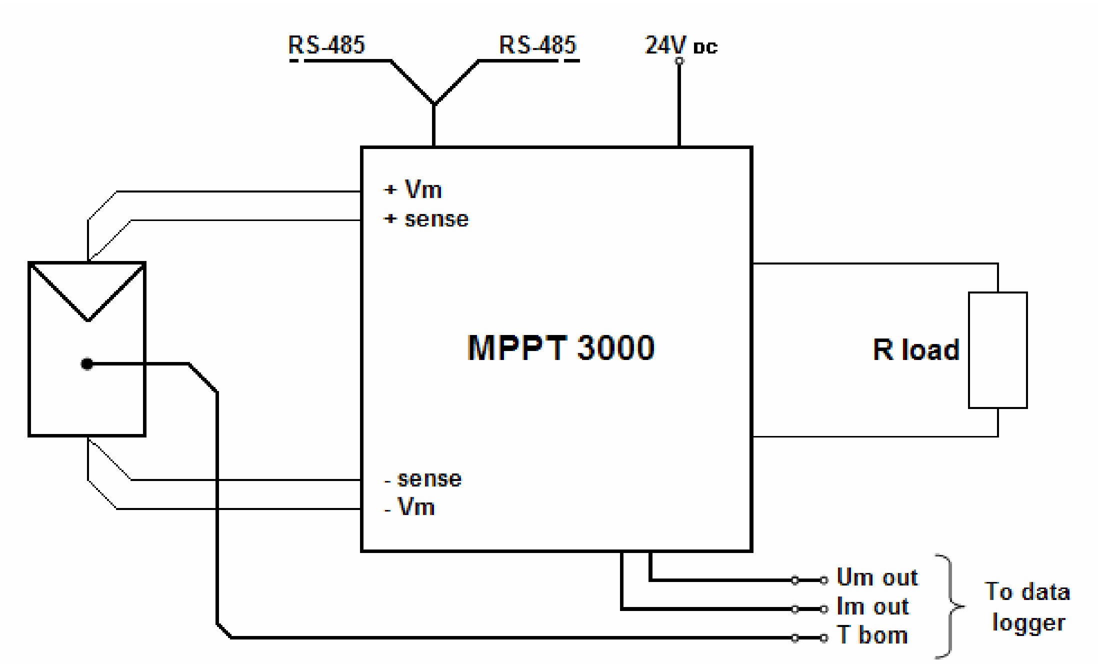


Figure 53: Basic MPPT3000 connections

Figure 54: Stands boxes with MPPTs during installation

Figure 55: Loads resistance and heat sink

2.8.5 Conclusions

The MPPT3000 works perfectly. Our main goal was to have an electrical equipment that tracks the maximum power point well and that gives accurate information about that point: we have proved that this main target has been reached. Our secondary goal was to have an electrical equipment with new features that helps the user test a photovoltaic module: this target has also been reached.

A second test proves that the static MPP tracking accuracy respects the required limits. Using manual range selection, from 100% to 10% of default range, the difference between the tracked MPP and the defined MPP is less than 0.5%. Using the auto-range the accuracy will rise.

The dynamic MPP efficiency is 98.40 %, thus very high. That means that the MPPT answers quickly each time the external conditions change, finding the new MPP.

The IV Tracer test shows that the measure of an IV curve has a difference between our curve and the reference curve lower than ±0.2% except when the current is below 20% of the current range; but around the MPP the difference is still less than ±0.2%.

References:

H. Haeberlin and L. Borgna: “A new Approach for Semi-Automated Measurement of PV Inverters, especially MPP Tracking Efficiency, using a Linear PV Array Simulator with High Stability”.

2.9 Measurement Methods and Data Acquisition Systems

Data acquisition and analysis:

The acquisition system has been improved, with a second data storage. In parallel to the old text file storage, a database has been added. A MySQL is utilized, because it is has a better performance than a simple Microsoft Access database, is free of charge, and widely used. Better file management, data accessibility and processing speed are the desired aims.

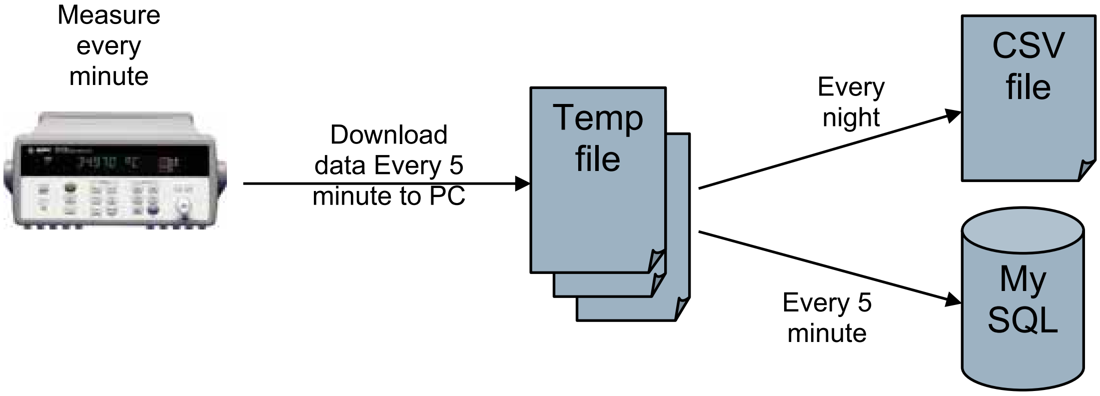


Figure 56: data acquisition file management

Every five minutes, data are downloaded from the dataloggers, and stored in CSV files. At the same time, parts of this data (weather and test-stand) are stored in a MySQL database. This database allows access to the data from any computer of the LAN. Error management and data control has been improved. Various programmes available allow plotting, comparison and testing of PV module values.

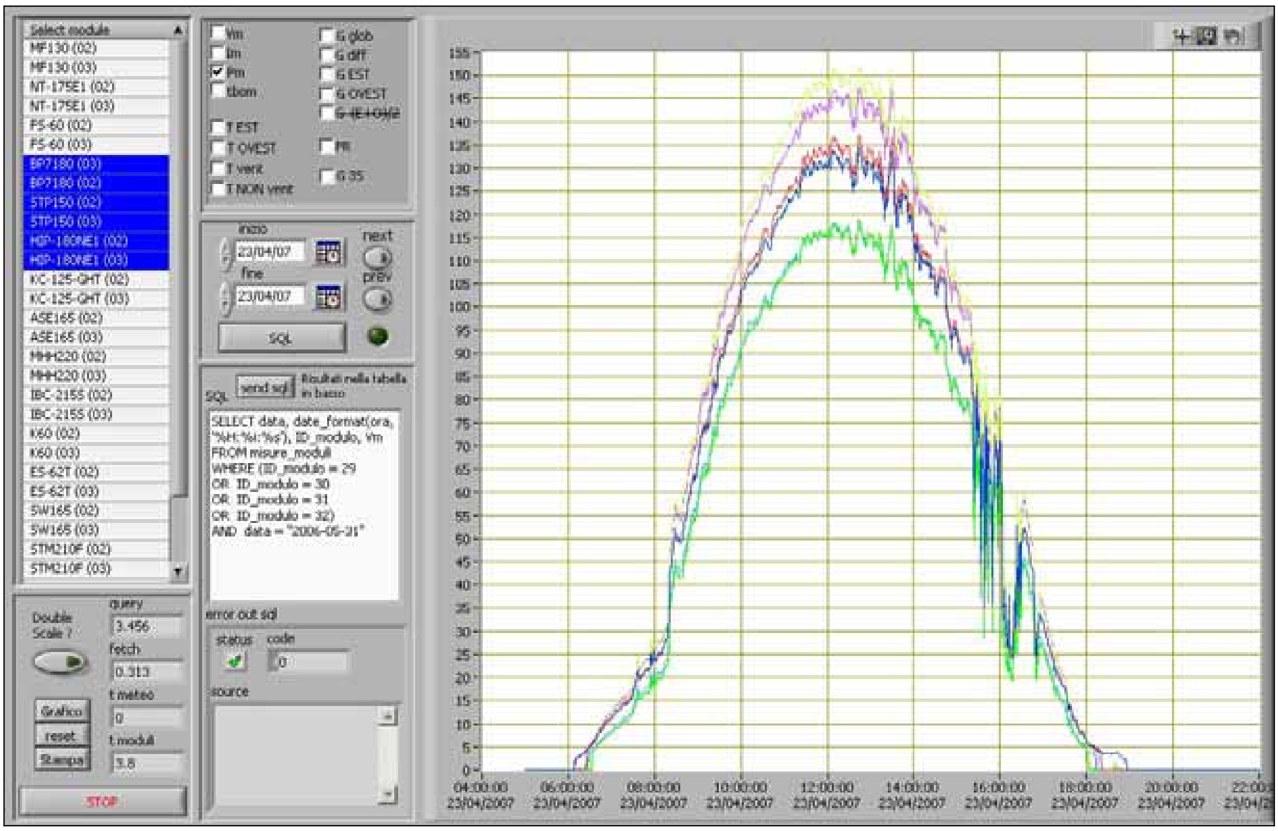


Figure 57: Analysis Programme Screen

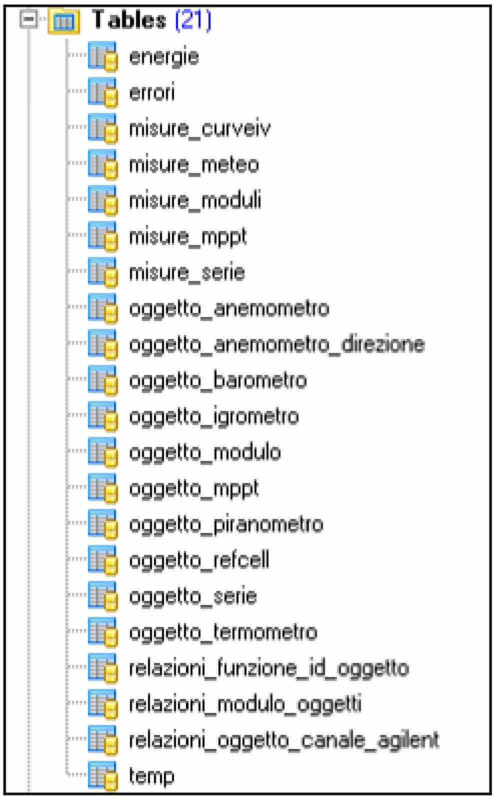


Figure 58: Table structure of database based on MySQL

The database is composed of many tables: one table for each type of object (module, hygrometer …), where characteristics, position and other information about the object are stored. Three tables are utilized for the relationship between objects (e.g.: relationship between datalogger channel and measure objects).

Measured data are stored in other tables, one for each kind of measure (module, weather, daily-energy, IV-curve). Each row contains date and time information, the identification of the object, and the measured values.

The last table contains the daily error information. In this table, are stored problems that are automatically checked at the end of the day (e.g.: a temperature outside a definite range, or an overgrown difference between energy measured by the MPPT3K, and that measured integrating the datalogger values …)

The online weather station utilizes the database too: meteorology data are published every five minutes on the website (current values, and daily graphs) (see Figure 59).

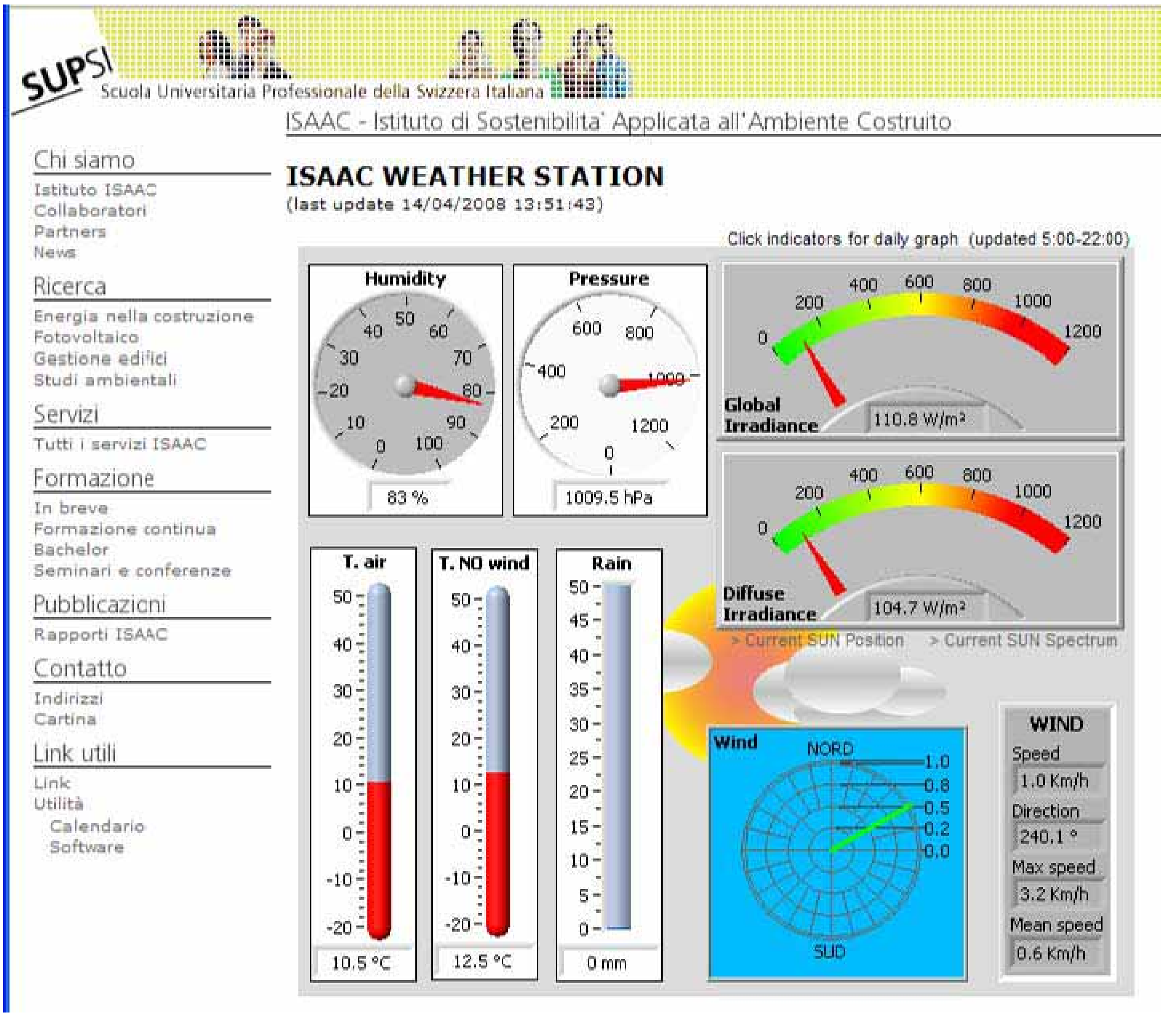


Figure 59: Information about the local weather and access to daily on-line data from the My_SQL data base

2.10 Outdoor spectroradiometer

The outdoor spectroradiometer, composed of a receptor (optic fiber), a sensor of 1024 photodiodes and a PC card has been reinstalled with a new PC and recalibrated. The sensor is fixed outside, -7 ° south, 45° tilt angle. The measured solar spectrum range is from 250nm to 1100nm.

With the spectroradiometer it is possible to monitor and analyse module characteristics with respect to solar spectrum, as well as irradiance sensors, and this for different technologies.

By measuring the solar spectrum in real time and by knowing the spectral response of the tested module and the reference device measuring irradiance (pyranometer, reference cell), it is possible to calculate the spectral mismatch factor M (see also 1.11), which allows characterisation of the module at Standard Test Conditions (1000 W/m^2, AM 1.5 and 25 °C).

Three main modes of operation have been implemented: *single measure*, *multi measure* and *measure in continuous mode*. The last one is the most used and allows selection of a desired period of the day and monitoring of the solar spectrum each day, during the same period at the same measurement regularity. At the moment the spectroradiometer is working in a continuous mode, measuring solar spectrum each minute and each day from 5am to 10pm.

3 SHORT TERM OUTDOOR MEASUREMENTS

3.1 Introduction

Currently the ISAAC laboratory operates two outdoor measurement systems: one large test stand dedicated to energy rating measurements of up to 36 different modules, described within the previous chapter, and a small sun-tracker system for multi-purpose measurements.

Whereas the main aim of the energy rating stand is to compare the energy yield of different modules and technologies over at least 1 year and to verify their electrical stability over time, the main aim of the sun-tracker system is to have a fast and flexible characterisation method, which allows the execution of a large number of different electrical performance tests in a short time and at different orientations.

	Sun-tracker System	**Energy Rating Stand**
Test duration	short term (flexible)	long term (15-30 months)
Load characteristics – between IV meas.	near to MPP; Voc; Isc Note: no active tracking	high precision MPPT
Module Orientation	- direct or indirect tracking - fixed user-defined position	-7° south, 45 ° inclination
Number of modules simult. under test	single module could be increased to two	14-18 module types two of each type
IV measurement test characteristics	different types and speeds of IV meas. possible	default settings: Isc → Voc (1 sec)

Table 7: Main differences between the two ISAAC outdoor test facilities

3.2 Outdoor I-V Measurement Facility - Sun-tracker

3.2.1 The Hardware (IV-Tracer, Environmental Sensors and Sun-tracker)

The Sun-tracker outdoor test facility consists of (1) an in-house developed electronic MOS load for the measurement of the IV-curves, (2) a DAQ PCI-MIO 16E-4 National Instrument acquisition card for signal generation and data acquisition, (3) an EGIS solar tracker (AZ360, EL68) for the control of the module orientation and (4) different irradiance, temperature and wind sensors for the monitoring of the environmental conditions. Currently the test stand allows measurement of only one module at a time, but it is planned to up-scale the system to two modules.

Figure 60 shows a picture of the facility and Figure 61 shows the Block diagram of the whole system.

Figure 60: The sun-tracker outdoor test facility of ISAAC-TISO at the SUPSI of Lugano (CH)

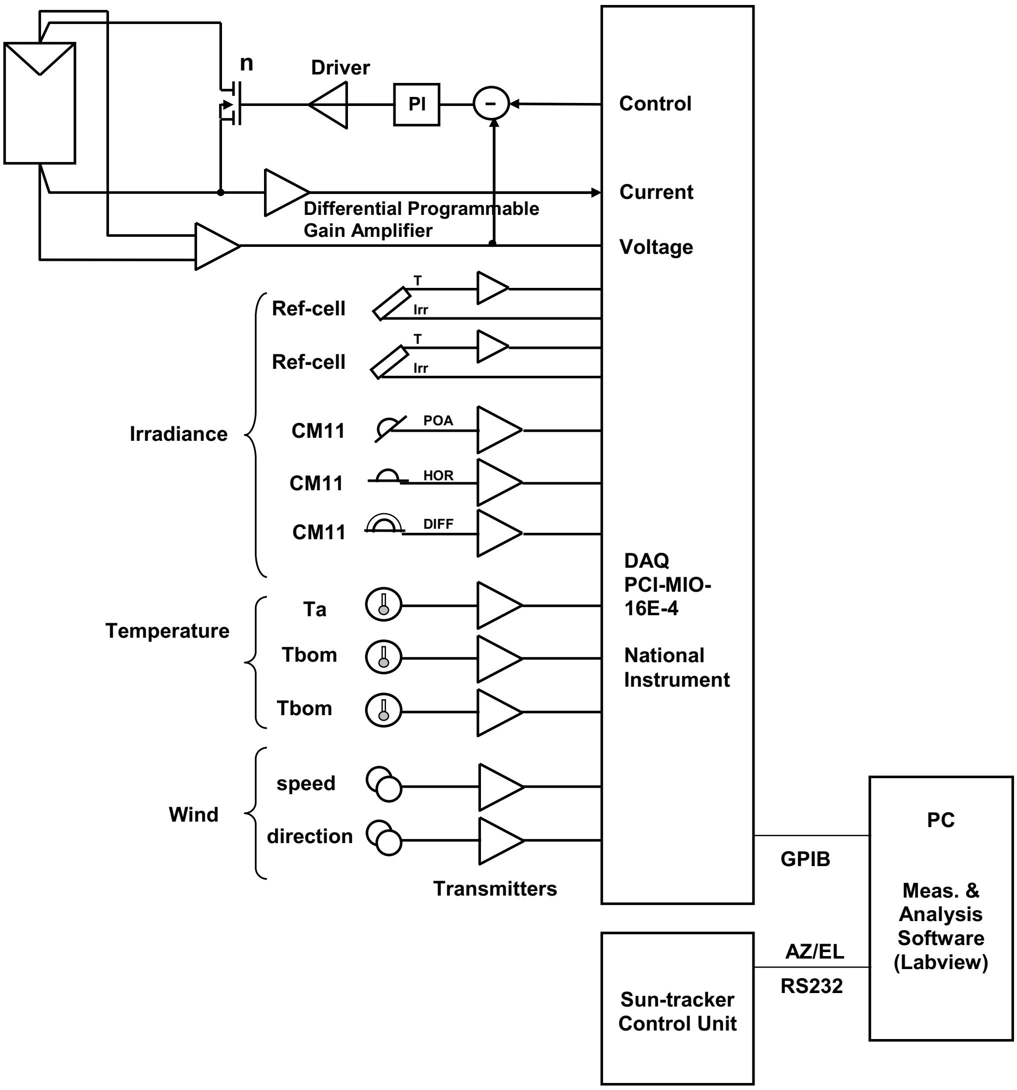


Figure 61: Block-diagram of the Sun-tracker system.

During the project, the existing electronic load and data acquisition unit of the sun-tracker system was entirely replaced. In this way a higher flexibility and better control of the applied bias voltage and sweep speed on the module could be achieved. The new configuration allows measurement of modules of up to 250W (Voc max: 150V, Isc max: 20A). To always guarantee the best resolution, the voltage and current ranges are controlled automatically. One of the new system features consists in the possibility of applying for example a triangle pulse to the module of the same sweep speed (2ms) and quality of the solar simulator I-V measurement system. This allows study of measurement artefacts caused by PV modules with high cell capacitance (see chapter).

For the measurement of in-plane irradiance the sun-tracker is equipped by default with two sensors, a Kipp & Zonen CM11 pyranometer and a crystalline silicon reference sensor (ESTI sensor). A third irradiance sensor can be added when required. The horizontal irradiance (CM11), diffuse irradiance (CM11 with shadow ring), ambient temperature, wind speed and direction, humidity and air pressure are measured on a separated meteo-pole, which is used as well for the energy rating stand. The module temperature is measured with a PT100 which is attached on the back of the module by means of an aluminium tape. The environmental conditions are measured immediately before and after the I-V measurement and the average of the two measurements is stored.

The EGIS sun-tracker is controlled via a RS232 serial connection, which allows both placing of the module in a user-defined position and tracking of the sun (direct or indirect tracking mode). The tracking uncertainty is around ±1°. The Sun-tracker elevation and azimuth values together with the local time and geographical coordinates are used to calculate the angle of incidence (AOI) and the air mass factor (AM).

3.2.2 The Software (Measurement and Data Analysis)

The measurements on the Sun-tracker are controlled via an in-house developed Labview program which is used to execute and store the I-V measurements, as well as to process, visualise and analyse the data.

The measurements executable with the new program are:

1. I-V measurement with the possibility to correct automatically to STC (see chapter).
2. I-V measurements in short intervals (minimum 5sec) for the determination of the module temperature coefficients (see chapter).
3. I-V measurements in regular intervals (default 60sec) and over longer periods (some days-weeks) for the determination of the performance matrix (see chapter).
4. I-V-measurements at different sweep speeds for the investigation of capacitive effects (see chapter).
5. Simultaneous measurement of different irradiance and temperature sensors for calibration purposes.

Figure 62 shows a view of the program. When starting the program the user is first asked to create a new module file (dev file) or to select an already existing file. This file contains all the information about the module to be tested such as: ID code, serial number, cells in series and parallel, cell and module area, data sheet values and eventual indoor measured IV parameter and temperature coefficients. The program is divided into 5 sub-panels: (1) Sun-tracker, (2) input channels, (3) electronic load, (4) single I-V and (5) continuous IV. The following paragraph lists the features of these sub-panels.

Sun-tracker (configuration of module orientation)
- control of the sun-tracker via software with 4 different options: 1. solar tracking - AOI=0°, 2. automatic search of the optimum position (AOI=0°) but without tracking the sun, 3. fixed position at AZ= -7° and EL=45° (same as energy rating test stand) and 4. user defined position (AZ,EL).
- calculation of the sun and module azimuth and elevation coordinates (AZ,EL), the angle of incidence (AOI), the incidence angle modifier (IAM) and the instantaneous air mass factor (AM).

Input channels (configuration of irradiance sensors and measurement channels)
- irradiance sensor configuration (pyranometers, reference cells)
- input channel configuration (name, type, range, offset & calibration factors)
- selection of module current and voltage ranges (I: 0.25A…20A; V: 2.5V…150V)
- configuration of a constant test voltage to be applied to the module
- single measurements of selected channels (avg. of 100 points, scan rate 200 points/channel*sec.)
- continuous monitoring of selected channels (avg. of n points n=1-100, meas. intervals t=1ms-1min)

Electronic load (configuration of IV-tracing characteristics)
- definition of signal type (single sweep Isc→Voc or Voc→Isc, triangle pulse or constant voltage)
- definition of sweep speed (2ms…10sec)
- definition of number of points within each IV-curve (default=200)
- definition of signal amplitude and offset

- activation of amplitude optimisation (Voc search + 10points)

Single IV (execution and visualisation of single I-V measurement, STC translation)

- manual triggering of a single I-V measurement (sequence in which data are acquired: meteo, IV-curve, meteo, module position).
- interpolation and calculation of module parameters I_{sc}, V_{oc} , P_m, I_m and V_m
- visualisation of calculated values (meteo, sun-tracker, IV-parameter)
- inter-comparison of manufacturer data, indoor measured data and calculated module parameter
- visualisation of IV data (single or multiple IV-curves, raw data)
- loading of an existing file (old measurement data and program settings)
- search of IV correction parameter (b, D) by analysing a set of IV-curves
- STC correction of a single IV-curve (see chapter)
- storage of single IV-curves with environmental and system configuration data.
- storage of IV parameter and environmental data in table in the case of multiple IV-measurements.

Continues IV (execution and visualisation of continuous I-V measurements)

- programming of continuous I-V measurements (daily start and stop time, measurement interval, sweep speed, data storage format, etc.)
- storage of single IV-curves (optional)
- storage of daily files (only IV-parameter, environmental data, etc.)
- it is possible to measure up to nine irradiance sensors simultaneously (to be configured in input channels)
- visualisation of last IV-curve
- visualisation of user-defined xy graph (x: n, time, Im, Vm, Isc, Voc, Pm, Ta, Tmod, Irrad 1, ..., AM, AOI; y: Im, Vm, Isc, Voc , Pm, Ta, Tmod, Irrad 1, …, AM, AOI)

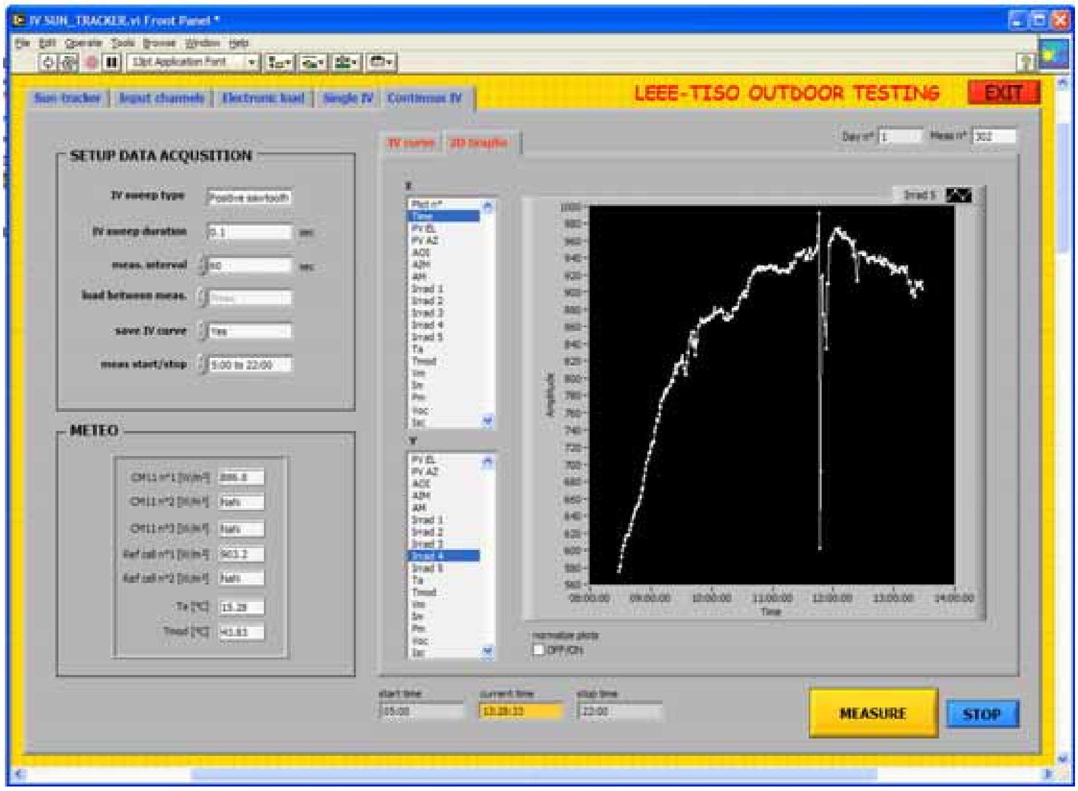


Figure 62: One of the main windows of the sun-tracker program: “Continuous IV”

3.3 Measurements with Sun tracker

3.3.1 Reference module of test cycle 10

As already mentioned in the previous chapter, within the new test procedure (see chapter 2.3), three modules of each type are to be tested instead of two. The third module, the so called reference module, will be only used for short term measurements. Many of these measurements will be done with the sun-tracker system.

Within the 10th test cycle the main objective of the measurement with the sun-tracker is to determine in very short time the power matrix - $P_m(G_i,T_a)$ - of each module type and to use this matrix to predict the annual energy production of the other two modules. The inter-comparison of the predicted kWh with the energy produced in reality over one year, will be used on the one hand to validate the energy prediction method (matrix method) developed at LEEE and on the other hand to optimise the quality of the matrix extraction and the duration of the measurement itself. The influence of single meteorological parameters will be analysed and in the case of thin-film modules main emphasis will be placed on the analysis of spectral effects.

Another objective of the new system is to compare outdoor to indoor data and to investigate existing translation procedures with a special attention to thin-film modules.

Last but not least a hysteresis test has been introduced, which allows verification of the presence of distortions due to high cell capacitances. Sweep speeds up to 2 ms can be reached. This corresponds exactly to the sweep speed of our indoor measurement system (see chapter 1).

3.3.2 STC correction

To validate the whole system (measurement accuracy, STC correction accuracy and software) an indoor calibrated standard crystalline silicon module has been used. The inter-comparison of the indoor measured IV-curve and temperature coefficients with the STC corrected outdoor IV curves and the outdoor measured coefficients proved the validity of the new measurement facility. Table 1 shows the results for the IV curve measurements.

	indoor	outdoor	
Pm	46.18	45.57	-1.3%
Isc	3.02	3.07	1.6%
Voc	21.10	20.83	-1.3%
Im	2.78	2.79	0.2%
Vm	16.59	16.36	-1.4%

Table 8: Difference of indoor and outdoor measured parameters of a reference module (indoor: Pasan simulator, outdoor: Sun-tracker system).

The STC translation procedure used here is a modification of the Blaesser method and is based on the determination of the two factors b and D. The objective is to further improve the software, to integrate it into the new sun-tracker program and to allow for the possibility of executing STC corrections to different kinds of PV module technologies, by incorporating the respective correction procedures.

4 BIPV (BUILDING INTEGRATED PV)

4.1 Introduction

The world photovoltaic market is rapidly expanding and as with any growth of this size there are problems in adapting to previous realities which, for photovoltaic technology, means architecture and construction. In the field of 'traditional' architecture, photovoltaic modules are still considered as an accessory which is added to the construction, or at least this was the image portrayed. Distorted impressions have been created which could compromise the acceptance of this 'new' (for architecture) technology. The introduction of photovoltaic plants into the building environment requires a sensitivity and non-technical knowledge which installers often lack. Although BIPV (Building Integrated PV) makes up only a small part of the overall PV market, it is becoming increasingly important for the eventual acceptance of PV. The photovoltaic module is no longer a building accessory which disfigures, but it is becoming a building element which has a role in the creation of the entire envelope of a building.

Developments in both technology and building construction have helped to reduce production costs while at the same time offering more advanced integrated solutions. The solutions proposed must be both *simple* (easy to carry out) and reliable (safe), so that architects can exploit them fully. Using photovoltaic modules, as building materials, can be promoted by architects who have the appropriate knowledge and tools.

The main objectives of the BiPV research project are:

- To facilitate and stimulate the use of BiPV systems (for architects and building owners)
- To promote the multifunctional aspect and the advantages of BiPV systems
- To improve the economic performance of BiPV systems through the double function concept
- To study the structural, physical and security aspects of PV modules as building elements
- To improve the architectural quality of BiPV systems

The contents of this chapter are:

- Directory of BiPV systems/products on the market
- ISAAC – BiPV workshops
- Partnership with Canton Ticino in the incentive programme for renewable energies (part PV)
- Call for BiPV projects in the Italian speaking part of Switzerland
- PV module appearance
- PV module thermal aspects
- PV module NIR Attenuation
- PV module impact test
- Website www.bipv.ch

4.2 Definitions of BIPV

In a building integrated PV system, all considerations regarding the architectural quality of the system and the structural aspects have to be contemplated like for any other building element; the architectural quality of the whole building will be the result of a careful study of each and every part of it, including PV modules.
Similarly, technical aspects regarding the mechanical features and the performance of the PV plant have obviously to be satisfied for a project to be considered BiPV. The main BiPV aspects dealt with in the project concern mechanical and visual functionality of the modules as well as architectural qualities and constraints of PV material as a building material.

The IEA PVPS (Task 7) has elaborated a list of seven criteria for good-quality BiPV projects:

1. Natural integration of the PV system
2. The PV system is architecturally pleasing, within the context of the building
3. Good composition of colours and materials
4. The PV system fits the *gridula*, or visual pattern of the grid (is in harmony with the building and, as a whole, forms a good composition)
5. The PV system matches the context of the building (contextualised)
6. The system, and its integration, are well engineered
7. The application of PV has led to innovative designs

The criteria are formulated as general indications and they can be interpreted with a certain flexibility, therefore it is essential that the criteria are carefully and critically considered in the context of each and every specific project. We consider the last criteria of IEA list (number 7) as not being objective in the sense that an innovative design is not always desired. In fact, in some cases, the contrary could be looked for, which is why we prefer not to take it into account.

In addition to IEA criteria list (except n°7), we focus the definition of BiPV on the following points:

1. **PV material** (modules) **must have a double function** (to produce power and to have a constructive or architectural function)
2. **PV system must be of high architectural quality** (care in architectural and constructive integration)
3. **PV system must respect the fundamental laws of PV technology** (orientation, ventilation, shadow, output level,…)

By constructive or architectural function, we consider: building envelope, sunshades, noise barrier, visual barrier, any part of the building that fulfils a proper function, parts of urban structures (vehicles covers, sport structures, playground structures,…). This definition is the reference used for access to the Cantonal incentive programme for renewable energies (see 4.7.1).

4.3 ISAAC - BiPV workshops

In the framework of the BiPV research project, ISAAC has organised two pluri-disciplinary workshops about "architectural integration of Photovoltaic systems". The first workshop took place internally at the Dipartimento Ambiente Costruzione e Design (DACD) of the SUPSI and involved architects and engineers interested in the theme. The second workshop took place on Thursday 15th February 2007 at SUPSI Trevano campus (Lugano- Switzerland). This second working session involving selected people from various professional horizons who are interested or directly linked with the Photovoltaic sector (architects, engineers, researchers, industries, institutions, investment companies and public sector representatives) had the following main objectives:

- To provide a global view of the BiPV sector in Switzerland and Europe (competence network)
- To strengthen the BiPV stakeholder network and to create new collaboration synergies
- To identify the difficulties of the BiPV sector and formulate proposals for improving the market's development
- To formulate guidelines for orienting applied research in the field of BiPV (through a multi-disciplinary approach)
- To identify one (or more) specific topic that should be further studied in BiPV applied research

29 people, representatives of the "PV sector" (13 people), "Architects" (9 p.), "Industry" (3 p.) and "Public sector" (2 p.) participated in the workshop (see annex 2). Industry and Public sectors were less represented partly because of last minute absences. It was also suggested that politicians should also have been invited to participate in order to have a more extended pluri-disciplinary group.

The first part of the meeting consisted in presenting the current 'state of the art' in BiPV, and it was divided in three parts:

- Definitions and limits of the theme, current state of research
- Physical aspects and standards for BiPV systems
- BiPV project design example

The goal of this introductive part was to make clear, to define and to fix limits to the topic in order to build a common basis of discussion and to avoid possible misunderstanding and confusions (some of the participants not being PV specialists). The interactive work was performed in two main parts, that is: work in groups on the four topics/questions to be analyzed and the presentation, synthesis and discussion of the results of every group.

The themes that were discussed were formulated in the following four questions:

1. What are the difficulties and obstacles that prevent a better development and use of BiPV systems?
2. In order to overcome or reduce those difficulties, what are the needs/necessities for the BiPV sector?
3. What are the systems, the technologies or the products with the most promising development potential in BiPV?
4. What would be the best direction(s) to give to applied research in the field of BiPV?

Every group was invited to reflect on two questions, groups 1 and 2 about questions 1 & 2 and groups 3 and 4 about questions 3 & 4 (see annex 3). The presentation and discussion of the groups' work in a plenary session was then summarised in order to provide a synthesis of the most relevant ideas and topics. Annex 4 provides the exhaustive list of proposals and ideas that where expressed during the group work session; the colours indicate the professional sector from which the proposals come.

The following synthesis shows the most relevant topics that were formulated for every question.

1. What are the difficulties and obstacles that prevent a better development and use of BiPV systems?

- BiPV is too costly
- Standardization is missing
- There are diverse standards for various climatic conditions
- PV material is not yet considered and tested as a building material
- *Modulability* and flexibility of systems are missing
- Guaranties about durability are missing
- High quality examples are missing (concerning the architectural aspects)
- Knowledge, information and education are missing (for building owners, building sector professionals and politicians)
- Access to information and selection of appropriate systems are difficult
- Mistrust from building sector professionals and the public towards Photovoltaic
- Willingness from building owners is missing
- Transparency of market and costs are missing
- Supplementary obstacles and commitments in the building design and construction process
- Risk linked to the guarantee of long-term insolation (territory planning and urban development)
- Visual and aesthetical impacts on the built environment
- Project tools (software) are not sufficient for complex BiPV project design

2. In order to overcome or reduce those difficulties, what are the needs/necessities for BiPV sector?

- Strengthening state incentives for BiPV (also through higher energy acquisition costs)
- Improving the transparency of the electricity market
- Increasing the offer of BiPV products
- Promoting solutions that aim at reducing the costs
- Strengthening the interaction between all stakeholders (Industry, architects, investors, designers, politicians)
- Publishing high quality examples of realizations (various possible typologies)
- Training polyvalent energy specialists (only one partner for the client)
- Providing Information and training at all levels (architects, building sector professionals, building owners, general public) and also about the relationship between PV and the environmental impacts of the energy sector
- Increasing efforts in applied research
- Defining and respecting standardization procedures worldwide (like PV material and building material, harmonization of standards in both sectors)
- Developing simple solutions
- Developing solutions that increase the architectural value of PV (example of the “energy storey”)
- Developing solutions for facilitating PV integration in existing buildings (for retrofit)
- Carrying out visible demonstration plants
- Working on integration also at the scale of the territory (not only at building scale)
- Protecting the plants from future shadow masking (with territory planning measures)
- Developing new software for BiPV plants design

3. What are the systems, the technologies or the products with the most promising development potential in BiPV?

- Solar protection systems (there are some doubts concerning the limits of movements for the elements, a good solar protection should be movable)
- Roofing systems, standard products with good flexibility (adjustable standards)
- Replacement systems for industrial roofing for retrofit
- Sheds roofing systems (south side) for industrial buildings
- Integrated systems in the roofing waterproof membrane for flat and curved roofs, with particular attention to the global ecological impact
- Flexible systems for curved surfaces
- Roofing surfaces with low aesthetic impact
- Roofing systems for urban equipment
- Modulable elements for ventilated facades (combination with static structure, development of complete systems
- Modulable elements to be integrated within windows/doors frames
- Systems that have compatible characteristics with building elements (life span, maintenance,…)
- Systems that can be easily separated from the building (to make maintenance, replacement and updating of material easier)
- Elements with low maintenance and service costs
- Hybrid PV-Thermal systems (! Complicated)
- Elements with well accepted aesthetics, fashionable, with many available options
- Systems with amorphous technology (a-Si), (possible laying on top of various materials, higher energy rating)

4. What would be the best direction(s) to give to applied research in the field of BiPV?

TECHNICS & PRODUCTS
- Improvement of systems and integration conditions, development of products specially studied for architectural integration
- Systems with double functions, good architectural and constructive qualities, good aesthetics and low cost
- Systems with high reliability and durability, with affordable costs
- BiPV in movable shadow elements
- Certification of systems/products (concerning PV and building material)
- Reliability of products and applications
- Appropriate solutions for specific contexts (industrial, historical)
- Standardization of products and systems for cost reduction and better availability on the market
- a-SI systems in variable dimensions, “cut & place”
- BiPV systems appropriated for retrofit projects

MARKETING – INFORMATION- EDUCATION
- Advertisement, BiPV as a trendy product
- Directory of exemplary BiPV realizations & systems (with operational characteristics, reliability, specific problems, indications about performance)
- Make the approach for possible user easier

TOOLS
- Financial tools for making investments in BiPV easier (banks)
- Tools for performance forecasting (energy-economy-building management)
- How to encourage building tenants (60% in Switzerland) to use BiPV
- Design tools (software) compatible with the tools commonly used by architects and user friendly

LAND PLANNING
- Identification of major exploitation potential of surfaces in urban space, considering the feasibility(economy-technique-architecture-urban constrains)
- Neighbourhood scale plants (analogy with *tele-heating* plants)
- Incentive mechanisms linked to urban planning (land occupation levels,…)

In the synthesis and analysis of the results, prof. A. Bernasconi outlined the following possible “integration ways” for BiPV:

Figure 63 illustrates the need to reduce the complexity of the BiPV systems in order to reach a degree of greater integration. Simplification is to be favoured at several levels of the realization process (accessibility to information, planning, characteristics of PV material, construction, service and maintenance, substitution).

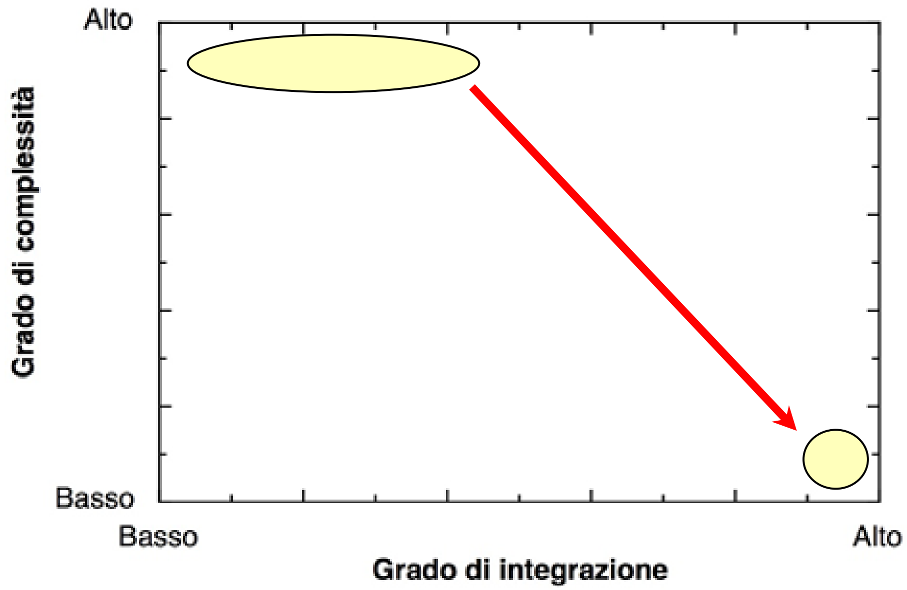


Figure 63: Relation between complexity and integration level of BiPV systems.

Figure 64 proposes a relation between level of integration and project scale. A small dimension project with low integration level is defined with the term “PV” (*Photovoltaics*), a small plan with a high integration level is “BiPV” (scale of a building) and a project of big dimensions with a high integration level is defined “UiPV” (*Urban integrated Photovoltaics* – at quarter scale, a town).

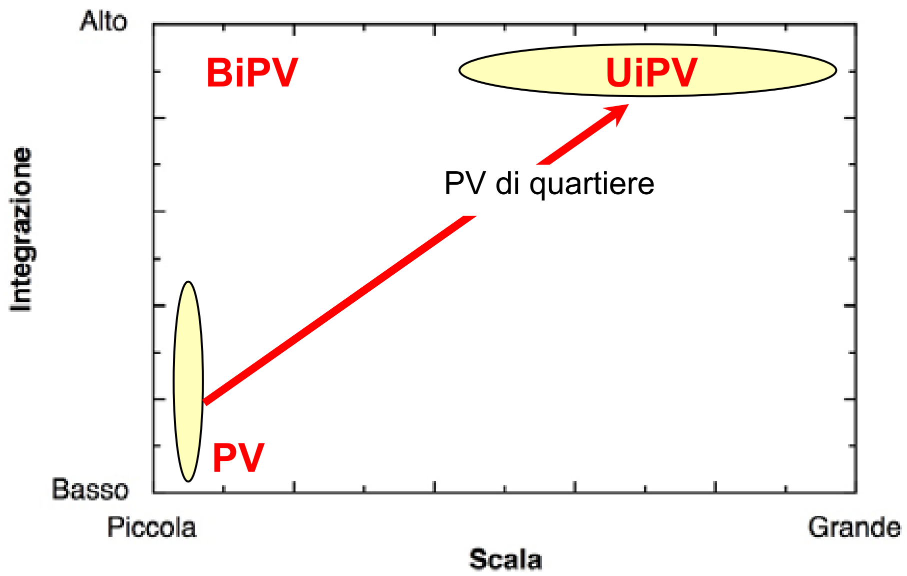


Figure 64: Relation between integration degree and scale of photovoltaic projects.

Figure 65 illustrates the relation between level of integration and importance of incentives. Integration projects at an urban scale, “UiPV”, are represented with the higher incentive level, “BiPV” project at a slightly lower incentive level and “PV” projects at a rather low incentive level.

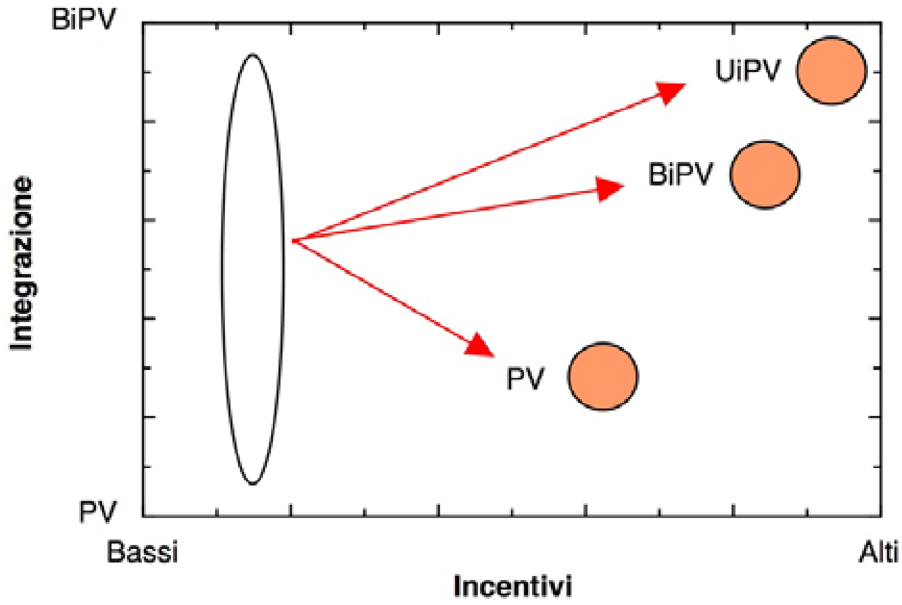


Figure 65: Relation between degree of integration and level of incentives.

The discussions and the solutions to problems offered by the participants of the workshop have helped to define guidelines for overcoming obstacles against a more widespread diffusion of photovoltaic integration in building envelopes, namely:

- Design: visual and aesthetic impact, different topology information (classification), best practice, etc.
- Territory planning and urban development: overcoming legal and planning obstacles etc facilitare il superamento di barriere legali e pianificatorie, etc.
- Construction: simplicity, modularity, flexibility, increasing the offer of BIPV products, BIPV for retrofit, etc.
- Test and standard: PV tested as building material, high reliability and durability, certification, etc.
- Project tools: simple and easy to use, high quality examples, information, etc.

Some of the items mentioned were taken up within the context of this project and form part of the subject matter for the following chapters.

4.4 Directory of BiPV systems/products on the market

The difficult access to information about BiPV products, technologies and suppliers appears to be one of the **main factors** that makes the use of BiPV solutions rather problematical for architects, engineers, planners and building owners (see chapter 4.3). In order to facilitate the search for solutions, products, examples and suppliers, we have elaborated a directory of the main BiPV systems/products available on the market. The list is presented as an *Excel* table which allows classification of different criteria (producer, plant typology and applications). The table is organised in four columns, namely: the producer’s name and complete address, the plant typology, pictures of applications, notes about the technology. Since the PV market in general and BiPV market in particular are developing very fast, this list will have to be frequently updated to be really useful. This updating process should be ideally done in collaboration with the producers of BiPV solutions. To date, 81 objects have been presented as shown in the extract in Figure 66 (see annex 7). The document is available on the ISAAC BiPV website (see chapter 4.4).

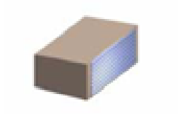
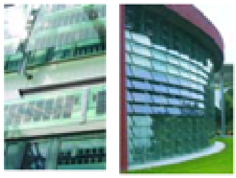
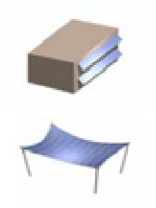
PRODUTTORE DISTRIBUTORE	APPLICAZIONE	FOTO	DESCRIZIONE - OSSERVAZIONI
Colt International Ltd New Lane Havant Hampshire PO9 2LY, UK Tel. +44 (0)2392 451111 Fax.+44(0)2392 454220 Email: info@coltgroup.com www.coltinfo.co.uk			**Shadovoltaic - PV Louvre** Shadovoltaic describes a fixed or controllable external solar shading systemthat incorporates glass louvres with photovoltaic cells integrated into the glassso as to generate electricity at the same time as providing shading. The louvresare available in various colours, surface finishes, patterns and coatings to meetspecific design requirements. Both monocrystalline and polycrystallinecells may be used. The photovoltaic cells may be integrated into the glass, either by attaching them onto the reverse side of the glass panels or by laminating them between two sheets of glass
Flexcell VHF Technologies SA Av. Des Sports 26 1400 Yverdon-les-Bains, CH Tel. +41 (0)24 423 04 94 Fax : +41 (0) 24 423 04 99 Email : marketing@flexcell.ch www.flexcell.com			The flexcell base material consists of ultra-thin polymer films of 50 microns thick. This flexibility allows for easy integration into various applications that are subjected to flexion or shocks.flexcell is also flexible in terms of shape (rectangular, square, round, other). This flexibility makes for easier, quicker design changes for cost-effective solutions.flexcell is also flexible in terms of connecting devices, encapsulating material and surface finishes.

Figure 66: extract of ISAAC collection of main BiPV systems/products available on the market. (annex 7)

4.5 Website www.bipv.ch

The internet site www.bipv.ch was created from the need to supply architects and project managers with information which was not only technical. It aims to satisfy the needs which emerged from the two workshops described in the previous chapter and it consists of a general information section, a section on the photovoltaic materials available and the various topologies, a section focussing on economic aspects and a section with examples.

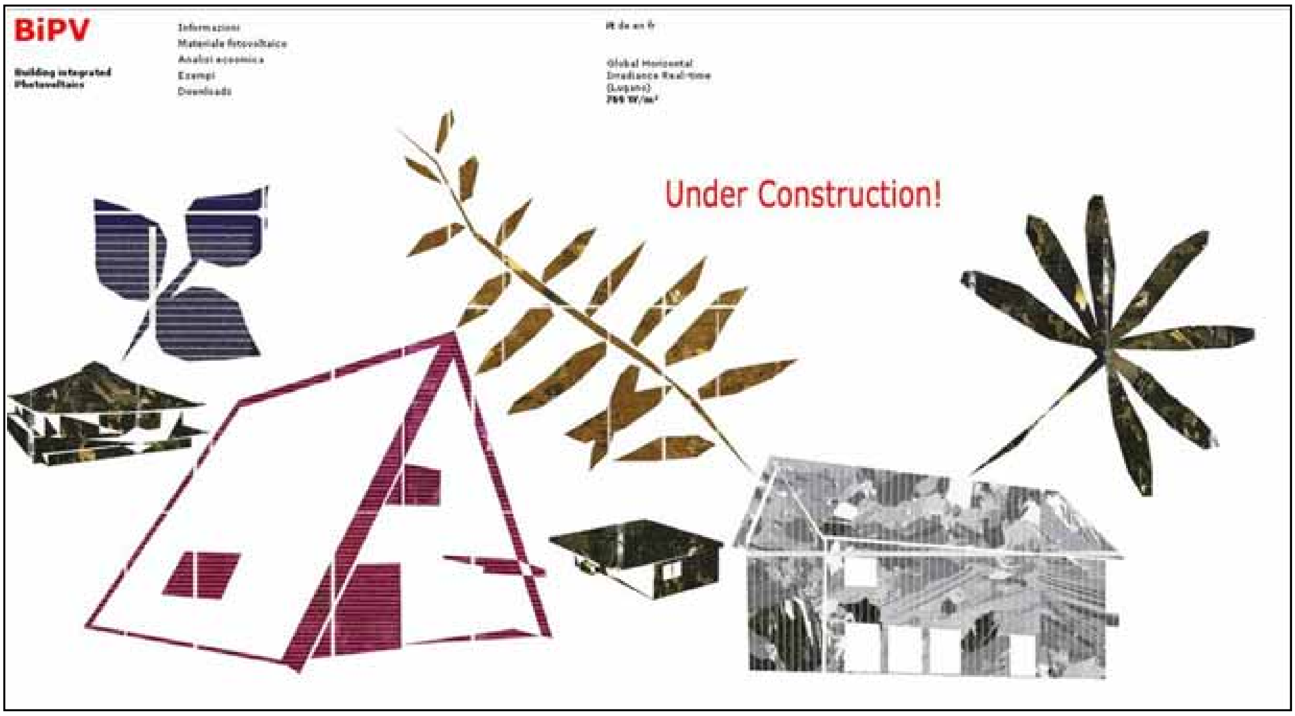


Figure 67: Starting homepage of www.bipv.ch

The site has been translated into the three main national languages (Italian, French and German) and English. It is continually being developed and will be updated with information on the latest products on the market as well as with all the latest news related to the topic.

4.6 PV modules appearance

In architecture, visual aspects of a PV integration are really important. We are used to seeing around us examples, that we can called “patchwork”, where all colours, forms and dimensions are mixed together.

To help the architects and the designers to choose a good combination, we characterize amongst other, the PV module colours (cells) with the standard palettes that are commonly used by architects, painters, etc.

Initial characterizations were undertaken on PV modules from the outdoor test cycle (10). The colour palettes used were the NCS S, 4041 Color Concept Sikkens. The RAL K5 palette didn’t contain enough colours.

Figure 68: color palettes and PV modules characterisation

All other appearance characterisations such as the colour background of the modules, the framed colour, the forms of the cells, the dimensions of cells, the space between cells, the electrical grids and PV module reflexion were indexed.

This work will be published on our website www.bipv.ch.

The polycristalline cells contain a lot of nacreous colours that are not represented by the palettes. For this reason, a home-made palette of polycristalline cells is in progress. Some preliminary tests of colour printing are being made by a printer “Imprimerie Morellon, 1032 Romanel-Sur-Lausanne”. The palette will be extended by asking for cells from producers and can be sold to architects.

Human eye colour impressions are the best “instruments” to characterize colour and is the most reproducible.

On the other hand, colour palettes covers all the spectrum in a logical way and allow satisfying characterisation with human eye comparison.

The use of a colour and luminosity meter CS-100, borrowed from Konica Minolta was not successful.

The CS-100 is a luxmeter with a colour function to measure source of light (lamps, traffic light, screen)

This instrument is calibrated to have almost the same sensitivity for colours as the human eye. However, as the measurement was not of a light source but a light reflection through glass, the colour obtained was clearly different from reality.

Figure 69: CS-100 from Konica Minolta

The COLORCATCH colour-meter from the Swiss company Colorix the aim of which was to characterize the colour of paints was not successful due to trouble caused by the glass on the cells.

Figure 70: Colorcatch from Colorix

4.7 Promotion and support of models for architects

Within the framework of the project and following the results of the first internal workshop at the university department, it was decided to promote and support examples of PV modules integrated into roofing. For this reason, an ideas competition was promoted among the municipalities of Ticino, which were able, at the same time, to profit from a programme of incentives backed by the Canton and with the technical support of ISSAC.

4.7.1 Partnership with Ct. Ticino in the incentive programme for renewable energies

With the executive decree of 25th August 2006, Canton Ticino has allocated CHF 4'800'000.- for promoting and encouraging Buildings energy retrofit, the Minergie® standard and the use of renewable energies. Among the various sectors where incentives are proposed, Photovoltaic plants projects are supported with an amount of CHF 400'000.-. The support is given as part of the initial investment for the plant with the following rule: incentive of CHF 4'500.- /kWp, with a maximum of CHF 18'000.- (corresponding at 4 kWp). The incentive for demonstration projects in schools is a lump sum contribution of CHF 6'000.-.
The necessary conditions for PV projects to receive the incentives are:

- Minimum nominal power of the plant = 1 kW
- The plant should be connected to the grid
- The quality of PV modules have to be approved by ISAAC-SUPSI
- The plant should be applied on Minergie® standard building **or recognised as BiPV plant** (excepted for demonstration plants in high and professional schools)

The condition linked to the recognition as BiPV project is based upon the definition presented in 4.2 and an ad hoc definition has been elaborated by ISAAC as a reference for the incentive request process (see annex). The notion of double function of PV material is strictly required to have access to the incentives. ISAAC is responsible to verify the fulfilment of the criteria, which is actually a good opportunity to enter into contact with architects and encourage them to design PV projects that are BiPV.
This interaction with building sector professionals (architects, engineers, real estate developers, building owners) actually participates to realise two of the objectives of ISAAC-BiPV project that is to say:

- To facilitate and stimulate the use of BiPV systems (for architects and building owners)
- To promote the multifunctional aspect and the advantages of BiPV systems

In fact, in more than one case, the discussion about the criteria "BiPV" has allowed to (re)formulate projects in order to make them real BiPV plants.

4.7.2 Call for BiPV projects in the Italian speaking part of Switzerland

In June 2006, ISAAC, together with the Cantonal Office for Energy Saving, invited communities -in particular all municipalities of the Italian part of Switzerland, Ticino and part of Graubünden- to submit architectural projects where BiPV plants could be developed. The objectives of such proposal were to stimulate the communities (as property owner) to invest in BiPV technology and to provide ISAAC with projects for experimentation of the realisation process and the technology as well as for technical monitoring of BiPV systems.

To date, height communities have announced projects for possible BiPV realisations (*Fondazione uomo e natura a Acquacalda, Canton Ticino a Bellinzona, Municipality of Chiasso, Municipality consortium in Cugnasco, Municipalities of Massagno, Paradiso, Roveredo, Stabio and Sonvico*).

The project in Bellinzona is under process of realization: the cantonal building named "Scerri 1" will have in 2007 his flat roof restored with VHF-technologies PV roof membranes. It's a first for the Swiss company VHF-technologies. The monitoring and the performance analysis will be made by the institute ISAAC.

4.8 Thermal aspects of PV modules (U-value and g-value)

4.8.1 Thermal conductivity preliminary test

Some trials were made to measure thermal conductivity of glass samples with a system composed of thermal baths (coming from EMPA) with the idea of adapting this test for PV modules. We obtained some uncertainty flux measurement due to the high conductivity of glass materials. This test is more suitable for building materials like concrete. Moreover, PV adaptation of this test will increase inaccuracy.

Figure 71: Thermal baths to measure thermal conductivity

The EMPA meeting and visit show us that thermal measurements of building materials are made with hot box to determine the U-value and with outdoor test facilities to determine the g-value. These tests require space and experience and EMPA services have a cost.

4.8.2 In situ measurements of g-value and U-value

The feasibility of measuring in situ the g-value and U-value (in real cases: i.e. newly built houses) on special glass and in dynamic conditions was demonstrated.

In 2006, These measurements were performed on 3 cases and the report with the following are available:

1) Determination of the solar factor g for a window with integrated roller blinds: a case study with in-situ measurements in a room at “Casa Monti”, May 2006.

2) Determination of the solar factor g for a window with a satiny glass: a case study with in-situ measurements in a room at the “Raiffeisen bank”, July 2006.

3) Determination of the solar factor g for a window with integrated roller blinds: a case study with in-situ measurements at one room of the “palazzo Mantegazza”, January 2007.

For case 1) and 3), The window consists of a double glazed window with integrated roller blinds.
The g characterizations were measured for different roller blind orientations.

Each situation required at least 2 days of good weather (the second day was for verification purposes) characterized by a sufficiently strong solar irradiation and without irregular intensity caused by clouds.

4.8.3 Measurements setup for each case

The data inside the room were collected by a datalogger **Campbell CR23X**, which was installed with the related sensors.
The different sensors used and the measured parameters are listed below:

- 1 pyranometer for the measurement of the solar irradiation inside the room (**Ivi**).
- 1 heat flow meter for the determination of the heat flux through the window’s glass (**flusso vetro**).
- 1 thermocouple for the measurement of the surface temperature of the glass (**Tsi**).
- 1 thermocouple for the measurement of the air temperature inside the room (**Ti**).

More complementary data were collected in order to obtain additional information on the room conditions related to comfort, even though they were not necessary for the determination of g. Those additional sensors are here listed:

- 1 heat flow meter for the determination of the heat flux through the window's frame.
- 1 thermocouple for the measurement of the surface temperature of the window's frame.
- 1 datalogger Elprolog for the temperature and the relative humidity of the room air.

The measurement setup is presented in Figure 72.

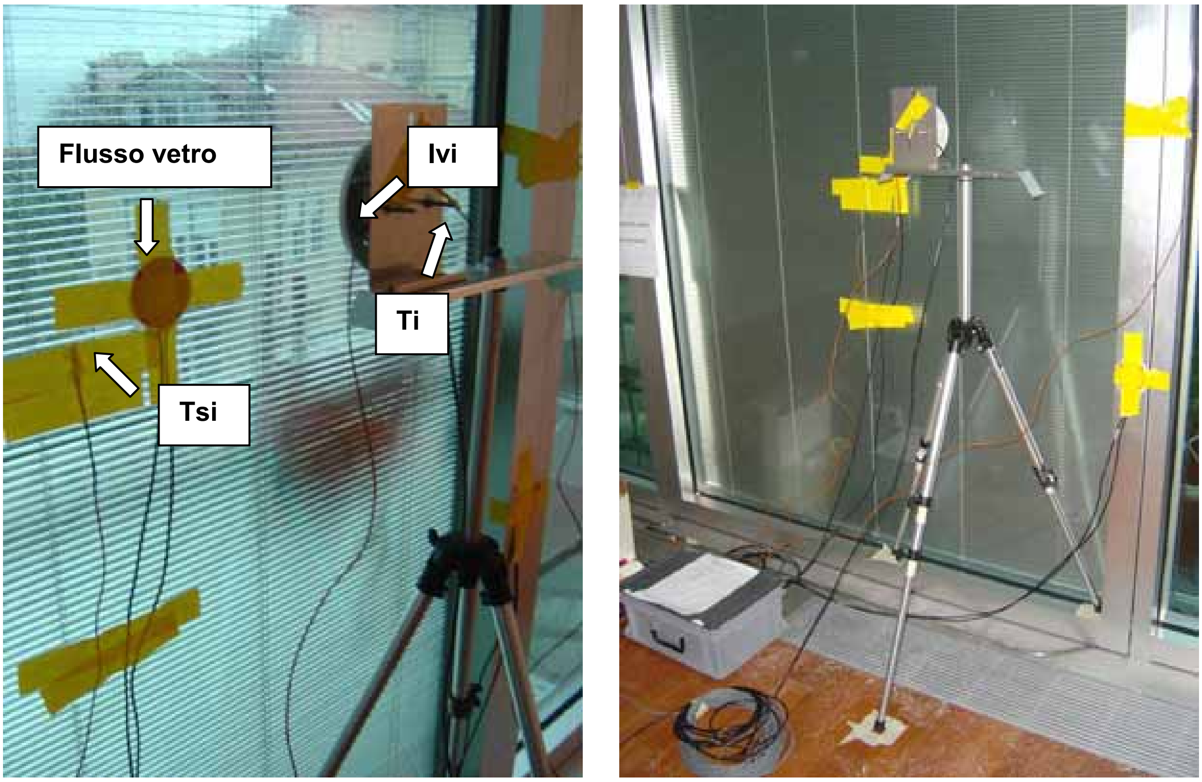


Figure 72: Inside measurement setup for the experimental determination of the solar factor g.

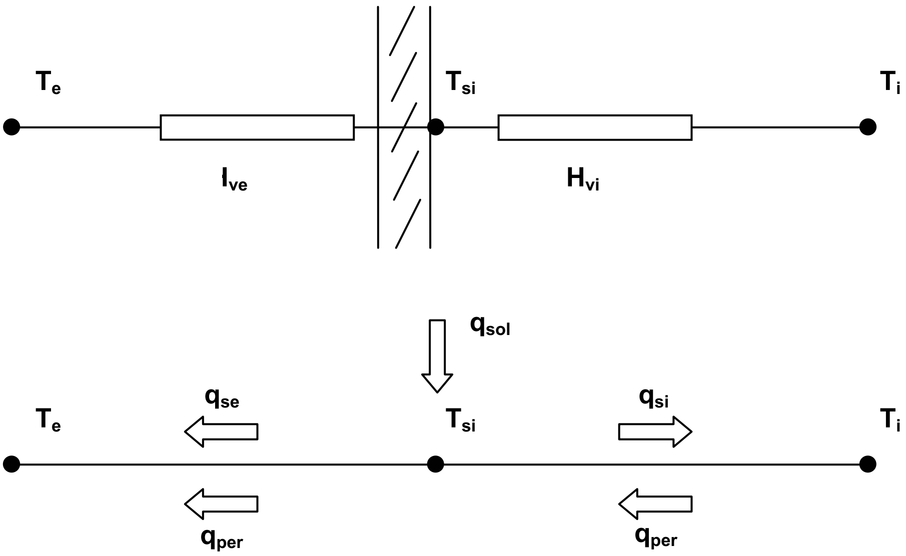
On the outside of the window, the data were collected by a datalogger **Campbell CR10**. The measurement setup on the outside is presented in Figure 73.
The sensors and the measured parameters are listed below:

- 1 pyranometer for the measurement of the solar irradiation (**Ivo**) on the window surface.
- 1 ventilated thermocouple, protected by a reflective double hat, for the measurement of the external air temperature (**Te**) (without the influence of direct solar heating).

Figure 73: Outside measurement setup for the experimental determination of the solar factor g.

4.8.4 Determination of the solar factor g

The determination of *g* is based on a stationary model for the heat transfer process (q_{se}, q_{per}, q_{sol} and q_{si}) through the window. The heat exchanges can also be represented, in analogy to an electrical schema, by the temperatures (T_e, T_{si}, T_i) and the thermal transmission coefficients (H_{ve} and H_{vi}) that are involved.



If the temperature difference between outside and inside is too small, the experimental determination of the coefficient of the glass thermal transmission (U factor) can not be determined. The value reported by the manufactures was asked for in case 2) and 3) and measured in case 1)

In case 1), the coefficient U is calculated from the heat flux q_{per} corresponding to the heat losses of the glass by the following relation:

$$q_{per}\ [W/m^2] = U\ [W/m^2K]\ (Ti - Te)\ [K]\ .$$

The relation between the coefficients U, H_{ve} e H_{vi} is:

$$U\ [W/m^2K] = 1/(1/H_{ve}\ [W/m^2K] + 1/H_{vi}\ [W/m^2K])\ .$$

The coefficient H_{vi} can also be expressed as $1/R_{si}$, where R_{si} is the thermal resistance of the heat transfer towards the inside. In general, a value of 8 W/m^2K is assumed for a vertical wall.

The solar radiation absorbed by the system is q_{sol}. In stationary conditions, part of q_{sol} flows to the outside (q_{se}) while the remaining part flows to the inside (q_{si}).

The solar factor *g* is defined as follows:

$$g = I_{vi}/I_{vo} + q_{si}/I_{vo}$$

where:

I_{vo} : incident solar radiation that hits the window [W/m^2];

I_{vi} : solar radiation that directly passes through the window. This radiation is recorded inside the room.

The primary component of the solar factor *g* is determined by the solar irradiation that directly passes through the glass, while the secondary component is determined by the heat q_{si} absorbed and transported to the inside.

The heat flux that enters the room (q_{si}) can be calculated by two different methods:

- By the measurement of glass heat flux (flusso vetro) with the heat flow meter,

$$q_{si}\ [W/m^2] = \text{flusso vetro}\ [W/m^2] + U\ [W/m^2K]\ (T_i - T_e)\ [K]$$

- By the measurement of the glass surface temperature (T_{si}) with the thermocouple

$$q_{si}\ [W/m^2] = H_{vi}\ [W/m^2K]\ (T_{si} - T_i)\ [K] + U\ [W/m^2K]\ (T_i - T_e)\ [K]$$

The solar factor *g* obtained with the first method is denoted as **g-flusso** and will be considered for the determination of the average *g* factor. The second method requires the knowledge of H_{vi}, which can not be measured and depends on local temperature conditions and on the heat flow. Here, it is assumed that the value corresponds to 8 W/m^2K, which is typical for vertical walls. The solar factor *g* obtained with this second method is denoted as **g-temp** and is used as a control value.

It is important to point out that the mathematical relations used here are based on a stationary model, while the measurements are taken in dynamical conditions since there are strong and natural variations in the incident solar radiation. Even if *g* is scaled by the incident solar radiation (I_{vo}), the value determined by the relations presented above varies during the day. Therefore, an average *g* value is calculated over the time of the day when the incident solar radiation is above 400 W/m^2.

The error estimation is based on the following instrumental uncertainty:

- Solar radiation: 2%
- Heat flux: 20%
- Differences in temperature: 1 K

However, both the pyranometers and the thermocouples induce some modification of the local conditions. In addition to the error estimation, the comparison between the temporal evolution of g-flusso and g-temp gives an extra indication on the reliability of the results.

Example of analysis:

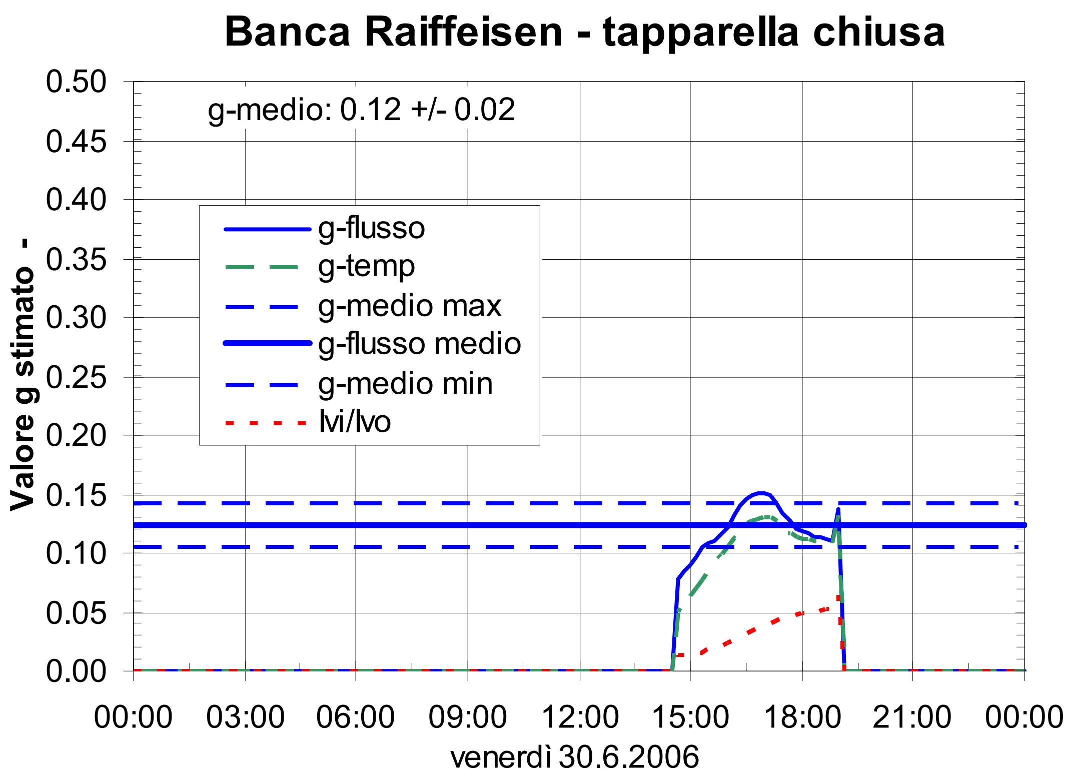


Figure 74: g-flusso and g-temp vs. time;

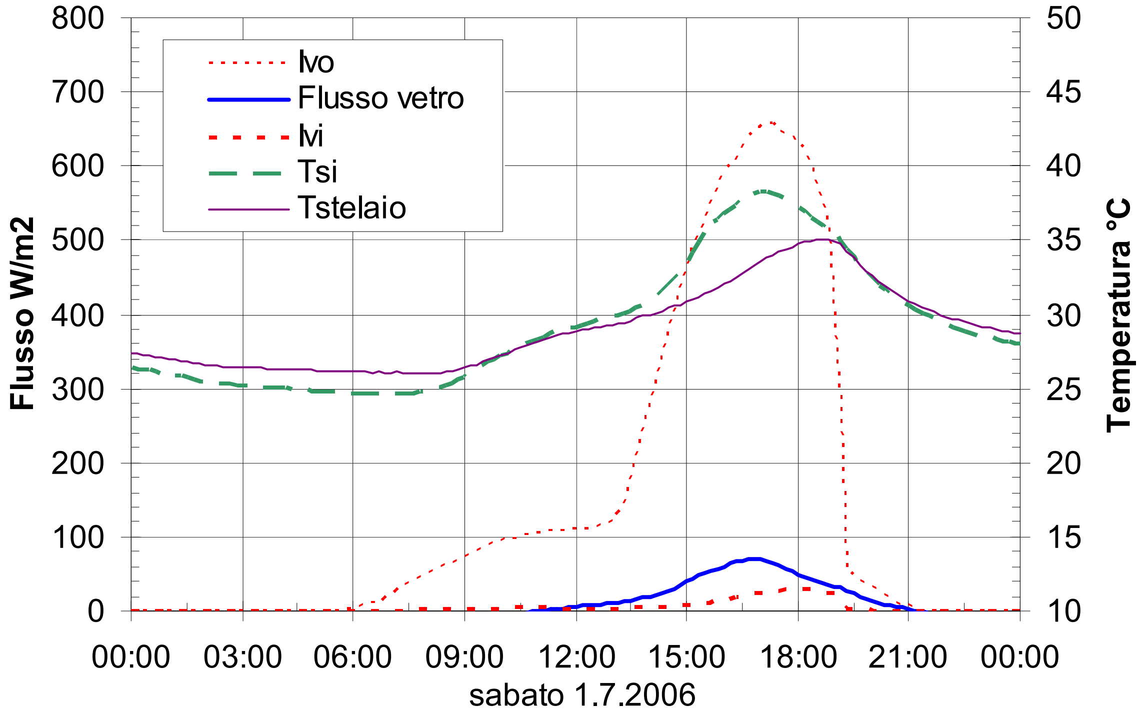


Figure 75: temperature and flux during the day

Example of results found in case 1)

Solar factor g and maximal temperature glass	East-oriented glass	Sud-oriented glass
open roller blinds with 90° orientation	0.39 +/- 0.04 40°C	0.20 +/- 0.03 39°C
open roller blinds with 45° orientation	0.28 +/- 0.04 41°C	0.15 +/- 0.02 36°C
closed roller blinds	0.17 +/- 0.02 37°C	0.20 +/- 0.04 38°C
roller blinds lifted up with outside blinds	0.04 +/- 0.01 24°C	0.05 +/- 0.01 30°C

Table 9: Example of results found in case 1): Solar factor g and maximal temperature glass.

4.8.5 Collaboration with ESCA to measure g-value

We have started joint work with the Physics Institute of the University of Basel “ESCA Gruppe” where they are doing indoor measurements to determine the “g” value in function of the incidence angle.

Data evaluation is based on the 'European Standard EN 410: Glass in building - Determination of luminous and solar characteristics of glazing.'

Firstly, the optical characterization of glasses is measured to obtain the solar direct transmittance.

The insulating glass unit (or individual glass panes) mounted on a revolving support is irradiated by a light source. The transmitted or reflected light enters a collimator and the spectral distribution of the light intensity is measured by diode array spectrometers.

The angular dependent measurements are enabled by rotating the glass and by defining the angle of light incidence by the collimator.

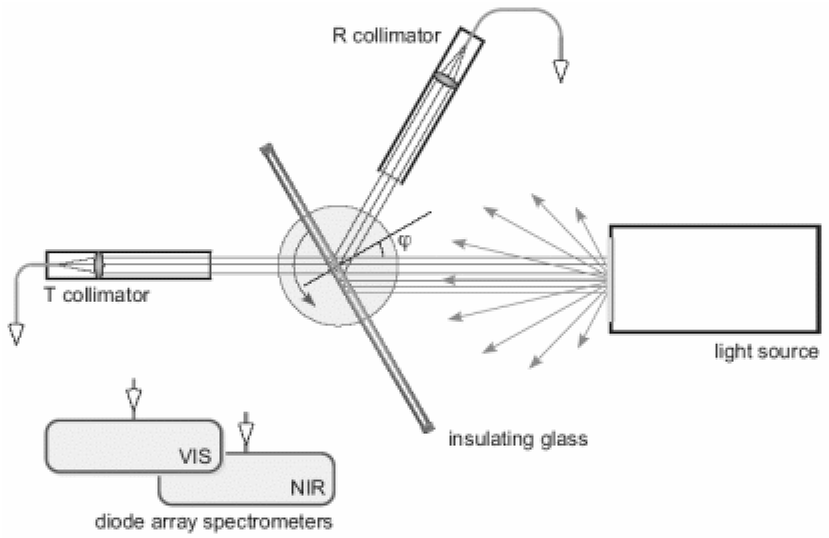


Figure 76: optical characterization of glasses by ESCA

Secondly, Thermal measurements to determine the secondary internal heat transfer factor.

The insulating glass unit is irradiated in a solar simulator by a spectral radiation close to the solar spectrum. The rise of the outer and inner surface temperatures in the steady state are used to calculate the outer and inner heat flows under laboratory conditions, i.e. in quiescent air.

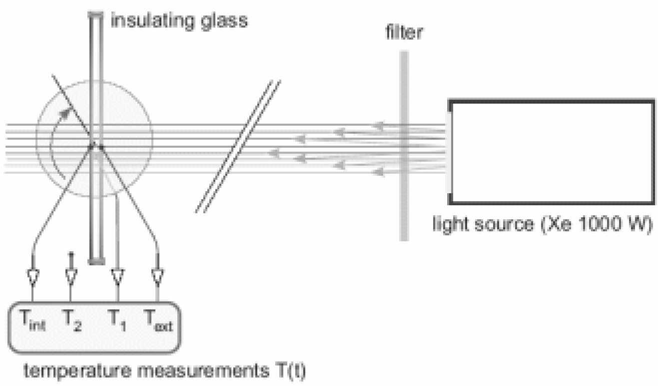


Figure 77: Thermal measurements of glasses by ESCA

Initial measure of optical proprieties were made with simple glass Schott Solar PV modules and double glass PV modules are intended to be measured.

A database of glasses has been made by the ESCA (http://pages.unibas.ch/phys-esca/) and contains optic proprieties based on EN410 and g value measurement. The idea is to complete it with PV glass modules.

4.9 PV modules NIR Attenuation

4.9.1 NIR attenuation test

The Non Ionising Radiation (NIR), commonly called Electrosmog, emitted by telecommunication installations is always present nowadays. The quantity of NIR to which the population is exposed will increase as well as the intensity and diversity.

Scientific studies and daily observations of exposed people lead to the supposition that a weak NIR, like the one that we measure in the environment, has consequences on health. However, these indications are not conclusive and do not allow a precise estimation of the risks.

In the population, the fears and the resistance towards NIR transmitted installations are decoming more and more important.

We are already finding on the market some new building materials to screen living space against NIR.

For example: 20dB (which means an attenuation of 99%) is considered a good degree of attenuation and typical values of attenuation for building materials are generally between 6dB (75%) and 20dB (99%).

The choice of screening implies using suitable domestic technologies for example the use of a mobile phone inside a screened house generates more power. In this case it is better to use, for example, a fixed phone.

4.9.2 Measurement of photovoltaics NIR attenuation

The measurements reported in this document are conducted following a procedure developed during an ISAAC project concerning the improvement of the tests on PV modules used in BIPV.

The TTHF (Telecom, Telematics and High Frequency) laboratory with whom the ISAAC is working for this project is well qualified in this field and has special instruments. Amongst others, they have the official STS309 accreditation (from METAS) for the measurement of the NIR generated by GSM and UMTS bases (mobile telecommunication).

The task of the TTHF was the development of a reliable test procedure for the characterization of radio frequency attenuation, also called shielding effectiveness (SE) for various PV modules and glasses.

The interval of frequencies considered for BIPV was from 800MHz to 2500MHz: in this range are found the main technologies of mobile telephony (GSM/DCS/UMTS).

4.9.2.1 measureMENT Set-up

The set-up is composed of one transmitting Antenna, one receiving antenna, a screening support with in the centre the photovoltaic module or glass and some instruments like a vector network analyzer (see Figure 78).

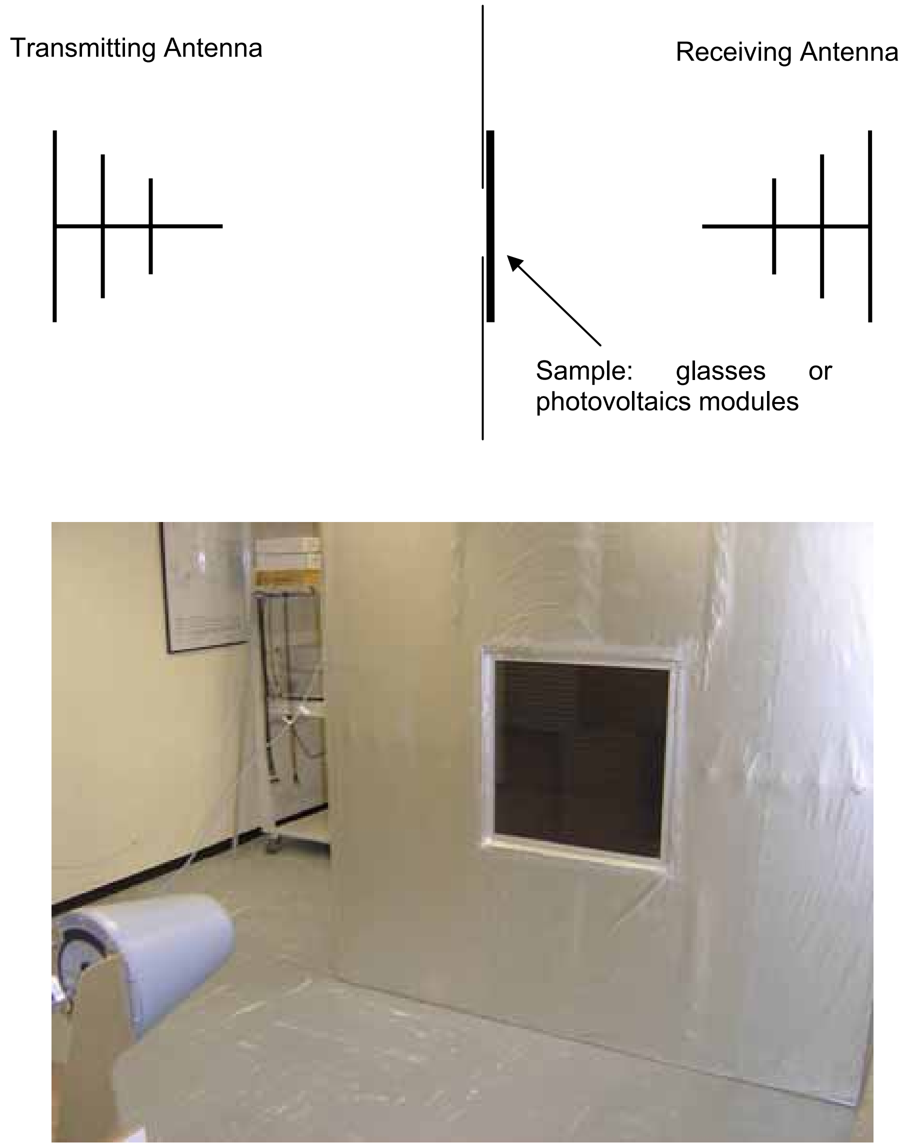
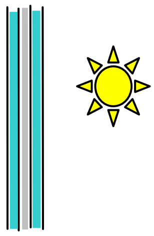


Figure 78: Scheme and picture of the set-up

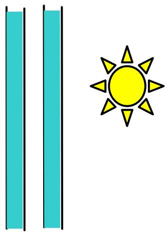
4.9.2.2 Results with Glasses

As a preliminary comparison element for the subsequent measurements on PV modules, attenuations of standard glass most commonly found on the market were analysed:

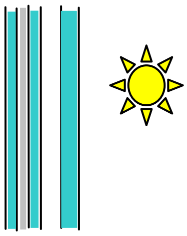
- float glass 3mm ∗ PVB ∗ float glass 3mm



- float glass 6mm ∗ Air 16mm ∗ float glass 6mm



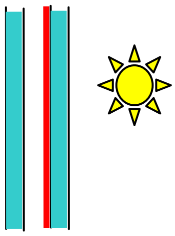
- float glass 6mm ∗ Air 16mm ∗ VSG[1] (float glass 3mm ∗ PVB ∗ float glass 3mm)



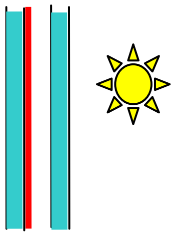
For the 3 **standard glasses** the attenuation value are very weak, and lower than < 2dB (37%).

The following two glasses with metallic deposition (called low emissivity glasses) have different results:

- glass 6mm ENERGY (magnetron layer position 2) ∗ Air 16mm ∗ Float glass 6mm



- float glass 6mm ∗ Air 16mm ∗ float glass TOP N (magnetron layer position 3)



[1] Laminated safety glass

The Shielding Effectiveness (SE; in dB), is an absolute value; bigger it is, better is the attenuation.

The values that we will take in consideration will be the minimum value (worst case) because the pick value comes from destructive interference generated by the reflection between the glasses and could depend on the incidence angle of the electromagnetic wave on the glass.

For the case of two **isolated glasses with magnetron layer (metal) deposition**, we obtain attenuation of more than 20dB (99%) (see Figure 79). The magnetron layer is a metallic coating that results in high reflectance of infrared radiation or heat.

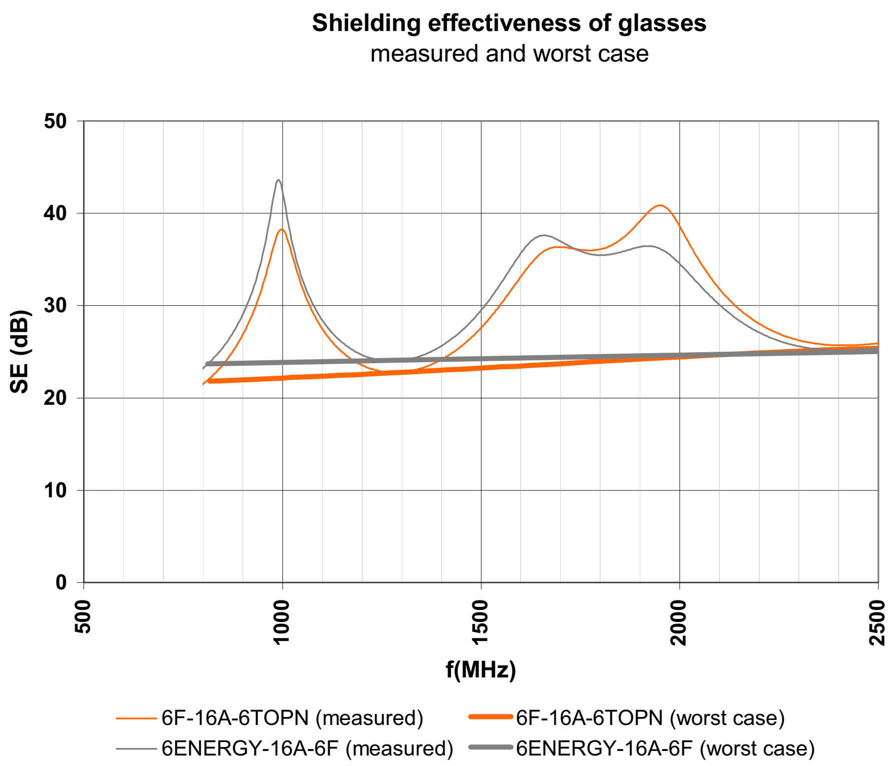


Figure 79: Shielding effectiveness of glasses, measured curve and worst case.

4.9.2.3 Results with Photovoltaics modules

Multicrystallin photovoltaics modules

The standard type photovoltaic module is composed of multicrystalline silicon (mc-Si) cells connected in series. The cells are spaced at a distance of 1mm from each other. Border effect was avoided on purpose and not taken into consideration.

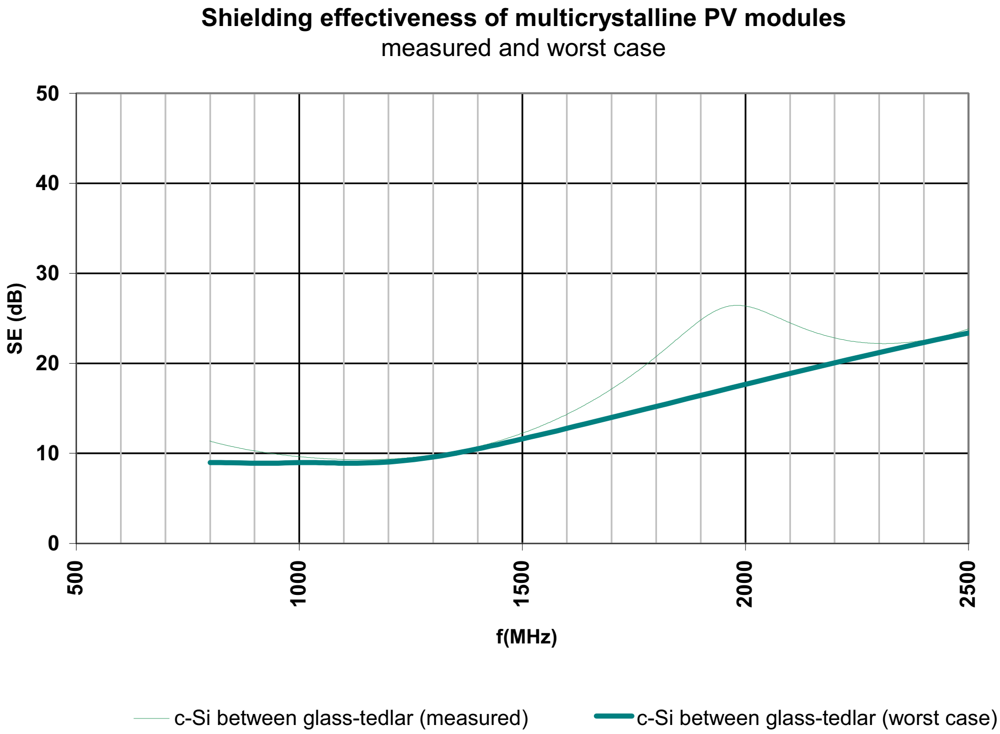


Figure 80: Shielding effectiveness of multicrystalline PV modules, measured curve and worst case.

Multicrystallin photovoltaics modules have an attenuation from about 10dB (90%) up to 20dB (99%) for higher frequency.

For inhomogeneous structures like PV modules the signal crossing the panel has frequency-dependent interactions which leads to local resonances. The physical dimensions of the cells and the space between cells are close to the wavelength, therefore it's possible to observe several resonances (interferences) in the frequency range considered. The angle of incidence modifies the physical length (projection) with a consequent frequency shift of the resonances. For this reason a worst case value is preferable rather than considering each single resonance.

The photovoltaic cells improve the attenuation compared to double or laminated glasses without a magnetron layer.

Thin-film photovoltaics modules

Two amorphous silicon thin film modules were chosen, one having a transparency of 10% , the other being opaque.

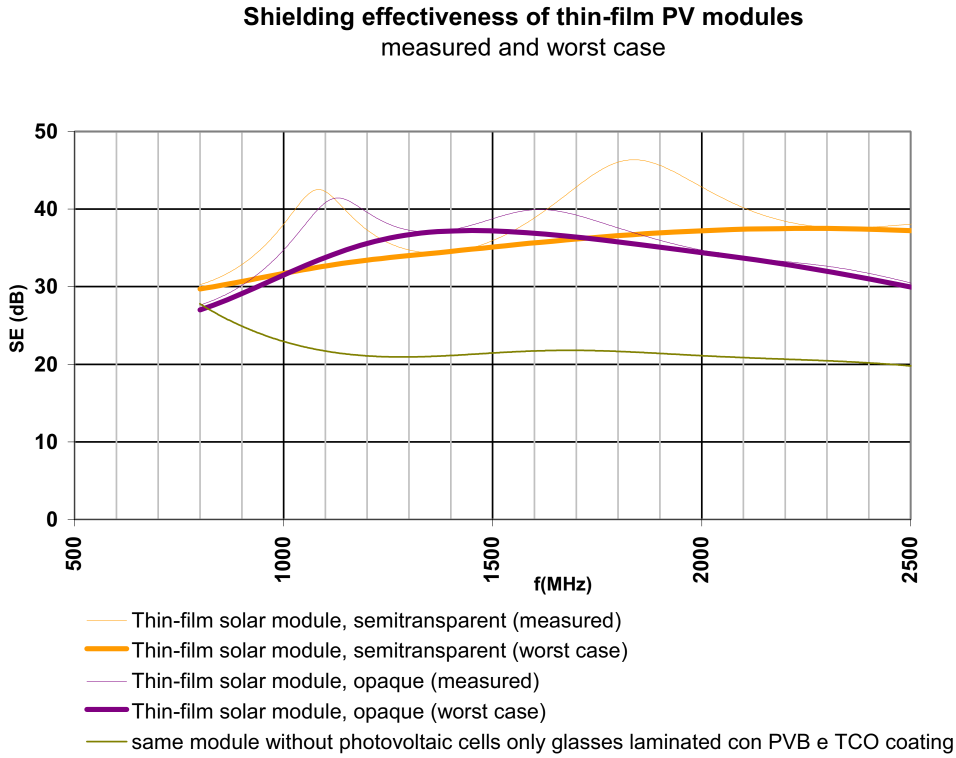


Figure 81: Shielding effectiveness of multicrystalline PV modules, measured curve and worst case.

For **Thin-film photovoltaics modules** we obtain attenuation of more than 30dB (99.9%). We will also consider the worst case for the same reason cited above. For higher frequency, the semitransparent module has a better attenuation property. Not only the TCO (transparent conductive oxide) contributes to a good attenuation but also the photovoltaic cells allow excellent values of more than 30 dB (99.9%) to be reached..

4.9.3 NIR produced by photovoltaics modules

The direct current (DC) produced by the photovoltaic modules create a static electric and magnetic field constant in time.

According to WHO (World Health Organization), few studies have been carried out for static electric fields. The results to date suggest that the only acute effects are associated with body hair movement and discomfort from spark discharges. Chronic or delayed effects of static electric fields have not been properly investigated.

For static magnetic fields, acute effects are only likely to occur when there is movement in the field, such as motion of a person or internal body movement, such as blood flow or heart beat. A person moving within a field above 2 T can experience sensations of vertigo and nausea, and sometimes a metallic taste in the mouth and perceptions of light flashes. But with photovoltaic modules the DC current is too weak to reach values of 2T and the recommended limits during the working day for occupational exposure that are time-weighted average 200 mT.

4.9.4 Conclusion NIR

Nowadays, photovoltaic modules need to be used as building materials. A probably future request made by the building owner could be the protection against electromagnetic fields from outside. The measurement of photovoltaic NIR attenuation show that thin-film photovoltaics modules have really good NIR attenuation properties as have low-emissivity glasses. Moreover, the photovoltaic modules do not themselves produce static electromagnetic fields that could affect health. Thin-film photovoltaics modules are really suitable for replacing building glasses. Besides the possibility of becoming thermically isolated and acting as safety glass, it can also have really good NIR attenuation properties.

4.10 PV Module impact test

Impact test with instrumented falling weight impactor - Comparison of photovoltaic waterproofing membranes for flat roofing

4.10.1 Introduction

A little damage appeared on the PV (photovoltaic) membrane situated on a school roof. Maybe caused by the fall of an object on it. Walnuts and stones were found on the roof and some birds were seen throwing them. The damage could also occurred during the assembly. The lifetime of the membrane can be reduced if piercing appears and water seeps into it.

Figure 82: PV plant and damage on the membrane

Using photovoltaic modules in conjunction with composite building elements can be problematic and create characteristics which are not compatible with the function of a building element. In the case in question, a triple-junction a-Si PV module (amorphous silicon deposited on a metal layer and covered by a layer of EVA and ETFE) is combined with a waterproof covering in flexible poliolefine (thickness 1.6mm) laid over rock wool insulation varying in thickness from 120 to 180 mm.

The aim was to test and relate two similar photovoltaic composite elements according to the present building standards.

4.10.2 PV waterproofing membranes

4.10.2.1 Samples preparation

To be comparable to the configuration of the PV waterproofing membranes of the school roof, the materials assemblage was reproduced as close as possible to reality.

The “stone wool” insulation material (12cm tick) was used for supporting the PV membrane.

We asked the PV producers to supply us with PV membranes usually delivered in roll. Then, PV modules with reduced dimensions were prepared. Figure 83 shows three types of PV modules: “A”, “B1” and “B2”. We prepared 5 modules type “A”, 5 modules type “B1” and 3 modules type “B2”.

Figure 83: three types of PV modules on stone wool

Each PV module was glued on the stone wool with two vertical thin silicone stripes applied on the left and right side of the modules.

“A” PV modules have an a-Si (amorphous silicon) triple-junction structure, that’s mean that they are made of 3 cells (placed one on top of the other). The “A” PV module <u>is glued to</u> a roof membrane.

“B1”PV modules have an a-Si one-junction structure. The module is composed by 26 cells placed side by side. The PV module <u>is laminated into</u> the roof membrane.

“B2”PV modules are similar to “B1”,with an added layer on the top of the encapsulant (only known by the producer).

4.10.2.2 Test methods

Before and after the impact test each “A”, “B1” and “B2” module was:
- observed with a microscope (zoom 5x),
- measured with a sun simulator to determine the electrical performance (IV curve).

The impact locations were chosen at the centre of the samples. For “B1” and “B2” modules, we choose the locations where the cells are connected in series (worst case).

The modules have not been exposed to sun irradiation during all the project to avoid the initial electrical degradation of a-Si (named Staebler-Wronsky degradation).

Moreover, one “A” module and one “B” module were tested to determine which impact energy physically destroyed the PV module.

4.10.3 Standards

4.10.3.1 Impact energy calculated from existing standards

Various standards with various impact test procedures and requirements exist in the photovoltaic field. The impact can be produced by hails or accidentally by other objects.

In the building field, a standard for roof plastic membranes exists in the Swiss building standard published by the engineers and architects society “SIA”.

As the input for the Rosand impact tester is the energy, every required performance described on standards (i.e. velocity, height, …) have been converted into energy. For comparing PV membranes with other materials, we also choose the energy corresponding to the impact resistance of Sarnafil® roof membrane (roof membrane without photovoltaic).

The following table gives a short description of standard including impact test:

PV standard	Description
IEC 61646 (1996)	**Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval** Requirements: - no evidence of major visual defects, - the degradation of maximum output power at STC shall not exceed 5% of the value measured before the test, - insulation resistance shall meet the same requirements as for the initial measurements. It require for a specified diameter of the impactor, a weight and a velocity corresponding. Procedure: ice balls are propelling by a launcher onto the module. We calculated an energy of <u>**12.6J**</u> for 40mm diameter.
IEC 61721 (1995)	Susceptibility of a photovoltaic (PV) module to accidental impact damage (resistance to impact test) Requirements: - no evidence of major visual defects, - the electrical performance parameters shall not decrease by more than 5% of the initial values, - insulation test shall meet the same requirements as for initial measurement. Procedure: the module is mounting vertically and a 40mm-diameter pendulum is dropped onto the module. We calculated an energy of <u>**20.6J**</u>.
IEC 61730-2 Ed.1	**Photovoltaic (PV) module safety qualification** Requirements: The module shall be judged to have successfully passed the module breakage test if it meets any one of the following criteria: - when breakage occurs, no shear or opening large enough for a 76mm diameter sphere to pass freely shall develop, - when disintegration occurs, the ten largest crack-free particles selected 5 min subsequent to the test shall weigh no more in grams than 16 times the thickness of the sample in millimetres, - when breakage occurs, no particles larger than 6.5cm2 shall be ejected from the sample, - the sample does not break. Procedure: A leather punching bag in pear form plenty of lead shot is dropped onto the module. The IEC 61730 was not used because the pass criteria are not adapted to PV module in plastic material.

Building standard	Description
SIA V280 (1996)	**Lès d'étanchéité en matière synthétique (Lès polymères) - Performances exigées et essais des matériaux (SN 564280)** Requirements: a damage velocity bigger than or equal to 17m/s. The damage is described as a loss of watertightness equivalent to a piercing of the membrane. Procedure: a vertical device allow to shot a 40mm-diameter polyamide ball on the roof sample placed on a flexible base. Two photocells measure the velocity of the ball. We calculated an energy of <u>**5.6J**</u>. According to this standard, membrane roof of Sarnafil® TS77-20 require a damage velocity bigger than 40m/s and we calculate an energy of <u>**30.8J**</u>.

Table 10: PV and Building standard

In our test we use also the smaller impact energy <u>**3.3J**</u> that can be obtained with this impact tester.

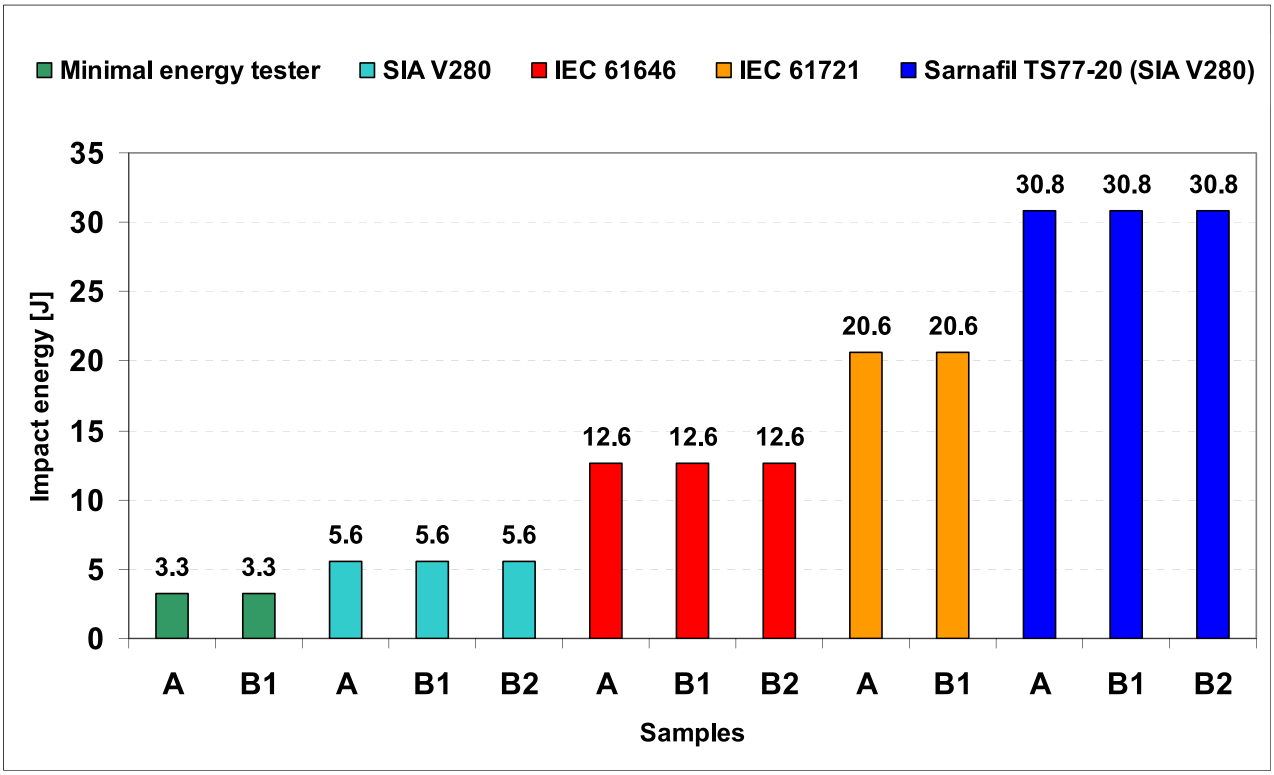


Figure 84: Summary of impact energies selected and samples tested.

As we have received from the producer only 3 x “B2” modules, we selected impact energies of 5.6J, 12.6J and 30.8J.

4.10.4 Impact test

4.10.4.1 The Rosand instrumented falling weight impactor test

The Rosand instrumented falling weight impactor, kindly provided by the EPFL (Ecole Polytechnique Fédérale de Lausanne), is a computer controlled falling weight device used to perform impact tests.

Drop weight is 5.7kg and the minimum impact energy is 3J. The impactor is a steel support with a half sphere striker. For this work, EPFL specially made a 40mm diameter spherical striker, which corresponds to the standards described above.

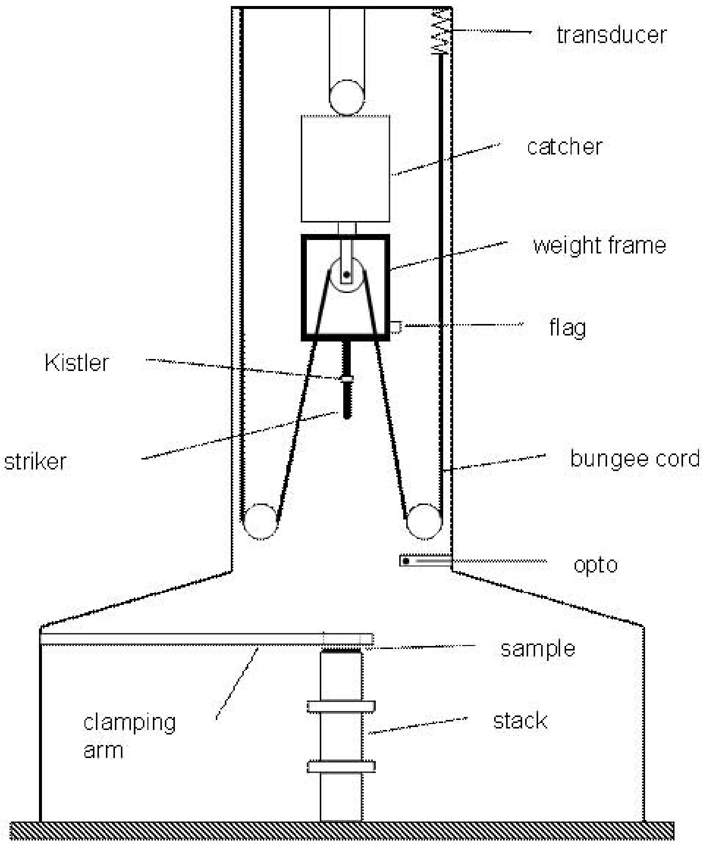


Figure 85: The Rosand instrumented falling weight impactor

4.10.4.2 Setting parameters

The drop height was initialised before starting the experiments. This is done by lowering the pointed end until it touches the sample. The height is then set to zero.

The input energy is defined by the user for each impact test.
From the potential energy, *Ep=mgh*, the control software calculates the needed drop height by knowing the impact weight m. If the maximum height is reached, the drop weight is accelerated to obtain the required energy.

During the impact the computer read and stores:

- the mean velocity before the impact (by optical sensors);
- the time;
- the force at the impactor during the impact (by piezoelectric force transducer).

From these measurements, the software calculates the following values:

- The acceleration is simply obtained by $a(t) = F(t) / m$.
- The velocity is obtained by the integral of the acceleration $v(t)=\int a(t)dt$.
- The displacement is obtained by the integral of the velocity $d(t)=\int v(t)dt$.
- Finally, the energy is obtained by the integral of the force $e(x)=\int F(x)dx$. The interval of the integration begins at the earliest time that the force exceeds 2% of the maximum force and end at the first time after the peak that the force reduces to 2% of the maximum force. Before and after the interval, the force is considered as zero.

Schematic representation of an impact

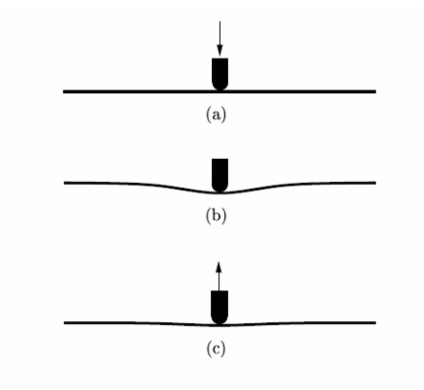


Figure 86: Schematic representation of an impact

At (a) the impactor hits the sample, the displacement of the impactor and the force is 0. (b) illustrates the sample at maximum deflection. The velocity of the impactor is zero and the force is maximum. The sample has absorbed all the impact energy as plastic and elastic energy. (c) the impactor leaves the sample. Some of the elastic energy in the sample has now been used to accelerate the impactor. Only the gravity force is now working on the impactor.

Error calculation is based on the known precision of the force transducer and velocity:

- Force transducer: 0.25%
- velocity: 0.4%

4.10.4.3 Test set-up

Each module was clamped with a circular steel frame (see Figure 87). The room temperature and the module temperature was maintained at 20°C.

Figure 87: module clamped with a circular steel frame.

4.10.5 Measure analysis

4.10.5.1 Visual analysis

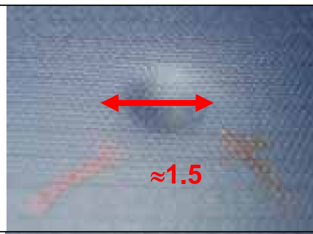
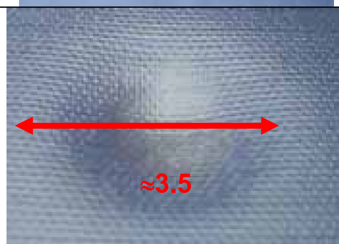
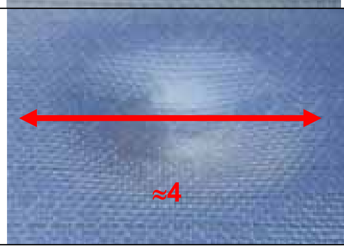
Impact energy (J)	A samples	Zoom
3.3		
5.6		
12.6		
20.6		
30.8		

Figure 88: Visual analysis on “A” modules after impact test.

The A samples have suffered from plastic deformation (non reversible change of shape in response to an applied force). The photovoltaic cell is, in fact, deposited on a metal layer.

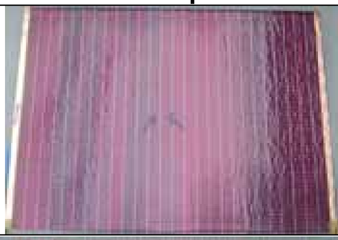
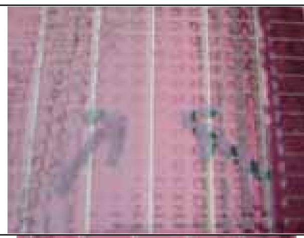
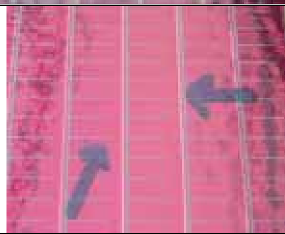
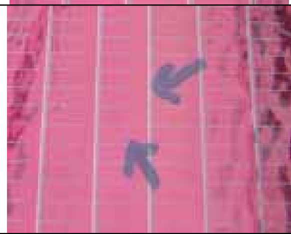
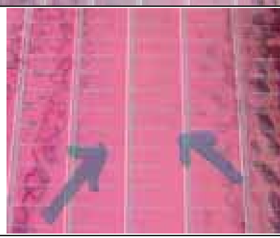
Impact energy (J)	B1 samples	Zoom
3.3		
5.6		
12.6		
20.6		
30.8		

Figure 89: Visual analysis on “B1” modules after impact test

For the B1 samples, microscope observation (at 5x) has revealed no evidence of visual defects. In this case, the cell is deposited on a layer of polymid and has no other metal layers.

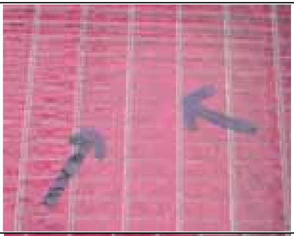
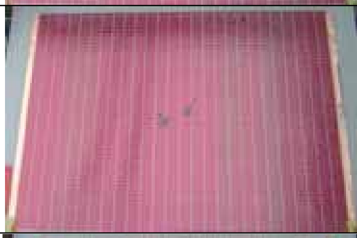
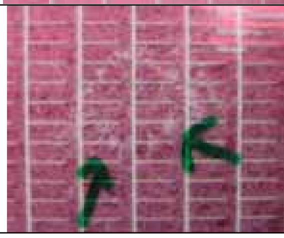
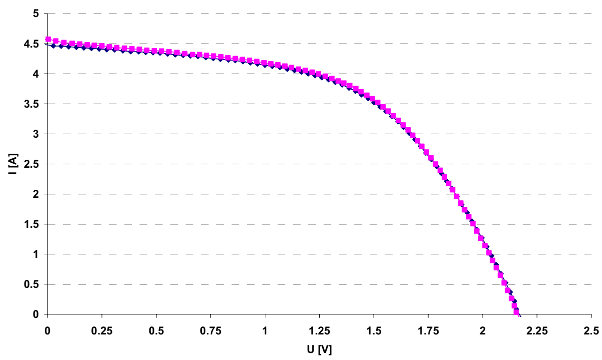
Impact energy (J)	B2 sample	Zoom
5.6		
12.6		
30.8		

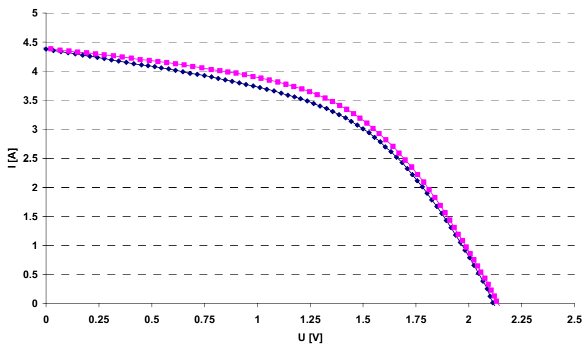
Figure 90: Visual analysis on “B2” modules after impact test

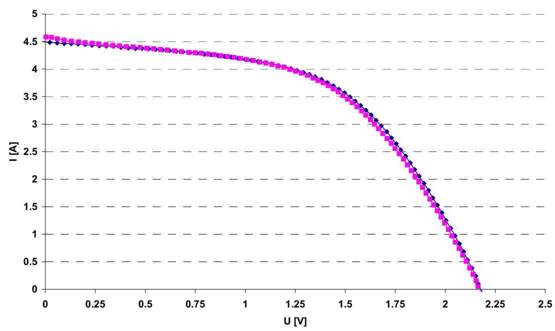
For B2 samples, visual defect has been observed onto the top layer at impact energy 30.8J.

4.10.6 Electrical analysis

Measurements of I-V characteristics before and after impact have shown, despite visibile malformation from 3.3J to 30.8, no electrical degradation in the cells. In fact, the deformation has not affected the functioning of the cell itself, which has a size of 237 by 336 cm2 and which is therefore much greater than the surface of the impact.

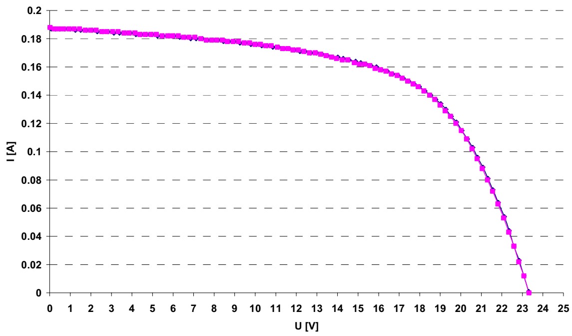
<table>
<tr><th>Impact energy [J]</th><th>Electrical characteristic; Before impact: in blue, After impact: in pink</th></tr>
<tr><td>3.3</td><td>

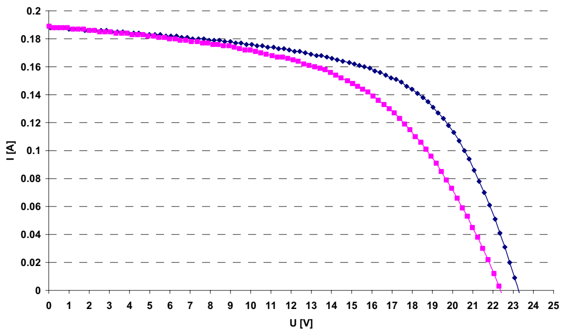
No electrical degradation was observed</td></tr>
<tr><td>5.6</td><td>

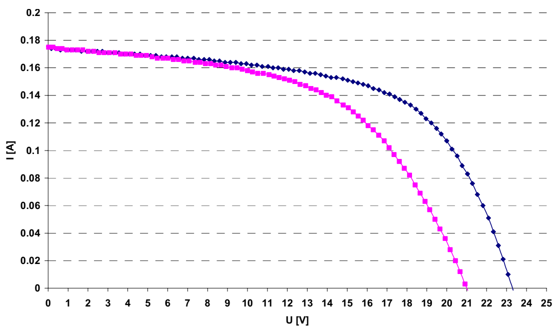
No electric degradation was observed. For this sample, the gain of power is certainly due to dirtiness on the module before impact test.</td></tr>
<tr><td>12.6</td><td>No electrical degradation was observed</td></tr>
<tr><td>20.6</td><td>No electrical degradation was observed</td></tr>
<tr><td>30.8</td><td>

No electrical degradation was observed</td></tr>
</table>

Figure 91: I-V curve of "A" modules

<table>
<tr><th>Impact energy [J]</th><th>Before in blue, After in pink</th></tr>
<tr><td>3.3</td><td>

No electrical degradation was observed</td></tr>
<tr><td>5.6</td><td>No electrical degradation was observed</td></tr>
<tr><td>12.6</td><td>No electrical degradation was observed</td></tr>
<tr><td>20.6</td><td>

The B1 module lost 1 cell.</td></tr>
<tr><td>30.8</td><td>

The B1 module lost 2 cells.</td></tr>
</table>

Figure 92: I-V curve of “B1” modules

The results of impact test on B1 modules, Figure 92, show the loss of one cell at 20.6J and of two cells at 30.8J of the module. It is important to consider the choice of performing the impacts in the worst conditions, that correspond to the cells interconnections.

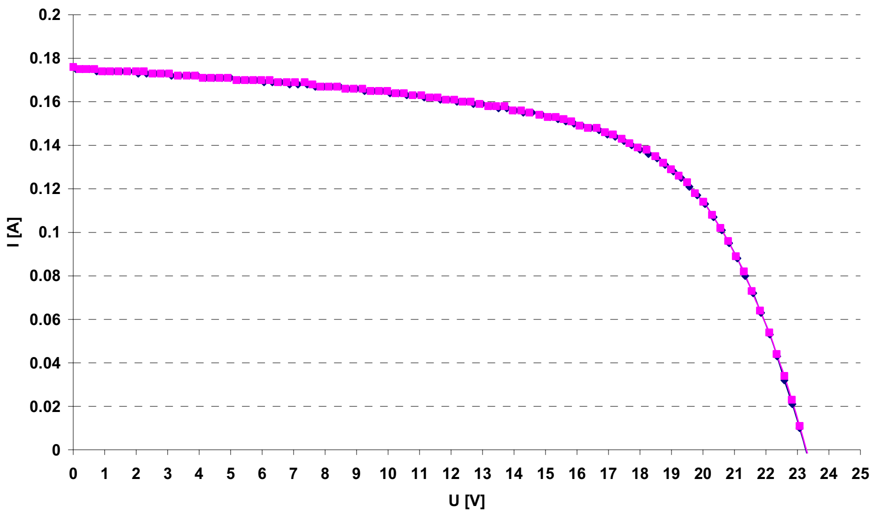
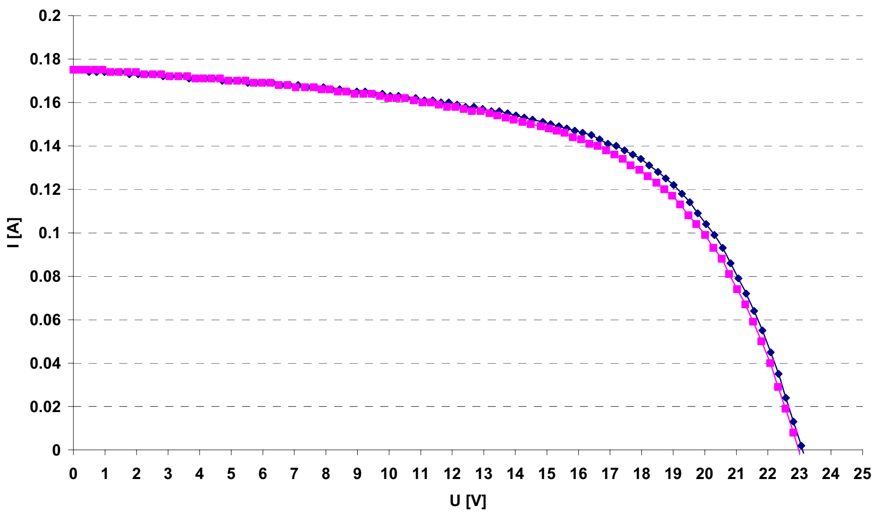
Impact energy (J)	Before in blue, After in pink
5.6	 No electrical degradation was observed
12.6	No electrical degradation was observed
20.6	No electrical degradation was observed
30.8	 No electrical degradation was observed

Figure 93: I-V curve of “B2” modules.

B2 module, which has an additional layer with respect to B1 module, does not show any degradation, even with an high impact of 30.8J. Nevertheless, it is not easy to draw a conclusion, as only one test on a single module is not statistically significant and the execution of several test on different modules is needed.

4.10.7 Impact energy behaviour of one “A” module and one “B” module

The following figures show the visible effects of the impacts at higher energies (50J, 100J, 200J), executed on samples of modules A and B1, compared with energies used in the previously described tests (3.3J, 5.6J, 12.6J, 20.6J, 30.6J).

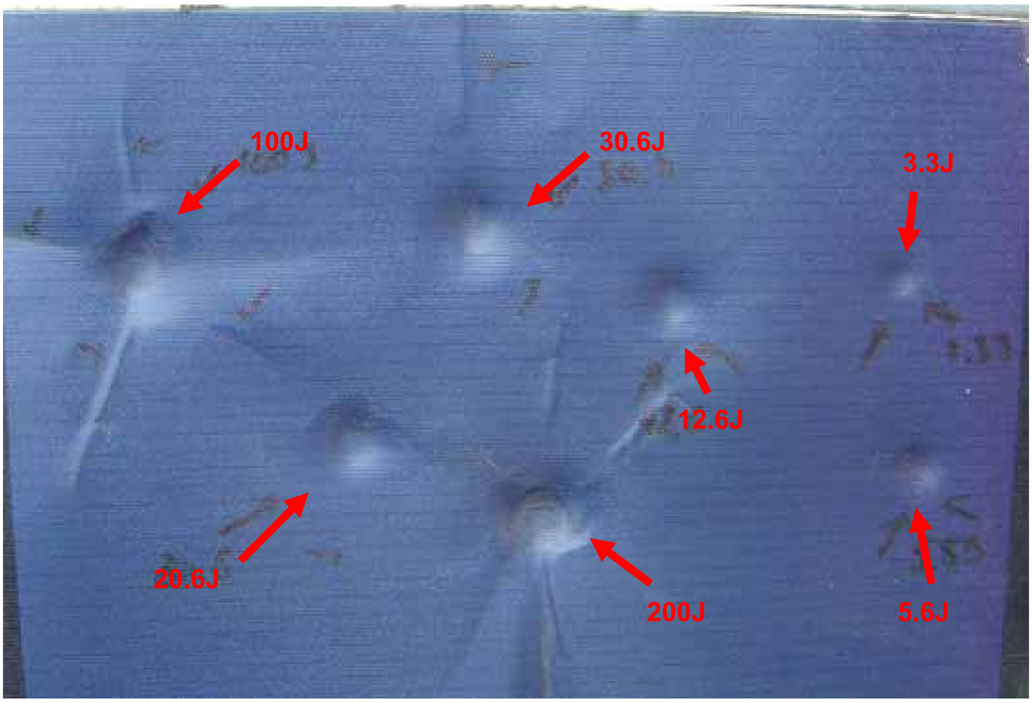


Figure 94: "A" module and impacts

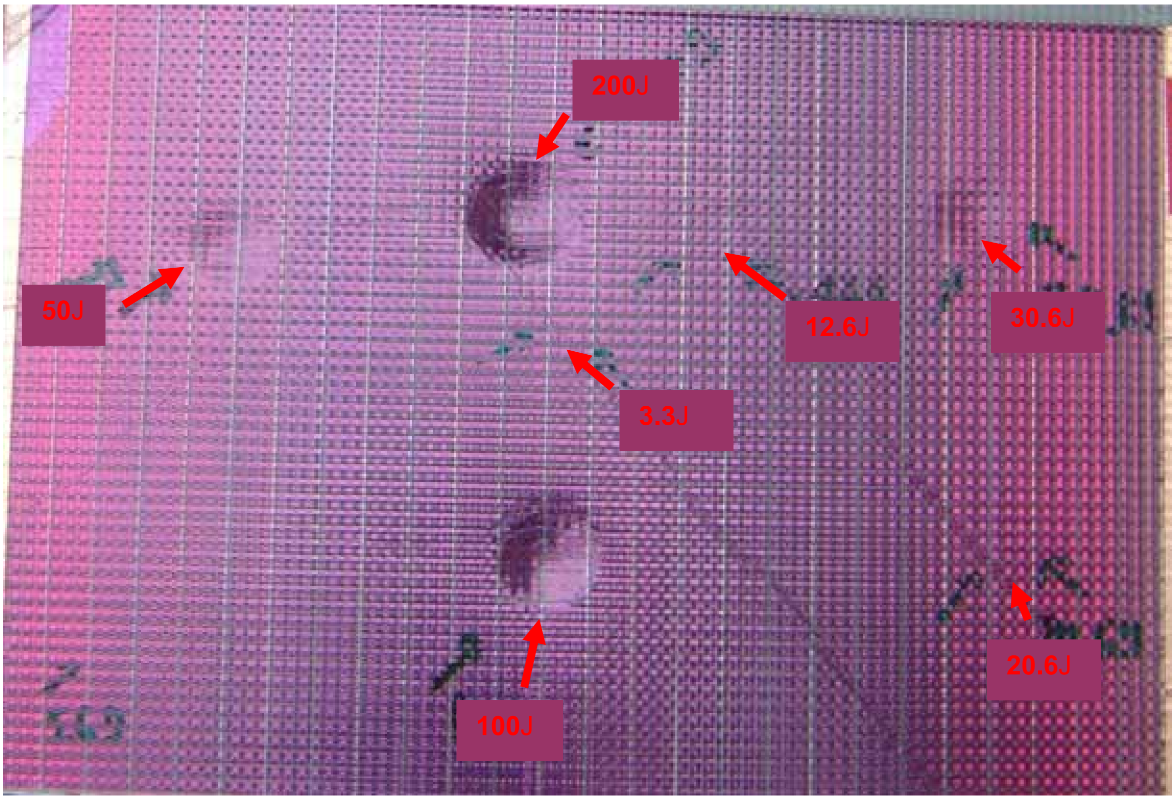


Figure 95: "B" module and impacts

“B1” module in Figure 95 has a rear encapsulant thinner than the other “B1” modules.

At higher energies the perforation of PV module has never been reached. In the following figures, a most important mechanical effect on module A is visible (Figure 96). Figure 97 shows some cracks on the cell in module B1.

Figure 96: "A" module, zoom on 200J impact

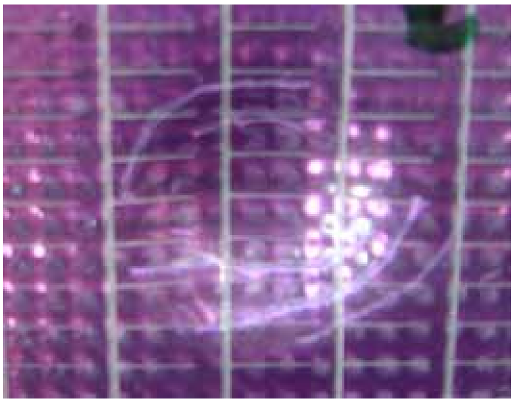


Figure 97: "B" module, zoom on 200J impact

4.10.8 Conclusion on impact test

On the one hand, we have photovoltaic standards that give their own procedures and requirements for impact resistance of standard photovoltaics modules. On the other hand, we have the building standard (SIA, in Switzerland) that gives procedures and requirements for impact resistance of waterproofing roof membranes. In both field, procedure and requirements are different.

In any case, photovoltaic standards should be similar to building standard.

Because of the new thin-film technology deposited on flexible substrate, present photovoltaic standards have not included this technology yet. This technology requires an adapted standard.

The choice of the impact energies as input for the "Rosand instrumented falling weight impactor test" was based on selected PV and building standards. We also added the impact resistance of Sarnafil® waterproofing roof membrane.

Choice of impact energies in relation with standards or materials		
3.3J	-	Lower impact energy that we can obtain with the impact tester
5.6J	SIA V280	Lès d'étanchéité en matière synthétique (Lès polymères) Performances exigées et essais des matériaux (SN 564280)
12.6J	IEC 61646	Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval
20.6J	IEC 61721	Susceptibility of a photovoltaic (PV) module to accidental impact damage (resistance to impact test)
30.8J	SIA V280	Sarnafil® waterproofing roof membrane TS7720 in accordance with the Swiss standard SIA V280

Table 11: Choice of impact energies in relation with standard or materials

Before and after the impact, the samples were examined with a microscope to check the presence of eventual visual defects.

The electrical properties (I-V curve) were measured with a sun simulator, before and after the impact, to verify an eventual electrical degradation.

The following tables show a short view of the results:

Impact energy (J)	Visual defect? (0=no; ✓=yes)	Electrical defect? (0=no; ✓=yes)
3.3	✓	0
5.6	✓	0
12.6	✓	0
20.6	✓	0
30.8	✓	0

Table 12: Summary of impact test on modules "A"

Impact energy (J)	Visual defect? (0=no; ✓=yes)	Electrical defect? (0=no; ✓=yes)
3.3	0	0
5.6	0	0
12.6	0	0
20.6	0	✓
30.8	0	✓

Table 13: Summary of impact test on modules "B1"

Impact energy (J)	Visual defect? (0=no; ✓=yes)	Electrical defect? (0=no; ✓=yes)
5.6	0	0
12.6	0	0
30.8	✓	0

Table 14: Summary of impact test on modules "B2" (with special encapsulation)

"A" modules have visual defects at all impact energies selected.
On "B1" modules we did not observe any visual defect.
The "B2" module at 30.8J has small visual defects onto the top layer.

"A" modules have no electrical degradation at all impact energies selected.
"B1" modules have electrical degradation at 20.6J and at 30.8J. We suppose the loss of 1 cell at 20.6J (-13.5% of initial power) and of 2 cells at 30.8J (- 18.6% of initial power).
"B2" modules with special encapsulant have no electrical degradation at all impact energies selected.

If we refer to the standards, will the modules pass the impact test?
We have to be conscious that the procedure was not exactly the same as described in the standards but it can give a rough idea of the impact resistance requirements.

Standards ✓= pass ; × = failed	A	B1	B2
SIA V280	✓	✓	✓
IEC 61646	(✓) (visual defect)	✓	✓
IEC 61721	(✓) (visual defect)	× (electrical degradation > 5%)	✓

The impact test of the SIA standard would be passed by all PV modules because the absence of perforation of the membrane is required.

The impact test of the standard IEC 61721 would not be passed by the "B1" modules because the electrical degradation is bigger than 5%.

The "A" modules should pass the standard IEC 61646 and IEC 61721. The requirements include no evidence of major visual defects as defined in clause 7, witch is the case of defects on "A" modules. In our opinion, even if there is no electrical degradation, the aspect of the surface is modified, the aesthetic of the flat roof is reduced and, from a mechanical point of view, we do not know the effects of these defects.

5 CONCLUSIONS

In the period 2003-2006, the main goals of the ISAAC-TISO testing centre project have been achieved:

- Maintenance and improving of the ISO 17025 accreditation of indoor performance measurements with solar simulator;
- Development of new MPPT devices for outdoor tests;
- Carrying on of outdoor test cycle and comparison of the PV modules energy rating;
- Energy rating prediction by means of matrix method;
- Completion and automation of the stand for short term outdoor measurement;
- Maintenance of the three plants 10kW c-Si (1982), 4kW a-Si (1988) and 0.5kW a-Si triple-junction (1996).

One of the objectives of the testing centre was the study of the non-electric problems related to the PV modules integration (BIPV) and to their use as building/structural elements/materials. In particular:

- Study of functional aspects related to building integration of PV;
- Analysis of limitations and obstacles encountered by the operators in the building sector (architects, civil engineers, etc.)

Indoor measurements:

Within the project, it has been possible to maintain the ISO 17025 accreditation for the indoor measurement of c-Si modules. The temperature coefficients determination has also been accredited.

The main activities, in this field, have been the following:

- weekly repeatability measurements: ±1%, for reference modules, in the period 2004-2006;
- instruments periodical calibration;
- annual audits by the SAS (Swiss Accreditation Service);
- international Round Robin tests with the 10 main laboratories in the world;
- new uncertainties according to ISO5725: Pm ⇨ ±2.0%; I ⇨ ±1.8%; V ⇨ ±1.0%;
- installation and put in operation of the thermostatic chamber;
- ISO 17025 accreditation of the temperature coefficients measurement;
- temperature coefficients determination of 27 modules (7 thin-films);
- measurement of the simulator xenon lamp spectrum and check of the light uniformity on the modulo area to verify the class A of the solar simulator according to the IEC standard.

The measurement of I-V characteristic at different irradiances on 18 PV modules showed results with linear behaviours. The accreditation of this kind of measurement is foreseen together with a periodical check of the lamp spectrum to assure the measurement reproducibility.

The I-V direct determination (from Isc to Voc) of capacitive modules can lead to important differences between measured power and real one (e.g. Sanyo – HIP: -12%).The introduction of multiflash measurements, with at least 15 points per I-V curve, allowed to obtain a realistic and accurate result also for modules with capacitive cells.

Finally, it has been confirmed the possibility to perform indoor, with the sun simulator, the power matrix determination. Nevertheless, an accurate matrix determination of thin-film modules will not be possible till the laboratory will be able to verify the lamp spectrum at low irradiances.

Outdoor measurements and test cycles:

The test cycle number 10, with its new procedures, has been successfully completed. In this context, the new developed maximum power point trackers (MPPT) have been used.

The results showed that:

- for 3 modules out of 14, the purchase warranty is not respected;
- after 15 months of exposure all the modules respect the final warranty. Nevertheless the warranty declaration is not always clear or, even, unavailable;
- after 15 months of exposure, the power of c-Si modules is about -3.6% lower, while the real power before the exposure is lower than -2.3% with respect the nominal value declared by the manufacturer (Pn).

The modules degradation refers to the real power measured before and after a defined period:

- the c-Si module degradation in the first stabilization period (H: 20kWh/m2) has been equal to -1.1%.
- in the next one-year period a mean degradation of -1.2% has been recorded.

Outdoor performance inter-comparison:

In technological Energy rating inter-comparison (stabilised power P3 as reference) the modules can be separated into 3 groups: **Group A** with up to 3% of difference respect to the best one, **Group B** with a difference of in between 3% and 6% and **Group C** with a difference from 6 to 10%. The module can be always correlated to the same groups independently of the 3 investigated cases (1 year, clear sky days, cloudy days).

Nevertheless, due to the performance seasonal variations of a-Si modules, the energy rating comparison normalised at P3 depends on the period in which P3 has been measured. At present, a standard defining the annual reference power for a-Si modules does not exist.

- The daily performance ratio (PR) of HIP (Sanyo) module shows a lower temperature coefficient (-0.32%/°C) compared to standard c-Si modules (-0.41 to -0.47%/°C). This lead to reduced temperature losses at high temperatures - and consequently at high irradiances -, so to a better daily PR in general.
- Despite the relatively high temperature coefficient of 0.47%/°C, the module performs very well with higher PR at low irradiances and low temperatures. A better performance at high incident angles or high diffuse fraction seems to be responsible for this.
- Compared to the other technologies, the two Sunpower modules show a higher instability in PR. This effect could be associated to some technology related effects called “surface polarization”.
- Thin film modules usually show an higher PR with respect to the c-Si modules one, despite their important initial degradation. In particular, FS modules have a low temperature coefficient (-0.2%), like a-Si modules, but a stable power during in all the seasons. On the other hand, a-Si modules show a trend with a minimum in winter and recovery in summer due to the combination of the typical annealing of the Staebler-Wronsky effect and the low temperature coefficient.

Energy Rating prediction with the Matrix method:

The final objective of the matrix method is to develop an energy rating procedure which reduces the number and complexity of the required tests and input parameters to a minimum, but still leads to a prediction accuracy which is in the range of measurement accuracy.
The tests on the third reference module are performed on short- term indoor and/or outdoor characterisation methods for the determination of the module performance at different temperatures and irradiance levels. The obtained power matrix $P_m(G_i,T_{amb})$, is the primary input parameter of the Matrix Method.
At this stage no spectral, angle of incidence or coverage effects are explicitly considered within the simulations. The assumption made here is that they make either a small contribution to the total energy output or that they average out over the year.

The ER method with the highest reproducibility and accuracy for all modules was the indoor approach. For all test modules, except for the Kaneka modules which were still not stabilised, the error remained in the range of ±3%.
A superimposition of the single indoor matrices with the respective measured outdoor matrices, not shown here, demonstrated that they are in fact very close to each other for almost all modules (±2%). This explains why the energy predictions through indoor measured power matrices leads to such good results.
To further reduce the error the other effects such as spectral and angle of incidence effects to the simulations probably need to be added. A probably more important aspect to investigate is the influence of the stability of the module. The initial degradation, the long term degradation or other degradation/recovery effects like for example the well known Staebler-Wronsky effect will be important for a good energy prediction.

It can be concluded that the differences in the indoor power matrix of single modules or alternatively a combination of the temperature coefficients and the performance ratio curves, explain already a large part of the differences under real operating conditions. A low temperature coefficient by itself does not guarantee a high energy output, a good PR over the whole range of occurring irradiances is also relevant.

A future energy prediction method for building integrated modules especially if of a-Si technology will of course need the introduction of some of the up-to-now neglected effects.

Unfortunately, it has not been possible to study the energy rating prediction for two different mounting systems, as initially foreseen.

New MPPT for outdoor test stand:

The MPPT 3000 is a multifunction testing device for photovoltaic modules. New features were included and moreover all main parameter ranges were extended. Among these new features, there is the on-line scan of the I-V characteristic and the possibility to measure, independently from data loggers or external peripherals, the main meteorological parameters. A photovoltaic module, when connected to the MPPT 3000, is set to work in an MPP tracking mode. It is possible to connect RTD temperature sensors, pyranometers or other external sensors. Interaction with the MPPT is possible directly using its LCD and buttons or through a simple graphical user interface. The PV module energy is dissipated using an external resistor load with heat sink that must be always connected.

The main characteristics are:

- accurate MPP tracking: maximum 0.5 % error on P_{MPP} tracking
- wide voltage and current scalable ranges: up to 200V / 20A / max 250W
- run-time selectable ranges (automatic or manual)
- I-V Tracer : use of the MPPT3000 as settable IV Tracer
- simultaneous Im and Vm measurement
- possibility to measure, thanks to an in-built micro-converter and independently from data loggers or external peripherals, the main meteorological parameters (T, G, …) by means of auxiliary sensors
- built-in independent data logging: internal data storage allowing the use of the MPPT as datalogger
- galvanically isolated RS-485 interface: dialog between PC master and one or more MPPTs
- optoisolated analog auxiliary outputs in order to measure, using an external measurement system, the PV module working condition and the auxiliary sensors
- non isolated analog output for other sensor measurement
- user friendly management software
- transportable, compact, IP 20 case, wide operating ambient temperature range (from -20°C to +40 °C)

Building Integrated PhotoVoltaic BIPV:

The use of PV modules as building elements, so having a double function, represent only a part of the world PV market, even though integrating a photovoltaic element into the envelope of a building is becoming an increasingly important factor for the acceptance of photovoltaic technology in an urban context.

One of the first analysed aspects has been the definition of BIPV, the limit between integrated and not-integrated is not always defined and univocal. An accepted definition is necessary in relation with the feed in tariff law, where different tariffs have been established.

In addition to IEA criteria list described in the text, we focus the definition of BiPV on the following points:

4. **PV material** (modules) **must have a double function** (to produce power and to have a constructive or architectural function)
5. **PV system must be of high architectural quality** (care in architectural and constructive integration)
6. **PV system must respect the fundamental laws of PV technology** (orientation, ventilation, shadow, output level,…)

The integration solutions proposed must be simple and reliable but must also satisfy non-technical criteria such as colour, shape, lines, and application methods etc and respect the typical functions of a building element (impermeability, safety, insulation, transmissivity etc). In order to confront the difficulties there are in including these non-technical aspects, PV engineers, architects, builders, PV module and building material manufacturers, stakeholders etc were invited to workshops to identify the main obstacles to integration. Two workshops have been organized: the first one grouped the interested people in the school, for the second event several operators at Swiss and international levels were invited .

The main aspects discussed during the workshops are following described:

- Knowledge, information and education.
- Standardisation (anche se difficilmente attuabile in questo contesto).
- high quality examples of BIPV system.
- Transparency of market and costs.
- Visual and aesthetical impacts.
- Increasing offer of BIPV products.
- Simple solutions.
- New tools per aiutare gli architetti.
- Flexibility and modularity.
- Reliability and durability.
- Directory of exemplary BIPV realisations and systems

From the observations of the sector operators, some subjects to be analysed in the project have been selected:

- Information and examples of project: A website was created (www.bipv.ch) to satisfy, at least in part, the demands of architects. It consists of a general information section, a section on the photovoltaic materials available and the various topologies, a section focussing on economic aspects and a section with examples. It also contains part of the results following described.
- Creation of a directory of BIPV systems and products on the market
- Study of the visual aspects (colour, shape, lines, etc.).
- Promozione e supporto per impianti BIPV modello.

In the promotion of BIPV examples, the ISAAC supported the cantonal administration in the definition and the choice of criteria for obtaining subsidies for the realization of BIPV plants.

The PV module’s functionality as a building element does not always match up to what it has substituted. The feasibility of some tests on aspects such as thermal behaviour (U-value and g-value) and impact resistance of PV elements integrated into synthetic roofing have been assessed. Finally the absorption/shielding properties of the non-ionising radiation (NIR) of the various types of modules (wafer or thin film) were analysed.

6 NATIONAL AND INTERNATIONAL PARTNERSHIPS

6.1 National

- 3-S (Swiss Sustainable Systems AG), Lyss (Bern);
- Accademia di Architettura, USI, Mendrisio.
- AET (Azienda Elettrica Ticinese), Bellinzona;
- AEM (Azienda Elettrica di Massagno), Massagno.
- Airlight, Biasca.
- AIM (Aziende Industriali di Mendrisio), Mendrisio.
- AIL (Aziende Industriali di Lugano), Lugano.
- Belval SA, Valangin;
- Berner Fachhochschule, Labor für Photovoltaik, Burgdorf;
- BUWAL (Bundesamt für Umwelt, Wald und Landschaft) – Divisione Comunicazione Educazione Ambientale, Bern;
- Colorix Sarl, Neuchâtel
- CUEPE (PVsyst), Geneve;
- Enecolo AG, Mönchaltorf;
- ESCA, Institut für Physik, Uni Basel;
- Greenpeace, JugendSolarProjekt Schweiz;
- IFEC, Rivera;
- Imprimerie Morellon SA, Romanel-sur-Lausanne
- IMT, Université de Neuchâtel ;
- Laboratoire de Technologie des Composites et Polymères, EPFL, Lausanne.
- Konika Minolta
- Meteotest, Bern;
- NET Nowak Energie und Technologie AG, St.Ursen;
- Oerlikon Solar, Trübbach;
- PSI (Paul Scherrer Institut), Villingen;
- RENINVEST, Chiasso,
- SIKA-Sarnafil Ticino, Lamone;
- Sezione Logistica, Cantone Ticino;
- Sezione Protezione Aria Acqua Suolo (SPAAS), Cantone Ticino;
- Solterra, Chiasso;
- Studio Ingegneria Ghidossi SA, Bellinzona.
- Ufficio Risparmio Energetico, Bellinzona;
- VHF Technologies /Flexcell, Yverdon;
- TTHF, SUPSI, Manno;

6.2 International

- CREST Loughborough University, Leicestershire (UK).
- Dipartimento di Ingegneria del'Innovazione, Università degli studi di Lecce (I)
- SIKA-Sarnafil International, Sarnen (CH);
- SIKA Italia (I),
- Politecnico di Milano, BEST (I)
- Edison SpA (I)
- ESTI (European Solar Test Installation), Centro Comune di Ricerca di Ispra (I);

- ECN (Energy research Centre of the Netherlands), Petten (NL);
- Unisolar (United Solar Ovonic Europe GmbH), (D)
- BP Solar (GB);
- Enerpoint (I);
- Enereco (I)
- Roma Energia, Roma (I);
- Heriot-Watt University, Edinburgh (GB)
- Thermal Systems and Building, Fraunhofer-Institute für Solare Energysysteme, Freiburg (D)
- Phönix SonnenStrom AG, Sulzemoos (D)
- Day4energy, Canada.
- TECNO.EL S.r.l. Roma, (I)
- Solyndra, (US)
- Universita di Roma, Tor Vergata (I)

7 PUBLICATIONS

All paper can be downloaded from the webpage www.isaac.supsi.ch ⇨ Publications.

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9 ANNEXES

1. Work procedure measure IV - PV01
2. I-V characteristic measurements - uncertainty calculation - PV01E
3. Determination of temperature coefficient - PV02
4. Temperature coefficient - uncertainty calculation - PV02E
5. Development of the MPPT3000
6. User Manual MPPT3000
7. List of manufacturers and BiPV typologies
8. Results of the Interdisciplinary Workshop on BIPV
9. BIPV standards and test procedures