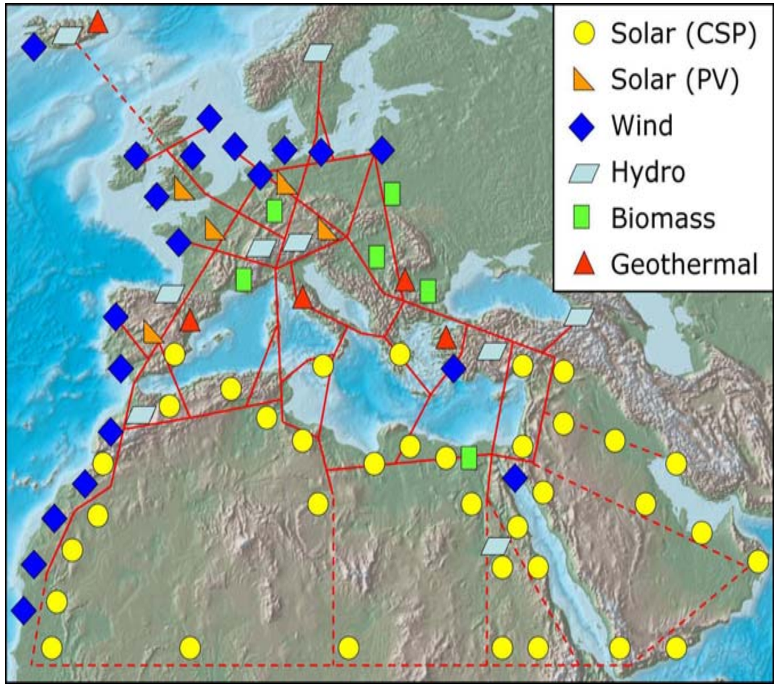
DESERTEC – SOLAR POWER FROM THE DESERT

Initial Position

In the year 2003 the Jordanian National Energy Research Center (NERC), the German Section of the Club of Rome (CoR) and the Hamburg Fund for Climate Protection (HKF) founded the Trans-Mediterranean Renewable Energy Cooperation (TREC), a network of activists that came up with an initiative to create a Trans-Mediterranean Electricity Grid based on High Voltage Direct Current Transmission (HVDC) to interconnect the regional centers of demand and the best sites for the production of renewable electricity.

Offshore and onshore wind power, geothermal power from hot dry rocks, biomass from agro-forestry and communal waste, hydropower and solar power would be generated where their resources are most plentiful, and brought to the major cities of the region with losses below 15% even for 3000 km distance, to be distributed to the consumers by the conventional grid at lower voltages.



„Interstate Highways“ for Renewable Electricity connecting Europe, Middle East and North Africa (EUMENA) as porposed by the DESERTEC Initiative

Research

In the years 2004 – 2007, a series of studies sponsored by the German Federal Ministry for the Environment (BMU) were undertaken under the lead of DLR Division of Systems Analysis in order to find the technical, economic and environmental implications of such a concept for 50 countries in EUMENA.

The analysis included a review and simplified modelling of existing power technologies, an assessment and mapping of the renewable energy resources of the region, and the prospects of electricity demand from the year 2000 up to the year 2050.

A target scenario was developed on the basis of a rigorous set of criteria defining sustainability in terms of cost effectiveness, security and compatibility with society and environment.

Technology options were weighted according to the criteria for sustainability defined before. All technical options were considered: renewable and non-renewable, central and decentralised, large scale and small scale.

Criteria for Sustainable Electricity Supply:

✓ **Inexpensive**
- low electricity cost
- no long term subsidies

✓ **Secure**
- diversified and redundant supply
- power on demand
- based on inexhaustible resources
- available or at least visible technology
- capacities expandable in time

✓ **Compatible**
- low pollution
- climate protection
- low risks for health and environment
- fair access

Criteria for Sustainability defined as Target for the TRANS-CSP Scenario

(www.dlr.de/tt/trans-csp)

DESERTEC – SOLAR POWER FROM THE DESERT

Results

A well-balanced mix of sources can lead to sustainable supply.

The cost of power generation can be stabilised at slightly higher level than in the year 2000.

Conventional power from fossil fuels will increasingly be used for peaking, but not any more for base load. Balancing power capacities will remain until 2050, but fuel consumption and greenhouse gas emissions will be reduced to compatible levels.

1% of the land area will be required for the renewable energy mix (1.2% used today in Europe for transport). 15% of EU electricity will be from solar electricity imports.International cooperation is required to tap the abundant resources in the region.

DESERTEC Industrial Initiative was founded in June 2009.

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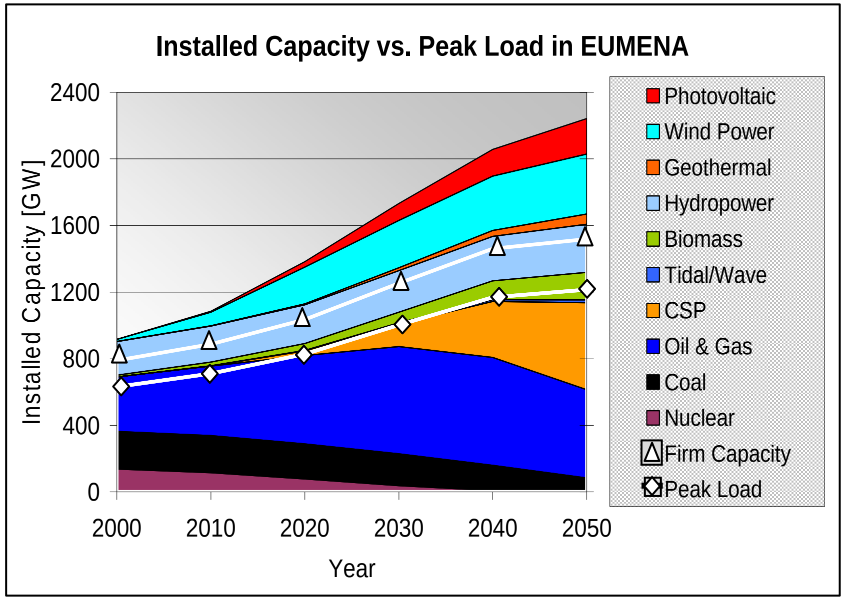


Resulting Scenario for EUMENA from the DLR-Studies. A well-balanced mix of sources can lead to sustainable supply.

Early Market Success of Solar Thermal Power Plants

Solar Power Plants

2.

Sustained Market Entry of Solarthermal Power Plants

▶ Initial Position

Research

Results

Initial Position

Solar thermal power plants can provide firm capacity by utilization of thermal storage and/or back-up firing. This is an important feature for the integration of large proportion of renewable energies into the electricity grid.

State of the art are power plants based on steam turbine power cycles, with live steam parameters up to 390 °C / 100 bar, and storage capacities of up to 8 full load hours. These systems are remarkably successful in the present developing markets, where political support creates favorable economic conditions for solar electricity generation by means of guaranteed feed in tariffs, renewable portfolio standards, tax incentives or direct subsidies.

For a sustainable market penetration, the electricity generation cost of solar thermal power plants need to be further reduced. Component cost reductions can be expected from increased production capacities and consequently improved design, manufacturing processes and logistics. Enhanced performance will also contribute to improved economics. A significant increase of the overall system efficiency can be achieved by raising the upper process temperature of the thermodynamic cycle.

Andasol 50 MW power plant in Spain (Copyright: Solar Millennium AG)

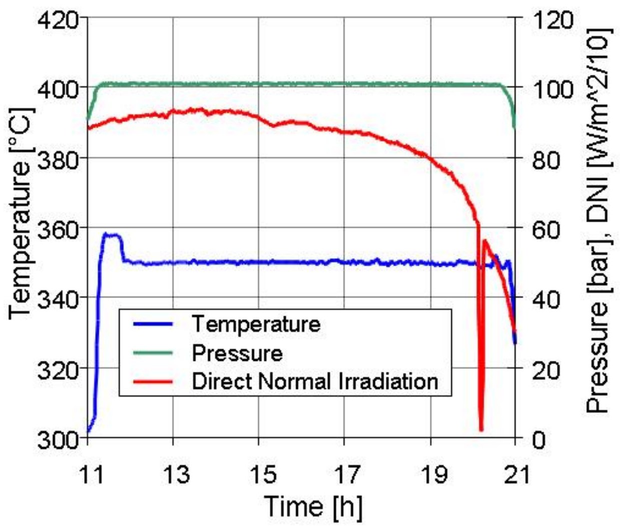
Increased Operating Temperatures for Improved Performance

Research

Two strategies are pursued to increase the operating temperatures of solar thermal power plants:

Near term: Direct steam generation (DSG) in parabolic trough collectors eliminates the temperature restrictions of the heat transfer fluid, as well as losses and cost associated with the primary thermal oil cycle. Challenges are the two-phase flow and resulting thermo-mechanical loads and control requirements. Understanding of the thermo-hydraulic effects by experiments and numerical modeling lead to the development of suitable process control.

Medium term: To exploit the efficiency potential of a combined cycle power plant, high temperature heat of a solar tower system shall be utilized to eventually replace the combustion chamber of a gas turbine. Different receiver concepts and materials have been developed and tested. Solar operation of a 250 kW gas turbine has been demonstrated in an experimental set-up at the Plataforma Solar de Almería.



Control of DSG Process: Constant steam pressure and temperature at variable insolation at the DSG Testloop at the Plataforma Solar de Almería

Demonstration of the Next Generation Technologies

Results

Direct steam generation in parabolic trough collectors is now ready for demonstration in a pre-commercial scale in co-operation with industries. Appropriate projects are underway under the lead of competing industry consortia. The most challenging approach is taken by the German DeTOP Project, where live steam parameter up to 112 bar and well above 400°C will be demonstrated together with an appropriate heat storage.

Solugas is the first demonstration of solar-hybrid gas turbine systems in the 5 MW power range and an important milestone in the development of this technology. The demonstration is based on a commercial gas turbine system that can later be offered to customers in several configurations (combined cycle, co-generation, etc...).

The continuous financial support from the European Commission and the Federal German Ministry for the Environment, Nature Conservation and Nuclear Safety is gratefully acknowledged.

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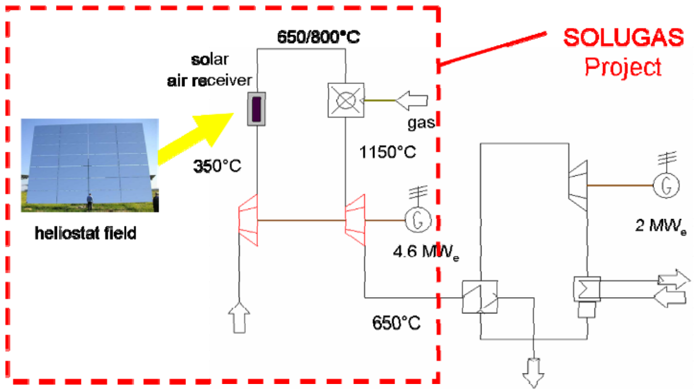

Concept of a solar-hybrid combined cycle power plant

Precise Dual-Axis Tracking for CPV Systems

- Overcoming classical methods

Solar Power Plants

3.

Precise Dual-Axis Tracking for CPV Systems

▶ **Initial Position**

Research

Results

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Initial Position

- Due to the **restricted acceptance angle** of Concentrating Photovoltaic (CPV) modules, the mechanical sun tracking plays an **important role** in the global performance of a CPV system.
- The great majority of CPV trackers are controlled by an **astronomic algorithm** which calculates the sun position depending on the time and geographical location. The accuracy of this control is **limited** by mechanical constraints. Although sun detectors can be used to increase the positioning accuracy, they are usually **too expensive** to be implemented in large scale CPV power plants.
- Therefore, it has been imagined to develop a **sensorless and power-optimized** position controller for dual-axis CPV trackers. The main targets were to **drive down the costs** for material, installation and calibration but also to increase the energy yield by using a **Mechanical Maximum Power Point Tracker (MPPTm)**.

CPV Tracker using FLATCON® modules (source: Concentrix Solar)

Precise Dual-Axis Tracking for CPV Systems

- Reducing costs and increasing energy yield

Fraunhofer ISE

Concentrix solar

Research

Reducing the costs

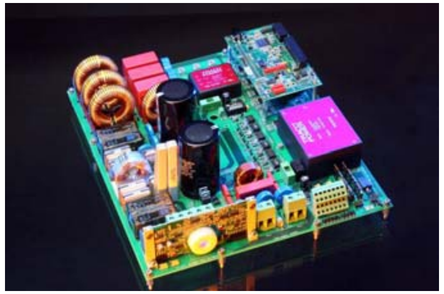
- The motor control unit driving the dual-axis tracker has been integrated into a CPV optimized grid-feeding inverter turning it into a „**Tracking Inverter**“. This allows a dual use of existing components and reduces the production and installation costs.

- The new Mechanical Maximum Power Point Tracker (MPPTm) was designed in order to avoid the use of a sun detector or any other irradiance sensitive device. Basic pulse generators are sufficient to guarantee **+/- 0.05° positioning accuracy**.

Increasing the energy yield

- The MPPTm has been designed to find the generator’s mechanical Maximum Power Point (MPPm) with a **non-invasive method**. The smooth tracking uses **no reverse motion and no deliberate perturbation**. Besides maximizing the electrical power, it minimizes the motor consumption and reduces the fatigue in the mechanical driving chain.

6.9 kWp Tracking Inverter for dual-axis CPV trackers



Motherboard of the 6.9 kWp Tracking Inverter

Precise Dual-Axis Tracking for CPV Systems

- Experience gained in CPV Power Plants

Fraunhofer ISE

Concentrix solar

Results

Currently, **all CPV power plants** from Concentrix Solar are equipped with the Tracking Inverter. A large amount of field data has now proven that the combination of Tracking Inverter and Mechanical Maximum Power Point Tracker (MPPTm) is **highly efficient**. Following points have been confirmed:

- 25 % less electronic costs compared to classical solutions
- No need for a sun detector (no extra time for alignment)
- No need for a precise astronomic algorithm
- No need for accurate position sensors
- Higher energy yield on both sunny and cloudy days
- Smooth tracking and preservation of mechanical parts

The Tracking Inverter and the MPPTm set **a new milestone** in the world of large scale CPV power plants. Their **outstanding performance** and reduced costs make them fully suited to highly efficient CPV systems and helps moving towards **grid parity**.

CPV power plant in Puertollano (Spain) equipped with the Tracking Inverter and using the MPPTm (source: Concentrix Solar)

Quality Control of Concentrating Collector Components

Solar Power Plants

4.

Fresquali

▶ **Initial Position**

Research

Results

Initial Position

The optical efficiency of concentrating collectors of parabolic trough or linear Fresnel type is crucual for the overall efficiency of a solar thermal power plant and for the electricity generating costs. Therefore, quality control during production of mirrors and construction of solar fields is essential.

A fast and flexible method with high spatial resolution had to be developed for indoor and outdoor quality control of concentrating mirrors.

Primary mirror field of Linear Fresnel Collector (FRESDEMO, Almeria, Spain)

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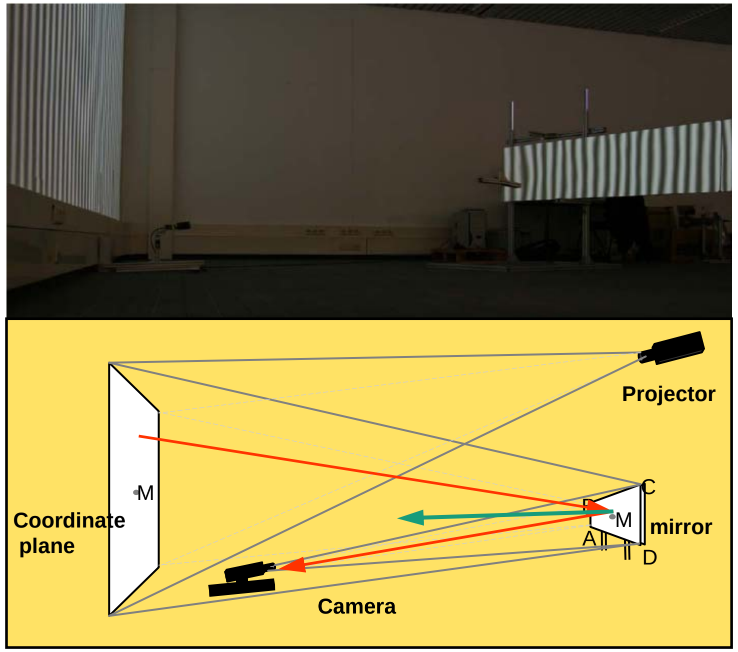
Quality Control of Concentrating

Collector Components

Research

The principle of fringe reflectometry has been used as a starting point for large mirror arrays. Using different possiblities to generate grey and white patterns like static posters, beam projection and LCD displays have been tested as well in a dark indoor environment as outdoors at the collector installation.

Software analyses a series of pictures taken of the reflected pattern, distorted by the real mirror shape.
Calibration has to take into account different geometries and focal lengths of the mirrors.
From angular deviations, the gradient distribution as well as curvatures and shape deviation of a mirror can be calculated.



Measurement principle of fringe reflection and picture of laboratory setup

Quality Control of Concentrating

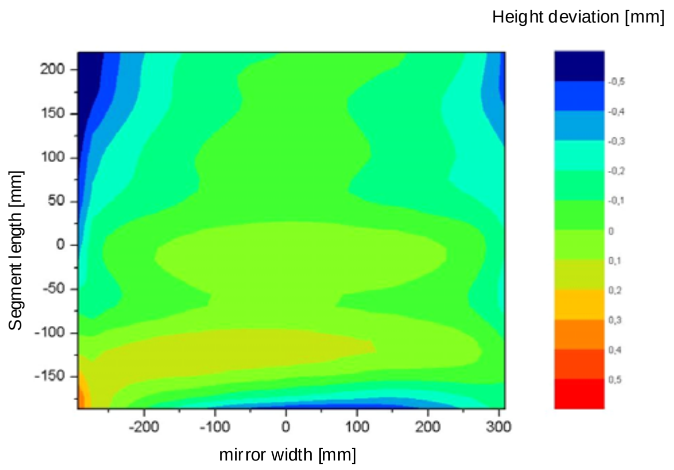
Collector Components

Results

A method suitable for assessing the optical performance of concentrating mirrors has been developed. It can be adapted to indoor and outdoor applications, and used for fast and precise quality control in industrial production.

In this project FRESQUALI, Fraunhofer ISE developed also other similar methods for optical and thermal performance assessment of concentrating collectors.

This work was supported by the German Federal
Ministry for the Environment, Nature Conservation
and Nuclear Safety (BMU) under contract FKZ 16UM0079.



Measured height deviation of mirror segment from ideal shape

Design Concept for Medium Temperature Parabolic Trough Collector

Solar Power Plants

5. Project: dCSP

▶ **Initial Position**

Research

Results

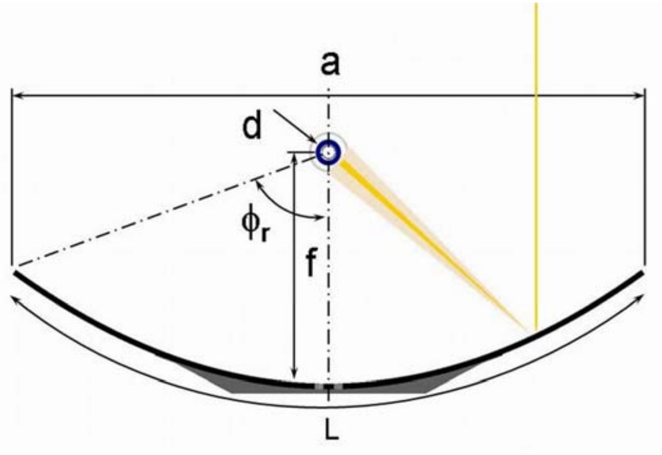
Initial Position

•Aim: Cost optimized concept for parabolic trough using aluminium reflectors

•Boundary conditions: Steam generation 250°C, DNI>1600 kWh/m2 p.a., latitudes <43°

•Industrial Research for Alcan Speciality Sheet and Alcan Innovation Cells

•Fraunhofer ISE: Systematic analysis of optical properties and possible geometry configurations.



Parabolic Trough Collector (PTC): Various combinations of aperture width (a) focal length (f), rim angle (fr) and absorber diameter (d) are possible.

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Optical Characterization and Ray-Tracing Simulation

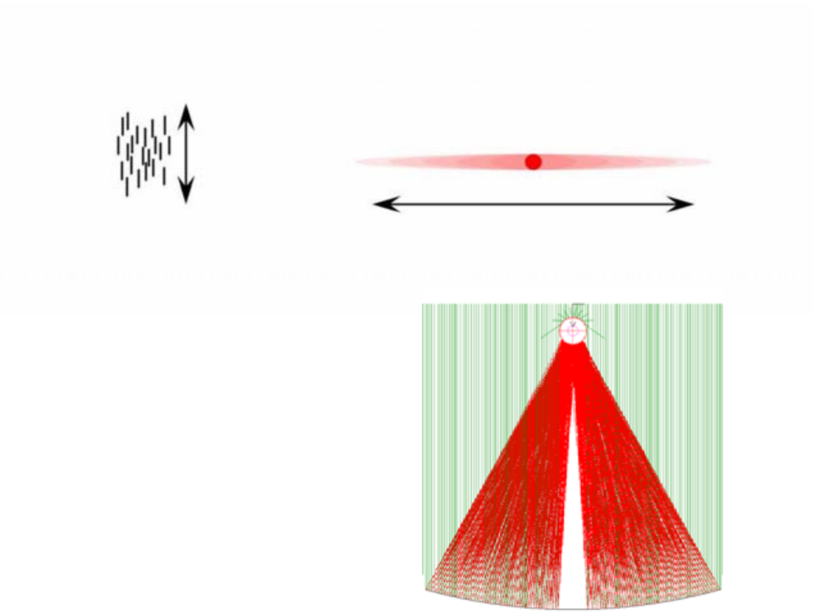
Research

Full optical characterization of reflector sheet

- Specular solar reflectivity
- Angular resolved reflectivity
- Beam profile and scattering

Identify the optimum trough design by ray-tracing and annual simulations

- Innovative modeling of components properties
- Variation of geometry
- Annual calculations for specific sites



Anisotropic beam spread by rolled aluminium reflector (top)

Ray-tracing of PTC for geometry optimization (bottom).

Optimized Design – a result of systematic simulations combined with measurement results

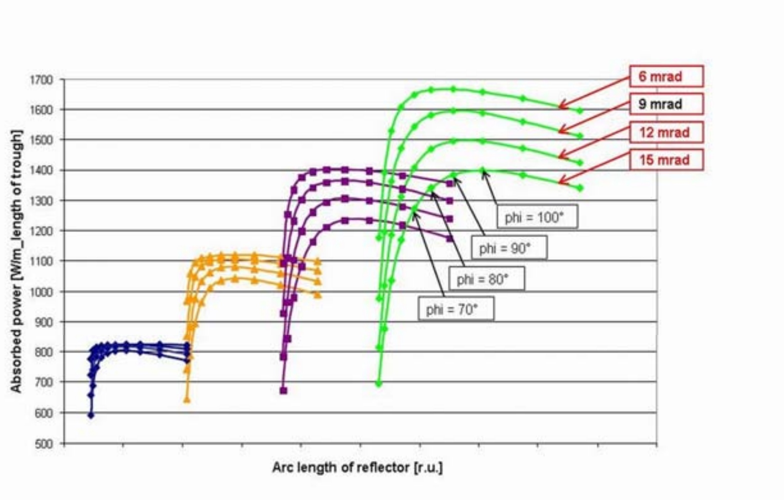
Results

•In the dCSP project the collector concept as a whole was considered and optimized : substructure – reflective sheet – absorber tube and tracking system

→ A full optical analysis of reflector material was carried out and allows precise yield calculations
→ An optical design was tailored for max. 250°C, best used for industrial process heat and/or co-generation

•Exemplary results for systematic ray-tracing calculation are shown in graph:
Influence of aperture width (Ap), rim angle (phi) und optical error of reflected rays (in mrad) on absorbed power (per meter trough), plotted against supplied material (arc length) of reflector sheet. Colored lines indicate increasing aperture width, from blue to green.

•Contact Fraunhofer ISE: Anna Heimsath, Peter Nitz



Influence of aperture width and error on absorbed power of PTC, assuming a direct irradiation of 1000 W/m2, no thermal losses, and fr between 30° and 120°