Optimisation of Design of Grid-Connected PV Systems under Danish Conditions

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The project ”Optimisation of the Design of Grid-Connected PV Systems under Danish Conditions” (PV-OPT) is supported by the Energy Research Programme (EFP) of the Danish Energy Agency under ref. no.: EFP-07 J.Nr. 33033-0057, and has been carried out in the period February 2007 to April 2009.

PV-OPT attempts to investigate existing operational data and design guidelines for grid-connected PV systems and to update or establish recommendations for design of such systems under Danish conditions.

The PV-OPT project recognizes the valuable data and input provided by a wide range of PV experts and institutions, in particular thanks are due to the International Energy Agency Photovoltaic Power Systems Program and the Renewable Energy Unit of the EU Joint Research Centre.

The PV-OPT project further recognizes the valauble data provided via the Energinet.dk supported PV Data Collection project, operated by EnergiMidt.

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ii. Contents

Photo from the presentation and discussion of the PV-OPT results at the Institute of Technology, April 30 2009 (an arrangement by the Solar Energy Group of DANVAK).

iii. Summary

The project ”Optimization of the design of grid-connected PV system under Danish condtions” (PV-OPT) (Optimering af design af nettilsluttede solcelleanlæg under danske forhold) was granted support under the Energy Research Programme (EFP) by the Danish Energy Agency on February 5 2007. Based on operational data regarding PV systems in Denmark and on international state-of-art operational data and expereinces the project aims to analyze critical design parameters and to develop recommendations for design of PV grid-connected system under Danish conditions.

International available operational data necessary for the intended analysis in the project turned out to be very scarce and scattered. Even the comprehensive IEA PVPS Task 2 database[1] does not contain systematically and realiably recorded data on critical parameters over longer time combined with data on PV plant lay-out and local insolation conditions. Litterature studies have revealed only few attempts to systematically analyse design parameters and methods with actual performance of PV systems.

In the project period the installed capacity of grid connected PV systems in Denmark has been about 3-3,2 MW distributed on aproximately 1000 installations, mostly PV roof-tops, and it was foreseen that this amount of installations would provide sufficient operational data for a more detailed analysis of grid connected PV systems under Danish conditions. However it was found, that access to reliable operational data including critical data such as insolation, PV array temperature and output and inverter output recorded systematically over a longer period of time at the same PV system was very limited, and so was critical information about the physical lay-out of same PV systems, such as array orientation & lay-out and local insolation conditions.

The Danish Institute of Technology has a database[2] on Danish PV systems, but the database relies primarily on data provided “volontary” by PV system owners, and the quality and quantity of data was found inadequate for the project. Some of the bigger Danish projects such as Solbyen, Sol-300 and Sol-1000 have also established databases, but these were found either to have been discontinued and no longer available for a variety of reasons or only to include data of questionable reliability on inverter output. It is strongly recommended to establish a systematic recording of Danish PV systems and their performance.

The most reliable data available –and in fact the only useable Danish data – were found in a project run by the utility EnergiMidt on behalf of the Danish TSO Energinet.dk, where critical PV system performance parameters are recorded on 16 PV installations (all crystalline Si modules) spread over the country, and where data on PV plant lay-out and installation are available as well. This effort started mid 2007, and will hopefully be continued for several years. The PV-OPT project has made use of these data covering half of 2007 and all of 2008, and strongly recommends an ongoing process for at least 5 years.

Several sources of the very basic PV system design parameter, the insolation or the irradience, can be found, but it was surprising to find quite large variations between data from the various sources for the same locations in Denmark, and due care should be taken when selecting sources of insolation. For most design purposes it was found appropriate to use the publicly available data recorded by the

[1] www.iea-pvps.org

[2] www.solenergi.dk (in Danish)

Danish Meteorological Institute at about 20 locations spread over the country; data has been recorded for more than 15 years at most sites. A geographical variation in insolation across Denmark of just more than 10 % has been found indicating that local data preferably should be used for design of PV systems above a certain size.

Recent research by the Fraunhofer Institute's Solar Energy Department indicates, that using high resolution time series of insolation values when analysing PV system yield, may provide a more accurate and slightly higher results, than the usual average hourly or daily values used. The main reason given is that short term peaks are masked in the averaged values.

Several both free and commercialy available simulation/design tools have been evaluated in a Danish context. If used properly these tools all give more or less the same results in terms of kWh produced to the grid; some of the tools have many, some only few, adjustable design parameters, but one has to treat these design parameters with diligence, and often run a series of simulations one a well known PV system in order to "calibrate" same parameters. The main problem in this context is again the insolation data used. Some of the tools come with an integrated database of insolation data, and one should be careful when using this as described above, even if it is the easiest choice. When fed with the same insolation data the results of the tools exhibit a very good agreement, and a good agreement between simulation results and actual recorded data is found for all tools when using on-site measured insolation data. It is furthermore found, that in order to carry out a detailed comparison between the results of simluation/design tools and actual PV system recorded data, it is necessary to have quite detailed and accurate information about the PV system physical lay-out and the insolation field, e.g. albedo, reflections, shadows etc. – information that normally will not be readily available and information that easily may change with time.

On the issue of the electrical layout of the PV array it has not been possible in the project to identify any general applicable experiences. It is well known, that if you have an array with modules with different orientation you loose output if connected to the same inverter. However, several small inverters are more costly than a single larger one indicating the choice should be based on analysis of the concrete PV system.

It has for some years been the rule, that the inverter capacity relative to that of the PV array under Danish conditions should be around 80 %, this being the optimal balance between cost of inverter capacity and loss of power, when the array produces at more than 80 % capacity. Analysis carried out in the project indicates, that at present array capacity and inverter capacity should be similar. This is because inverter cost has gone down and many inverters have short time overload capacity. The same experience has been reported from Germany.

It seems more important to have a good match between inverter voltage range and PV array voltage under all operating conditions than to specify a very accurate power ratio. Some inverters will have a higher efficiency at certain voltages, despite a wide power range, in this case the PV array voltage should match this peak efficiency voltage window.

None of the 16 PV systems monitored by EnergiMidt includes thin film modules. The project has therefore carried out some indicative spot measurements at the Institute of Technology. These spot measurements do not underpin the often stated belief, that thin film modules may have comparative better performance at low insolation than crystalline types.

1. Introduction

The project ”Optimization of the design of grid-connected PV system under Danish condtions” PV-OPT (Optimering af design af nettilsluttede solcelleanlæg under danske forhold) was granted support under the Energy Research Programme (EFP) by the Danish Energy Agency on February 5 2007[3].

Based on data on PV systems in Denmark and on international state-of-art the project aims to analyze and develop recommendations for design of PV grid-connected system under Danish conditions. The project results will be disseminated to key market actors in Denmark and will go into the IEA PVPS work.

The project has been carried out in three phases:

Data collection

Analysis

Recommendations

The project period was originally foreseen as 2,5 years, but was extended by another year primarily to allow ongoing data collection from 16 well monitored PV systems spread over the country and only established mid 2007.

International data and experiences have been collected via Denmark’s participation in relevant international PV fora, via visits, via the international network of the project partners and via available literature and reports. It was somewhat surprising to find, that relative little systematic work is available on the main topic of PV-OPT: optimization of design based on operational data and experiences.

National data and experiences have been collected mainly from the partners own sources, but also from other available sources. Again it was somewhat surprising to find, that the availability of good quality PV plant monitoring data is quite limited. It can only be encouraged to establish a national monitoring scheme for grid-connected PV systems, thus building a good quality database on operational data this way facilitating future evaluations of the promising PV technology under Danish conditions.

Furthermore, it was somewhat surprising to find – even in small country like Denmark – relatively high variations and uncertainties in the very basic design data for PV plants: the resource i.e. the insolation. Again with a view to the future it can only be encouraged to start a process of firming up data on insolation in Denmark.

[3] Letter J.Nr.: 33033-0057 dated 05.02.07.

2. PV System Performance – European/International Status

2.1 Definition of PV System Performance

The actual performance of a grid connected PV power plant with its own meter may seem simple to report, but when the aim is to do a reasonably fair comparison between individual plants, there are many complications. First of all, the solar climate is different from site to site, and weather data are not always measured nearby. Next, the real installed power is normally not known precisely, and finally there can be local unknown effects from shading, overheating and grid availability. However, different standard presentations of performance have been developed over time, and the most common ways to normalise the energy output from a PV plant on an annual or monthly base seem to be:

a) Specific performance in net kWh delivered to the grid per kW of installed nominal PV module power, equivalent to the number of full load hours for the plant.

b) Capacity factor. This is derived as the equivalent full load hours above in % of the elapsed time.

c) Monthly or annual Performance Ratio, defined as actual amount of PV energy to the grid in the period, divided by the theoretical amount according to STC data of the modules.

The last method will be preferable if the systems are distributed over a certain geographical area, with significant variation of the irradiation level. The amount of solar energy may be calculated from satellite data or local meteo stations, and then corrected to the actual surface. The main advantage of this method is that the effect of tilt and orientation are largely filtered out, so that the remaining performance difference can be related to the quality of the components and the system design, which is the main purpose of this study.

Uncertainties in evaluation of system performance are among others:

- accuracy of meters, commercial electricity meters are not precision instruments
- down time of the grid, not a big problem in most of Europe
- deviation of actual power from rated power. This is mainly a problem with older modules
- transformation of solar data to the actual site and surface

IEC TC-82[4] definitions for performance parameters can be found in IEC 61724 : Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis.

The most important definition in this standard is probably the performance ratio

$\mathbf{R_p = Y_f/Y_r}$, where

Y_f = final daily system yield in kWh per kW_p and

Y_r = number of peak sun ($1000W/m^2$) hours per day on the array

[4] IEC TC-82: International Electrotechnical Committee, Techncial Committee 82 (on Photovoltaics)

The performance ratio is a dimensionless number, expressing the output of the entire PV system, compared to the reference case where there are no system losses, and all the PV modules are operating with their nominal conversion efficiency. Performance ratio is in practice often calculated on a monthly or annual time base. It is a good indicator of plant quality and operating conditions, because it compensates for the actual level of solar energy input on surfaces with different orientation or different geographic position. The amount of solar energy may be calculated from satellite data or local meteo stations, and then corrected to the actual surface.

2.2 Parameters Relevant for the Performance

Design parameters for grid connected PV systems include: Configuration of PV Panel and Inverter

General data	**Use**	**Source**	**Units**	**Typ.range**	**Importance**
Site/Location	Reference to meteo data	System owner	^{0}latitude and longitude	+/- 60	High
Inclination	Correction of irradiance (or insolation)	System data	Degrees from hor.	0-90	High
Orientation	Correction of irr.	System data	Degrees from S to W	+/-45 from south	High
Fixed/tracking mount	Correction of irr.	System data	-	0,1,2 axis	High
Shading/Horizon profile	Correction of irr.	Site data			Moderate-high
Albedo	Correction of irr.	Site data		0.1-0.4	Moderate-high
PV panel					
Area	Check of limits	manufacturer	m^2		Low
Nominal power	General sizing	manufacturer	W_p		High
System voltage	Match with inverters	Manufacturer	V	100-500	High
Number of strings	Electric design	Manufacturer		1-10	Moderate
Reflectors/concentrators	Booster	Manufacturer			High
Mismatch of modules	Quality check	Manufacturer	% or min/max	+/- 5%	Moderate
Thermal behaviour of array	Operating temperature	System designer	K at 1000 W/m^2	20-40 K over ambient	Moderate

General data	Use	Source	Units	Typ.range	Importance
Modules					
Electrical data	Simulation	Manufacturer			High
Temperature coefficients	Simulation	Manufacturer	% per K		Low
Irradiance influence on module efficiency	Simulation	Manufacturer	% efficiency	Depends on technology	Moderate
Number of bypass diodes	Mismatch/shadow sensitivity	Manufacturer			Moderate
Angle of incidence correction	Simulation	Manufacturer			Low
Shadow tolerance	Simulation	Manufacturer			Moderate
Long term degradation of performance	Economic analysis	Manufacturer	% decrease per year	0.25-0.5%	Moderate
Inverter					
Efficiency curve	Simulation	Manufacturer			High
Inverter configuration (string-central)	Electrical design	System designer			Moderate-Low
Input voltage range	Electrical design	Manufacturer			High
Standby consumption	Simulation	Manufacturer	W	0-5	Moderate-Low
MPPT efficiency	Simulation	Manufacturer	%	90-99%	Moderate/High
Response to overload	Electrical design	Manufacturer		Close down, reduced power	Moderate
Control strategy e.g. master/slave	Simulation	Manufacturer			Moderate

2.2.1 System Configuration – Balance Panel-Inverter Capacity

There are three basic concepts for system configuration of grid connected PV plants:

1) systems with central inverter and parallel PV strings
2) systems with string inverter(s)
3) systems with AC modules in parallel

Most small scale systems today are using the string inverter concept, though central inverters are gaining market share. Large scale systems will almost always be using central inverters. New generations of central inverters can have several independent MPP trackers for optimum operation of individual PV strings; therefore the advantage of string inverters is not so evident today. AC modules, with module integrated inverters, have almost vanished from the market, as the total cost of inverters becomes quite high in medium and large scale PV systems. It is also difficult to build small inverters with the very high efficiencies that have become standard for larger inverters.

Circuit diagrams:

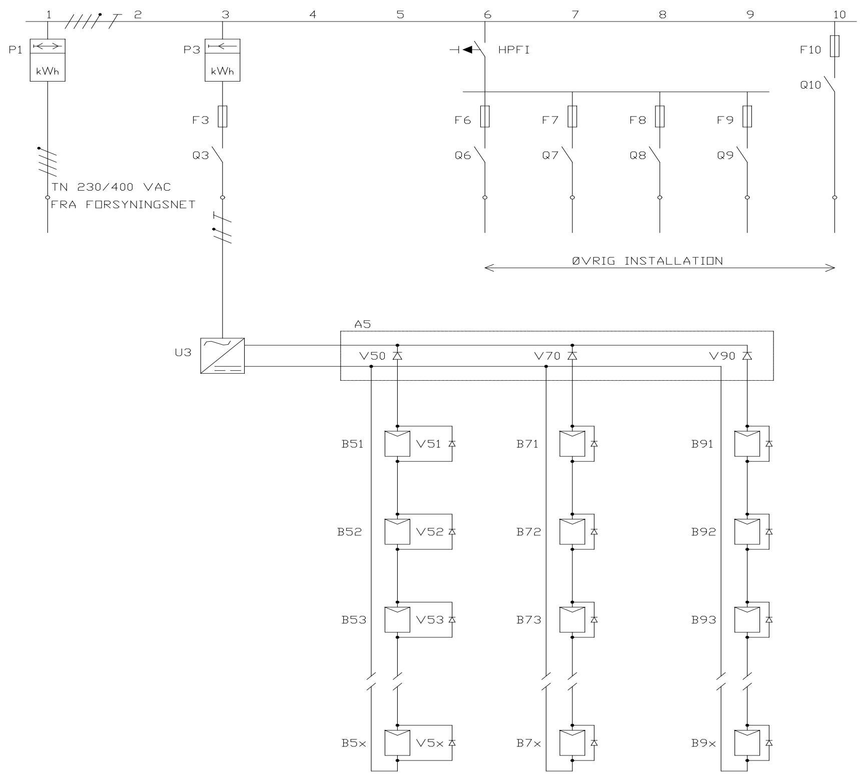
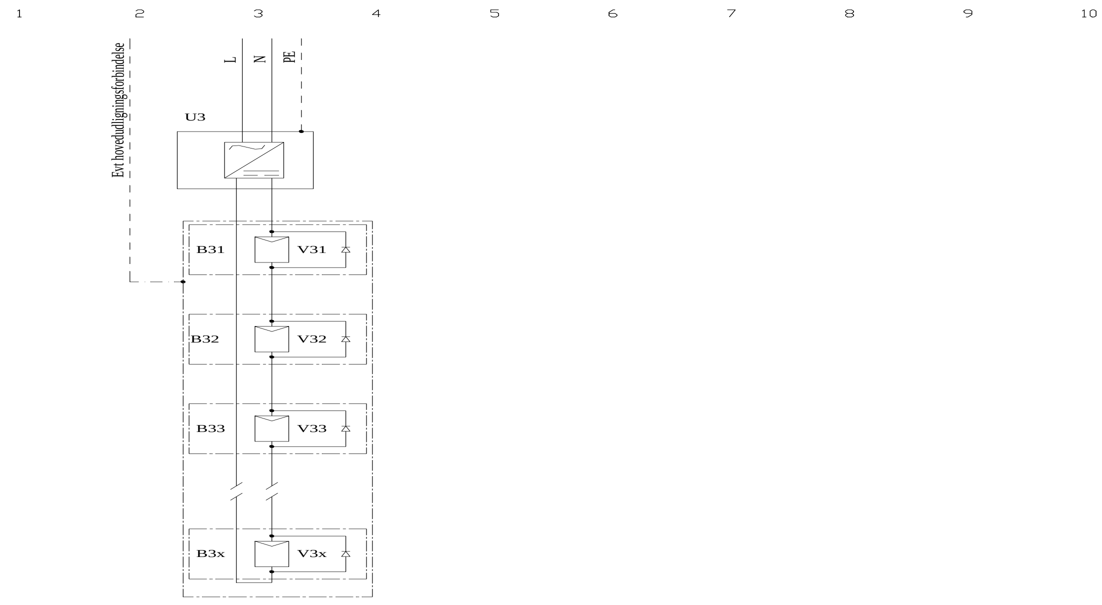
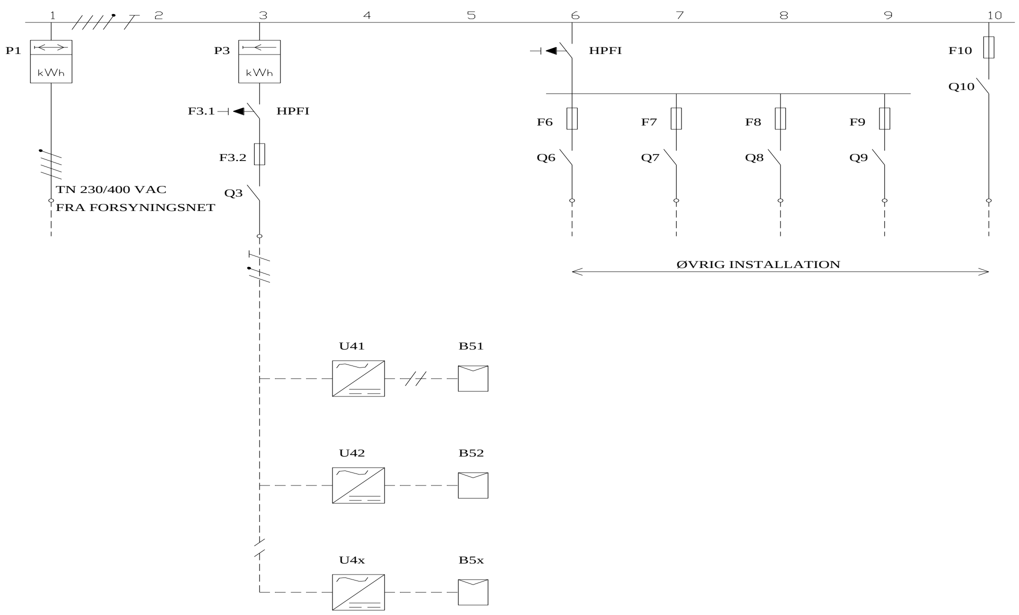


Figure 2.2.1.1 PV system with central inverter



Figur 2.2.1.2 PV system with string inverter



Figur 2.2.1.3 PV system with module integrated inverters

There is no data showing clear advantages or disadvantage from a technical point of view, as long as all parts of the PV array has the same operating conditions. However, many practical examples can be found of malfunctioning PV systems with central or a few string inverters, mostly in the case of BIPV systems with shadows or heterogeneous arrays. It is therefore recommended to use one inverter or one MPP tracker per sub-array in these cases (same electrical data and same irradiance).

Data for analysis of optimum PV/Inverter power ratio

It is obvious that inverters in PV systems are one of the major contributors to efficiency losses, though they are being improved continuously. The peak efficiency of an inverter is insufficient to estimate the energy loss, especially if the efficiency curve exhibits a pronounced maximum at a certain load. The so-called European efficiency is an attempt to compare average efficiency on a uniform base, and most inverter manufacturers list this value in their data sheets.

Eur. efficiency $=0.03\times \eta\, 5\%+0.06\times \eta\, 10\%+0.13\times \eta\, 20\%+0.1\times \eta\, 30\%+ 0.48\times \eta\, 50\%+0.2\times \eta\, 100\%$

In the perfect world, the inverter should keep a high efficiency in the whole power range from 0 to 100% of nominal input. But because there is very little energy in the few hour of maximum panel output, it is common to undersize the inverter relative to the PV array. The authors have tried to find evidence for the best design strategy from:

1: Traditional sizing based on standard climate data (Design Reference Year). Several studies can be found, for example “Sizing of grid-connected photovoltaic systems”, by Jayanta Mondol.

2: Sizing based on high- resolution time series of solar irradiance. To the knowledge of the authors the only analysis of this kind has been carried out by Fraunhofer Institute[5].

3: Empirical data based on recorded performance of real PV systems. No sources found.

<u>Optimum size of inverters in grid-connected PV systems</u>

The Fraunhofer study has revealed that the current practice and rules-of thumb for sizing of inverters does not always result in optimum system solutions. The main reason being that current analysis are typically based on 10 minute-hourly or daily mean values of solar irradiance, and are thus not describing the sort term fluctuations of light intensity. In climates with rapidly changing cloud cover, the inverter runs in a much more dynamic way than reflected in the simulations.

The conclusion of the study is that the more accurate simulation with 10 second averages leads to the recommendation of a 115% ratio of Pmodules/Pinverter for the location of Freiburg. For the more cloudy location of Copenhagen, a slightly higher value of 120% could be chosen.

It must also be noticed that the real behaviour of the PV modules can be different from the standard way to describe their characteristics. For example the temperature effects can lead to considerably different power curves. The over ambient temperature of a typical module @1000W/m2 is found to:

22 K for free standing modules

29 K for roof mounting with good ventilation

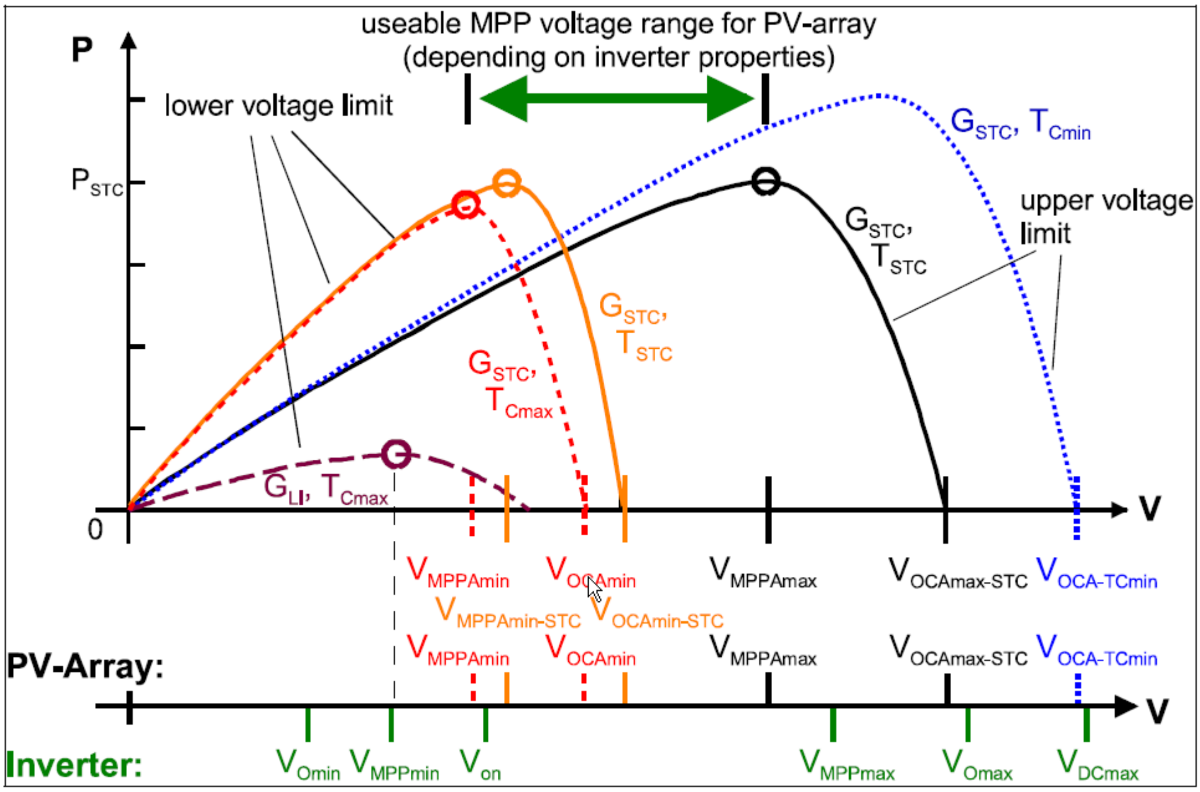
32 K for roof mounting with poor ventilation

43 K roof integrated without ventilation

[5] **Auslegung und Dimensionierung von Wechselrichtern für netzgekoppelte PV-Anlagen**
Dr.-Ing. Bruno Burger, Fraunhofer-Institut für Solare Energiesysteme ISE

The voltage will typically be 10% higher in the first than in the last case, and this could lead to mismatch between the voltage window of the inverter and the MPP voltage of the module.

It is possibly more important to have a good match between inverter voltage range and PV array voltage under all operating conditions than to specify a very accurate power ratio, see graph below. Some inverters will have a higher efficiency at certain voltages, despite a wide input voltage range, in this case the PV array voltage should match this peak. Data can be found in the magazine Photon, which has tested several inverters.



Graph showing the correlation between inverter operating voltage range and PV array voltage as a function of irradiance ant temperature. Special attention must be paid to low operating temperature in combination with high irradiance. For thin film modules, the initially higher-than-nominal performance must also be observed.

Source: Optimum DC operating voltage for grid connected PV plants. H.Häberlin, Berne University of Applied Sciences.

In case the inverter is situated in a warm attic or has been mounted in a way so it is not cooled efficiently, it can have severe effect on power production on warm and sunny days, because the output power is decreased automatically.

Recommendations in this context could be:

1) Ensure that the inverter MPP voltage range is sufficient for the maximum and minimum array operating voltage (-10°C/1000 W/m^2 and 80°C/100 W/m^2)

2) Use an inverter with multiple MPP tracker or several inverters in case of heterogeneous arrays

3) Undersize the inverter with 15-20% relative to the array power. In the case of vertical or east/west oriented systems, the inverter may be 30% undersized.

2.2.2 Listing of Critical Design Parametres

For designers and planners of PV systems, it is of course important to have an idea about which parameters are critical for system performance and safety, and which may be relaxed on without significant consequences. From the table in section 2.2, the following parameters can be identified as the most important for a successful PV system design:

General data	Implication
Site/Location	Even in Denmark, there are regional differences of 10-15% on solar irradiance. In general, islands and coastal areas have the highest potential.
Inclination	Optimum is about 40° from horizontal. For vertical systems, like facades, there is 25-30% less energy available, somewhat depending on the ground albedo.
Orientation	Optimum is due south. For systems with very low slope, the sensitivity to orientation is low, for systems with high slope the sensitivity is pronounced.
Fixed/tracking mount	Perfect tracking allows a 25-30% higher yield in Denmark than fixed systems, but has not been used for practical reasons. With new and cost effective trackers this may change for ground mounted PV plants.
PV panel	
Nominal power	Correct nominal power is important for the design, for example the initial power of some thin film modules can be much higher than the stabilized power. Module mismatch is another issue, but fortunately most manufacturers do now sort their modules in narrow bins of power.
System voltage	A high system voltage tends to minimize losses in cables and inverters, but most components are limited to 600 or 1000 V DC.
Reflectors/concentrators	Diffuse or imaging reflectors are widely used in sunny regions to increase PV performance. In Denmark, where 50 % of the sun´s energy is diffuse light, it does not make much sense to use imaging concentrators.
Modules	
Electrical data	Currents must be matched in series connections, voltage in parallel connections. High open circuit voltage on sunny winter days must be observed! Module efficiency should be high also at low irradiance levels.
Inverter	
Efficiency curve	High conversion efficiency over a wide power range is very important in PV systems, and most modern inverters perform very well, even at low load.
Input voltage range	Inverter selection depends on the voltage window as well as the power. Some inverters are quite sensitive to the import voltage, meaning that maximum efficiency is obtained only for a narrow voltage range.

2.3 Examples of Typical Design Simulation Software Packages

A number of simulation software packages or tools for analysis of the solar resource, the insolation, and analysis and design of PV systems or hybrid systems with PV can be found – some free, some commercially available and some proprietary developed by PV companies for own use. Most of these tools are time step simulators, but a few statistics-based and database tools can be found as well. An attempt to list some of the current and most used tools is given below, however many more tools exist.

Name	Type	Comments
Free tools:		
Retscreen	Dimensioning	Focus on economics & GHG
HOMER	Dimensioning/Simulation	Analysis of PV/RE systems
Hybrid II	Simulation	Detailed RE system simulations
VIPOR & Jpélec	Dimensioning/Simulation	Design of distribution networks
Commercial tools:		
PV-Design-Pro	Dimensioning/Simulation	Focus on PV system design
Off Grid Pro	Dimensioning	Focus on PV system design
PVSYST	Dimensioning/Simulation	Detailed analysis and design tool
PVSOL	Dimensioning/Simulation	High resolution time steps
PVS 2000	Dimensioning/Simulation	Focus on PV system design
PV F-Chart	Simulations	Statistical variations
Meteonorm	Simulations	Solar ressource tool
Proprietary tools:		
Off Grid Sizer	Dimensioning	Conergy
PV Designer	Dimensioning	Siemens Solar
Sunny Island Design	Dimensioning	SMA

Besides theese more specialized tools a number of standard commercial system simulators are often used to analyse and design PV systems, such as Matlab Simulink, PowerSim, Simplorer (APL) and Dymola.

The characteristics of the tools can be summarized as:

- Fundamental data such as meteorological data vary considerably from tool to tool
- Data exchange between different tools are often very difficult or not possible

- Some tools do not allow for co-generation (hybrid system designs)
- Only some tools include (editable) databases of meteorological data and/or PV system components; only some tools allow for setting of control and dispatch schemes
- Only some tools include financial and/or environmental analysis
- Some tools present results in a non-transparent way; different tools often provide different results; PV system loss factors can be difficult to control; shading effects only possible in some tools
- Most tools require experienced operators

In this project it was decided to use the following tools for a more detailed analysis, Retscreen, HOMER and PVSYST, as these tools were found in general to have the highest number of users globally, see also section 4.

2.4 Examples of Publicly Available PV System Operational Data

2.4.1 The IEA-PVPS Task 2 data base

This comprehensive data base contains more or less detailed monthly data from several hundred installations throughout Europe. It is possible to sort the data according to certain criteria, such as country, installed power or module technology. The most relevant plants to study in a Danish context will be those installed in Northern Europe, where temperature and solar resources are comparable. This leaves about 80 installations to be included in the study if a limit of 50 degrees northern latitude is set. Not all of the plants are reporting insolation data, and this will further limit the number of useful data.

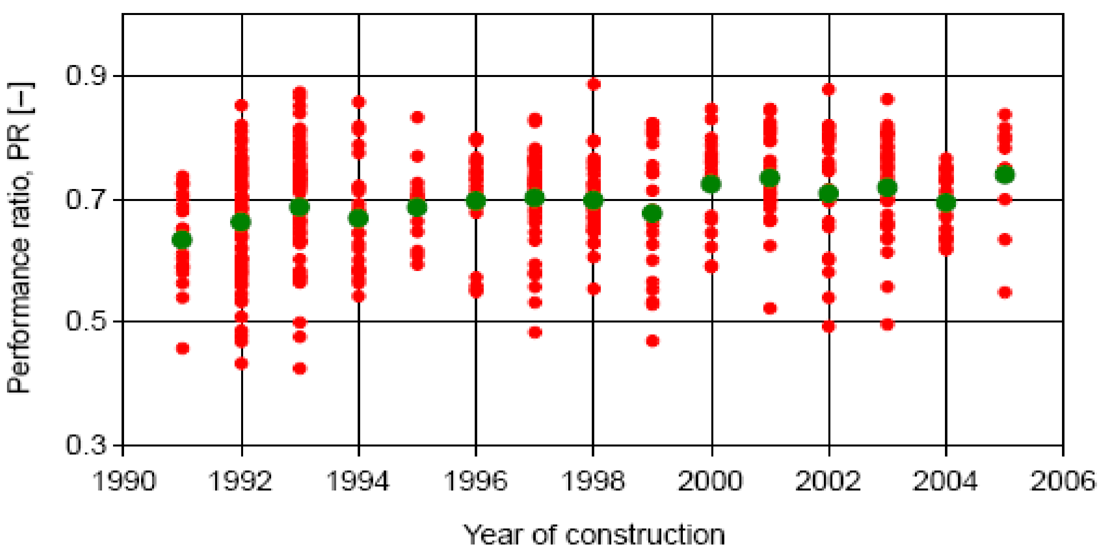


Figure 2.4.1.1. Trend in Performance Ratio from the Task 2 data base analysis

A report from IEA summarises the results for all the registered PV plants as illustrated in Figure 2.4.1.1. , the main conclusion being that the performance ratio has increased from a historic value of

70-75% to a level of 80-85% for the better systems. It is not possible to pinpoint a single cause, but the two most likely explanations are:

1) improved inverters with good part-load efficiency and high reliability. The average annual operational inverter efficiency rises over time from 87% in 1991 to 94% in 2005.

2) more stringent sorting and labelling of modules, which means more precise rated power values

The table below outlines the main technical trends behind the improvement of the performance ratio.

Table 5, A typical grid-connected PV system for 1991 and 2005.

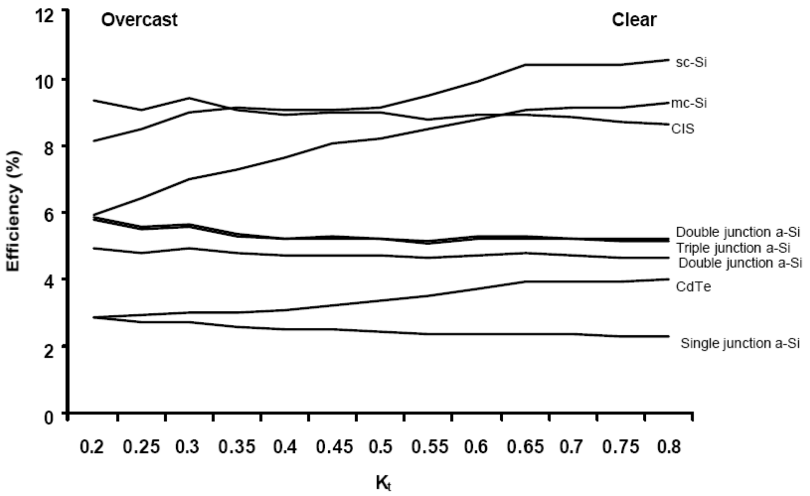
Typical system	1991	2005	
Nominal module efficiency (ηA0)	11.6	12.9	%
Operational inverter efficiency (ηI)	89	94	%
Outage (O)	0.03	0.01	–
Performance ratio (PR)	0.64	0.74	–
Overall PV plant efficiency (ηtot)	7.4	9.5	%
Improvement	100	129	%

2.4.2 Studies of the influence of module technology and module mounting on system performance

In Denmark, the vast majority of PV plants are of the crystalline type; only a few amorphous plants exist, and they have not been systematically monitored.

International studies indicate, that certain thin-film modules perform better in low irradiance conditions. In the EU project COMPARE[6], 11 different module types have been measured in Great Britain and on Mallorca in order to evaluate the real performance in two extremes of the European climate.

The results are showing a significantly higher specific production for the a-Si modules and the CIS modules in low level irradiance.



[6] PV-COMPARE project: http://www.eci.ox.ac.uk/pvcompareweb/frameset.htm

Figure 2.4.2.1 Efficiency vs clearness index for different solar cell materials

Table 2. Normalised power outputs from the Mallorcan and the UK arrays

Sub-array		kWh/kWp Mallorca (h)	kWh/kWp UK (h)	%
Unisolar US64	a-Si	1429	838.6	58
ASE 30 DG-UT	a-Si	1706	968.8	56
Solarex Millennia	a-Si	1555	904.1	58
Intersolar Gold	a-Si	937	479.2	51
Evergreen	mc-Si	1265	841.4	66
Astropower	mc-Si	1036	736.3	71
Solarex MSX 64	mc-Si	1201	765.9	63
ASE 300 DG UT	mc-Si	1352	784.7	58
BP Solar 585	sc-Si	1341	773.8	58
Siemens ST40	CIS	1590	1003.9	63
BP Solar Apollo	CdTe	1007	558.8	56

Table 2.4.2.1 Performance ratio reported for various module types.

In another study from NREL, USA, the performance ratio of different PV modules has been monitored for almost ten years in Denver. Though the climate is different from the Danish climate, the curves indicate the degradation and seasonal fluctuation of module performance ratio.

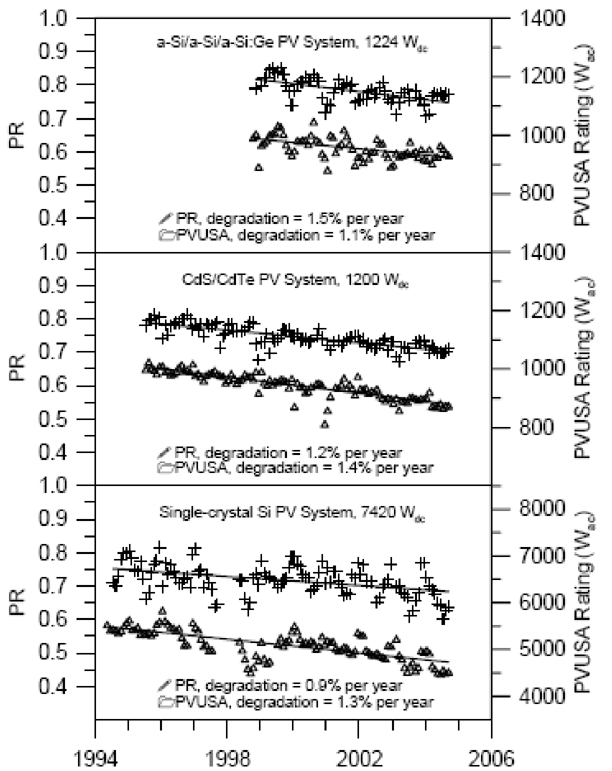
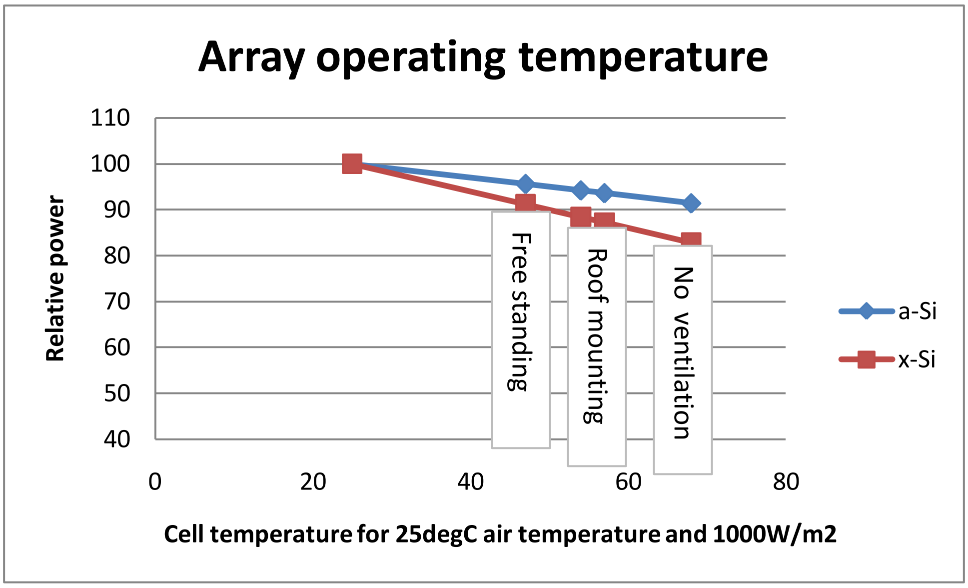


Fig. 6. Long-term degradation rates for three PV systems at NREL from monthly values of PR and PVUSA ratings. Upper regression lines from monthly PR values shown by + symbols. Lower regression lines from monthly PVUSA values shown by Δ symbols.

The way that PV modules are mounted or integrated in buildings will have an effect on the operating temperature, mainly due to differences in the convective heat transport to the surrounding air



Typical operating temperature in full sun for a-Si and x-Si modules and corresponding power. A calculation in PV syst shows an annual production of 926, 917 and 897 kWh/kWp for a crystalline plant in free standing, roof mounted and roof integrated installation mode.

Special consideration has to be taking into account when inverters for a PV plant equipped with thin film (TFPV) modules have to be selected as well as installed.

First of all, many TFPV modules have a higher nominal voltage than crystalline modules of same power, so when TFPV modules are connected in series the system voltage can become very high. Also the fill factor is often rather low, which results in a high open circuit voltage relative to the mpp voltage. New modules will typically have an even higher voltage than stabilized modules. It is therefore crucial to select an inverter type that can tolerate the highest possible voltage (Open circuit voltage for new modules in clear cold weather).

Another issue is the problem of DC feedback voltage from the inverter to the modules. In some cases corrosion in the modules TCO[7] layer has been observed in the case of earth leakage in situations where the solar system and the load circuit is not galvanically isolated via a transformer in the inverter.

As a consequence, several TFPV module manufactures recommend – in some case require – that the negative pole of the solar module system is earthed. Other module manufactures, state in the data sheets, that utilization of transformerless inverters are not permitted.

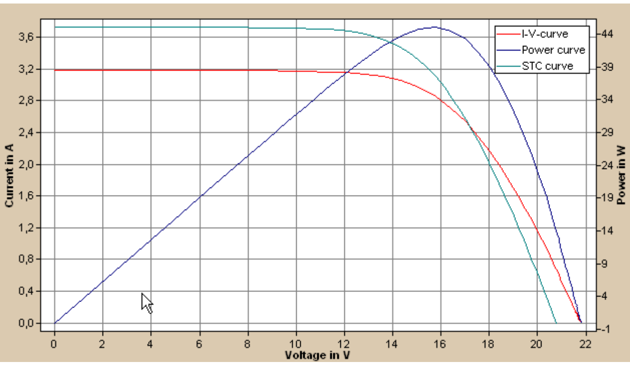
It is therefore highly recommended to check the manufactures specifications for permitted combinations and installation practice for inverters and TFPV modules.

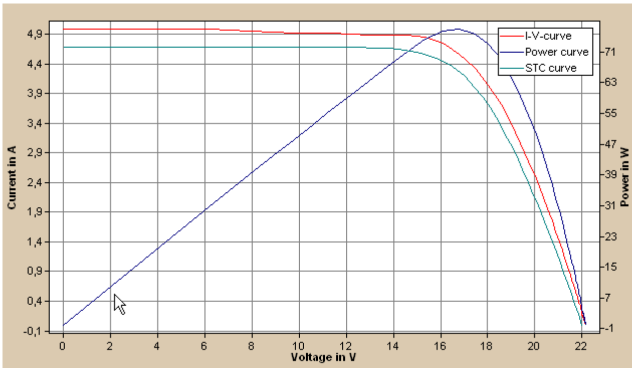
[7] TCO: Transparent Conductive Oxide layer; one of the top layers serving as front contact.

As no good quality operational data under Danish conditions could be found, see also the chapter 3, it was decided to perform a few tests on typical thin film and crystalline PV modules in order to verify (or reject) the claim of some module manufacturers regarding performance in diffuse light. Two modules were tested, one standard polycrystalline module from PB Solar and one CIS module from Würth Solar. These are only indicative spot measurements and should be taken with due caution.

The module performance was tested outdoor at DTI with a PVPM curve tracer. First measurement series is from a day with bright sunshine and operating conditions close to STC (1000 W/m^2 and 25 °C cell temperature)

Measurent in bright sunshine, corrected to STC				
	Isc	Uoc	FF(stc)	Power@stc
	A	V		W
BP poly x	4,98	22,2	0,697	71,9
Würth CIS	3,73	20,8	0,646	50





Recorded reference IV curves for PolyX and CIS module

Second measurement series is from an overcast day with irradiance around 50 W/m^2. Since the irradiance sensor is not calibrated for measurements at such low irradiance levels, the accuracy of the second measurement is not very good, so the absolute value of the results must not be used uncritically. However, the two outputs can be directly compared to see if there is any significant difference in high and low irradiance conditions, respectively. The results are shown in the following table:

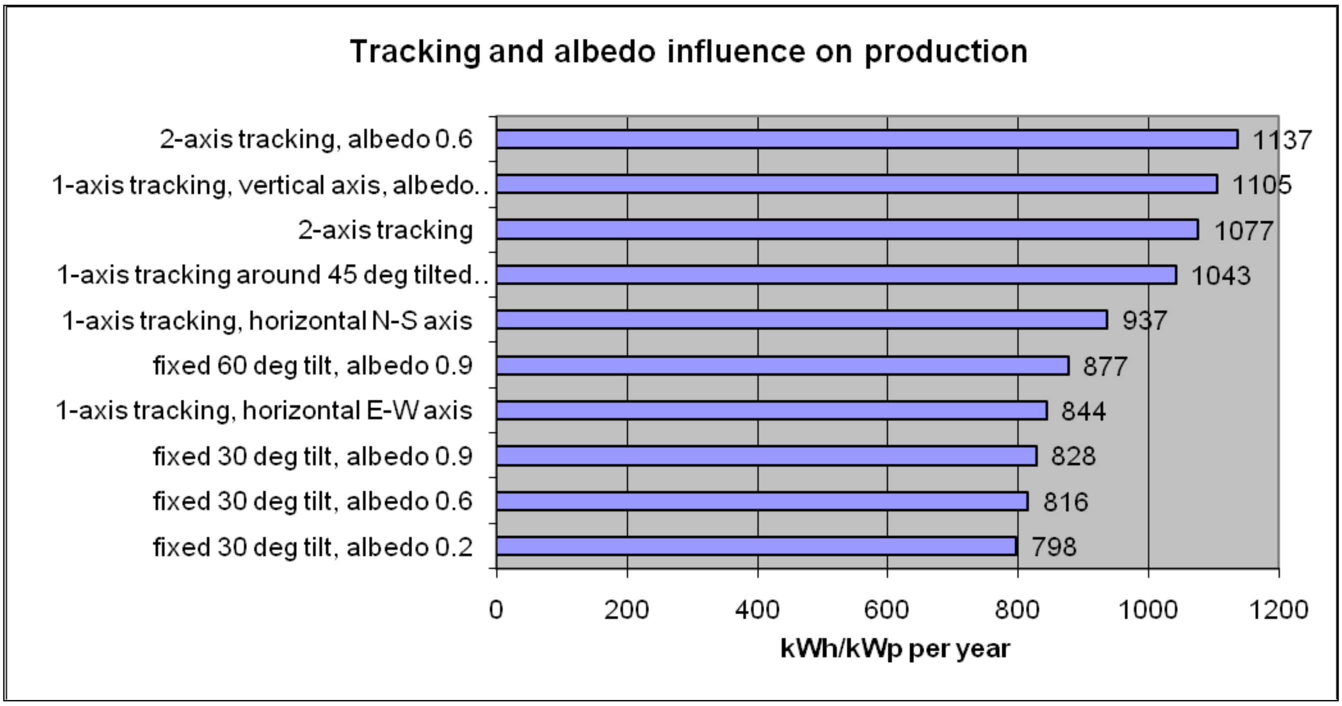
Low light performance for Cell temperature 4°C and irradiance 50 W/m2							
	Isc	Uoc	FF(stc)	Power	Rel. Current	Rel. Voltage	Rel. Power
	A	V		W			
BP poly x	0,47	20,41	0,697	6,69	0,094	0,92	0,093
Würth CIS	0,35	20,43	0,646	4,62	0,094	0,98	0,092

The relative values in the table are calculated with respect to STC values

The fill factor measured in bright sunshine has been used to calculate the power on basis of measured I_{sc} and U_{oc}. The results are remarkable close, and both modules exhibit a very good performance at this very low irradiance level, though the voltage drop is higher for the crystalline module at low light conditions. For this particular thin film module there is thus no evidence of superior performance in diffuse light when compared with the crystalline module. These matters will be investigated in detail in another ongoing Danish R&D project named Thi-Fi-Tec.

A parameter study was carried out in PVsyst in order to quantify the theoretically possible boost of performance if tracking is implemented in Danish PV plants. The albedo value of the ground was varied between 0.2 (grassland) and 0.6 (limestone, white sand) up to 0.9 for a dedicated reflector.

It can be seen that the ground albedo has some significance at high slope installations, but tracking alone is the most effective way to enhance energy output with up to 35% gain.



Tilt degr.	Albedo	kWh	Relative	System data
30	0,2	798	1,00	fixed 30 deg tilt, albedo 0.2
30	0,6	816	1,02	fixed 30 deg tilt, albedo 0.6
30	0,9	828	1,04	fixed 30 deg tilt, albedo 0.9
	0,2	844	1,06	1-axis tracking, horizontal E-W axis
60	0,9	877	1,10	fixed 60 deg tilt, albedo 0.9
	0,2	937	1,17	1-axis tracking, horizontal N-S axis
	0,2	1043	1,31	1-axis tracking around 45 deg tilted axis
	0,2	1077	1,35	2-axis tracking
50	0,6	1105	1,38	1-axis tracking, vertical axis, albedo 0.6

	0,6	1137	1,42	2-axis tracking, albedo 0.6

PVsyst simulation of generic Danish grid tie PV system

A simulation of the same type of modules for a roof mounted PV project in Denmark results in the following annual typical performance ratios (for simulation results see Annex 6.1)

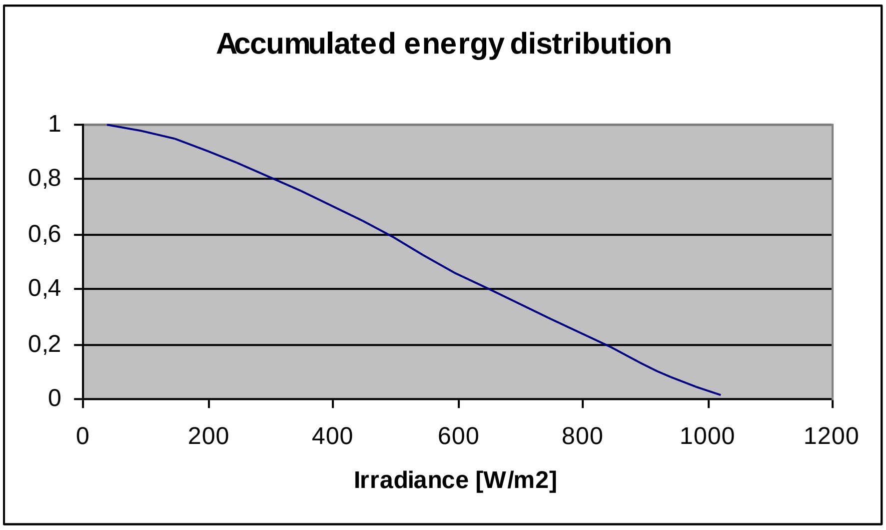
- 0.76 for CIS
- 0.81 for a-Si
- 0.74 for poly-X Si
- 0.72 for mono-X-Si

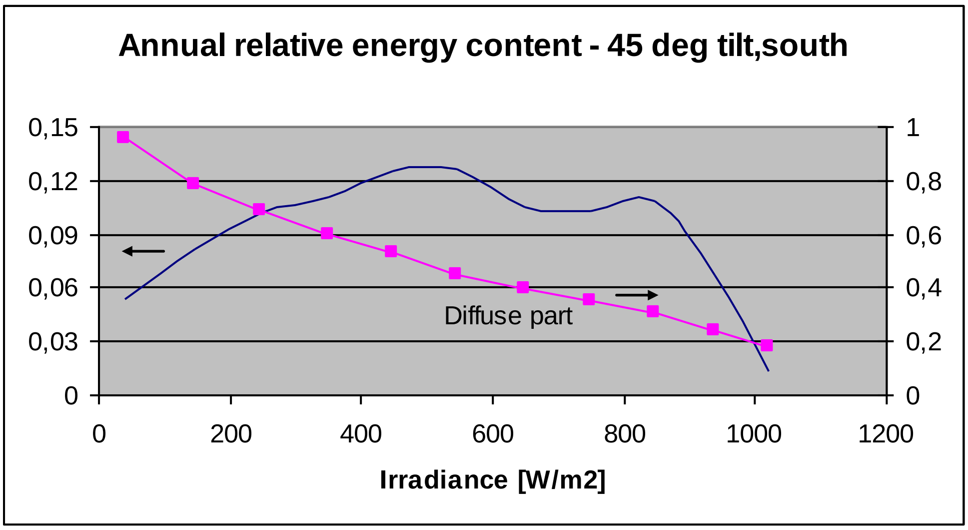
The difference is mainly caused by the difference in low-light performance and temperature coefficients found in the PVsyst component database. The picture may look different for other specific module brands.

3. Danish Publicly Available Operational Data and Yields

3.1 Solar energy resources in Denmark

As an average, a south facing surface with 30-50 degrees tilt receives almost 1200 kWh annually in Denmark. For optimum design of a PV plant, it is important to know the distribution on intensity and wavelength. A calculated distribution of annual available solar energy in solar irradiance bins for an optimum oriented surface in Denmark (Meteonorm) is presented here.





From these graphs it is clear, that the PV plant should respond to a wide range of irradiances, only the very high and very low values do not contribute to the annual yield.

As expected, most of the energy in low light situations arises from diffuse radiation. Over the whole year, 50% of the energy on the surface comes from diffuse light. There are very few measurements of the solar spectrum, but Bason[8] reports some Danish measurements.

[8] Danish Energy Agency project 51181/99-0003; Frank Bason.

Solar maps or irradiation tables are essential tools in planning and dimensioning of solar energy installations. In this study we have tried to collect most of the available data sources for the solar climate of Denmark and analysed the differences. It is important to distinguish between statistical data and time specific data series; the latter may differ substantially from year to year, but a systematic analysis of these variations is outside scope of this project. The statistical data sources we have identified are:

1) Danish design reference year (DRY) based on long term data from Danish Meteorological Institute.
2) Meteonorm database found in the Swiss Meteonorm software package
3) PVsyst database in PV simulation software PVsyst
4) RetScreen database from the Canadian web tool of same name
5) ARCO solar data base from a former major PV module manufacturer
6) PVGIS solar data from the website www.pvgis.org

Some of the data above represent average values for all of Denmark, while other contain data from specific stations (It is not always clear how the detailed data are obtained, for example Retscreen uses a large number of stations, but it looks like they are using data from only a limited number of measured stations).

Apart from statistical data, monthly measurements have been compared from a number of DMI stations and 16 stations connected to geographically distributed PV systems in Denmark. This should provide a certain overview of the regional variation of solar irradiance.

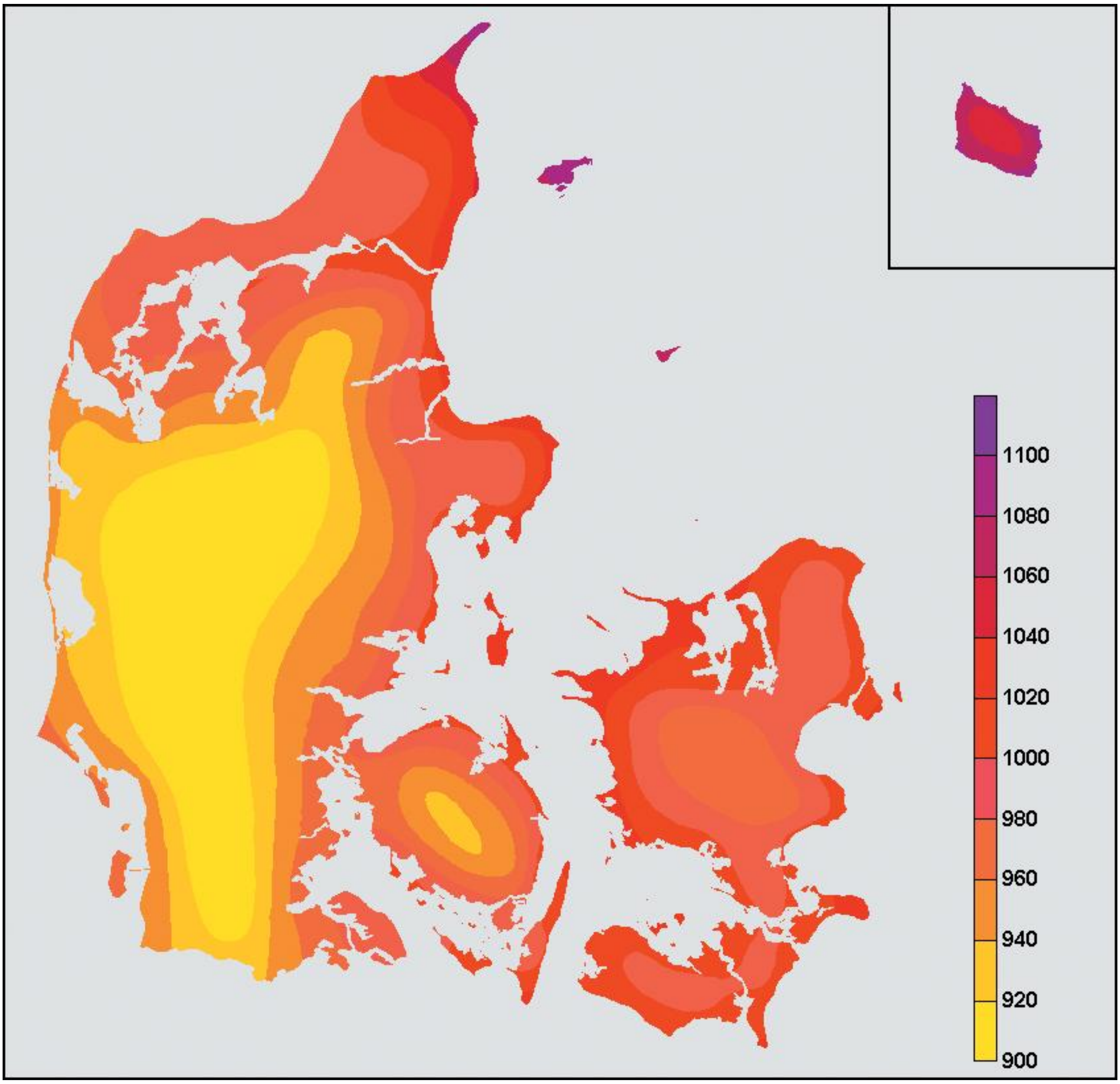
DRY data.

The Danish Design Reference Year DRY is an artificially created data set, based on long term (1960-1991) measurements from Danish Meteorological Institute, DMI. It is one of the most widely used data sets for solar energy calculations, and has therefore been selected as a reference in this report. The monthly irradiance on a horizontal surface, compared to other sources, is:

		DRY	ARCO	Meteonorm	PV GIS	RetScreen
		kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2
Jan		*16*	12	16	14	19
Feb		*32*	30	32	31	36
Mar		*65*	72	63	63	78
Apr		*114*	117	115	112	119
May		*163*	156	156	159	165
Jun		*165*	182	154	154	165
Jul		*160*	164	165	162	164
Aug		*134*	138	132	129	138
Sep		*82*	85	80	80	89
Okt		*43*	45	45	44	50
Nov		*19*	19	19	19	23
Dec		*10*	11	11	10	16
Year		***1002***	**1031**	**988**	**976**	**1062**

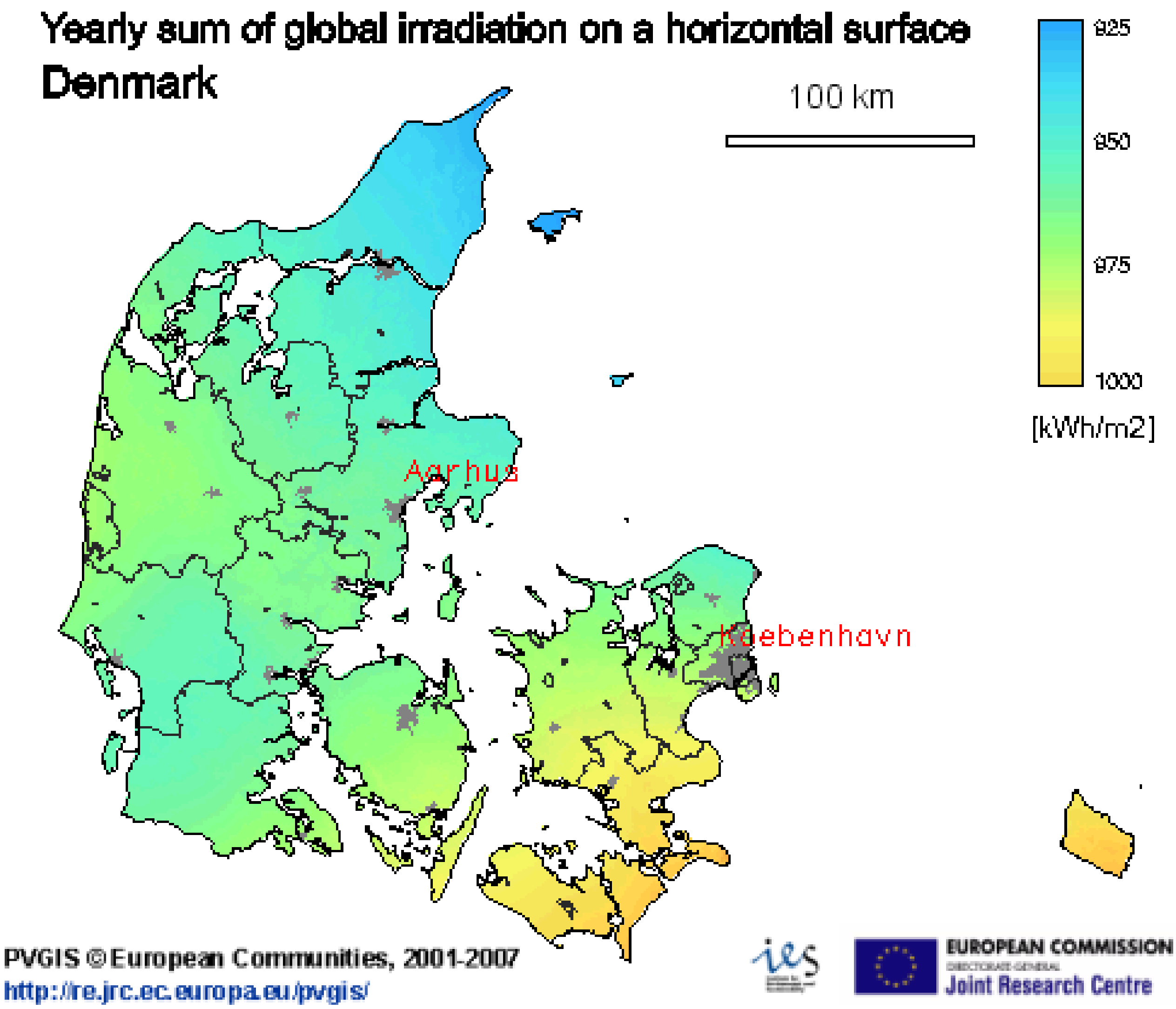
It is important to mention that the data from PVGIS, RetScreen and Meteonorm are selected for a representative site, Taastrup in the Copenhagen area.

The annual sum of DRY values is seen to be significantly lower than the RetScreen data set and the old ARCO data, but higher than the PVGIS map indicates. Not surprisingly, the DRY value corresponds very well with the map from DMI since the raw data are similar. The question is why, and one explanation could be that some of the data sets use average values, and other are geographically specific. It is therefore important to have a look on the solar maps for Denmark:



Global irradiance for Denmark (kWh/m2) based on DMI measurements

Source: DMI

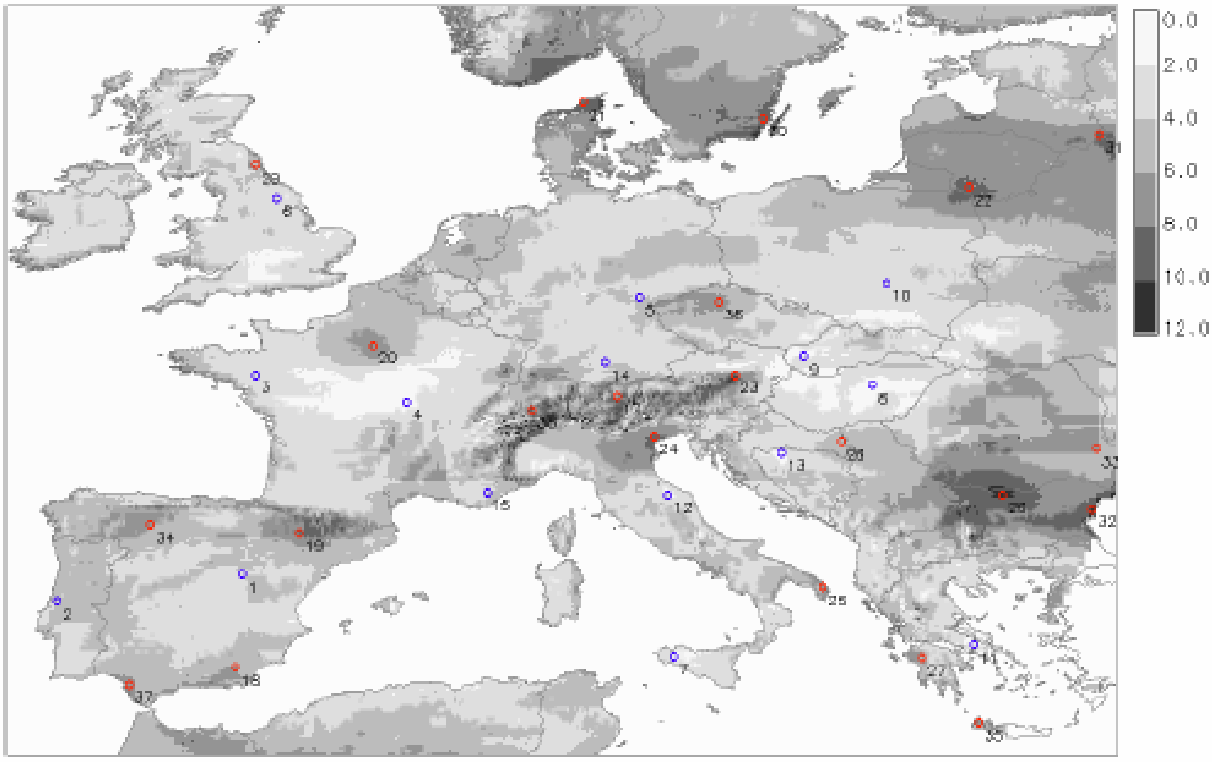


Global irradiance map for Denmark from PVGIS website, mainly based on satellite data., source: JRC Ispra

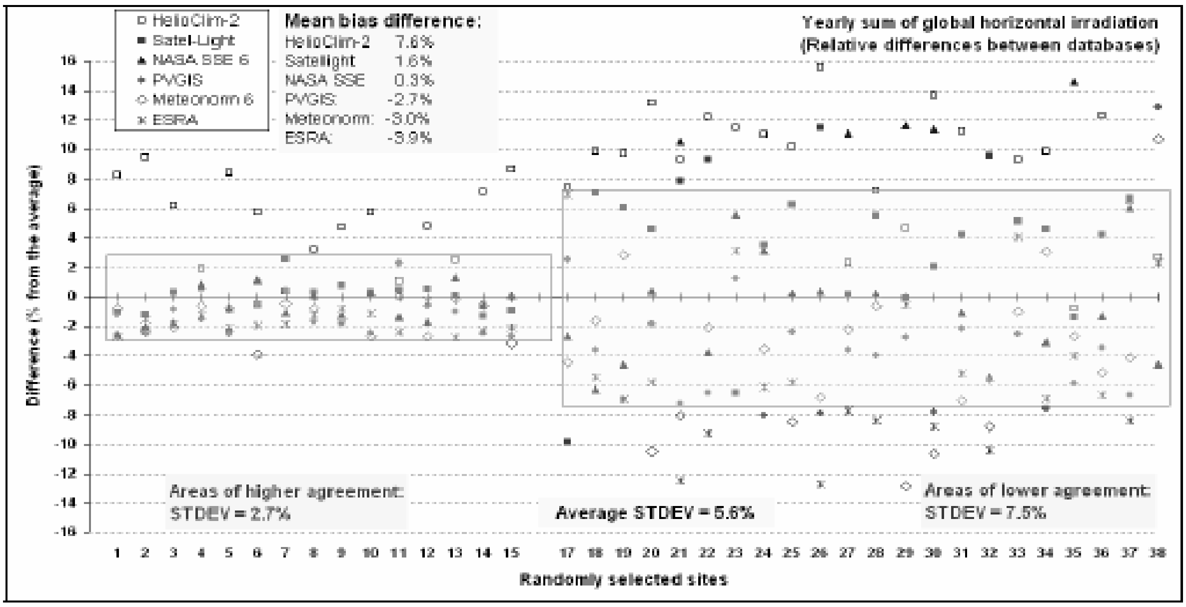
On this map it is evident that some regions differ substantially from DMI data, especially Northern Jutland. According to the creators of the map, the deviation is caused by the influence of a Norwegian station used in the interpolation of data for the map. Coastal effects are also not taken into account, so areas near water will generally be underestimated.

There is no doubt that the distribution of solar irradiance on the DMI map is closer to reality than the PV GIS map, because the DMI map is based on a relatively large number of ground stations and not the less accurate satellite data. The advantage of the latter is that it covers a huge geographical area, and has an interactive calculation tool.

The difference in the various sources of Danish insolation is illustrated in the below map, again originating from the JRC, Ispra. The darker the color the more differ six well known sources of European insolation. The difference is expressed as the standard deviation between the six databases from a common average.



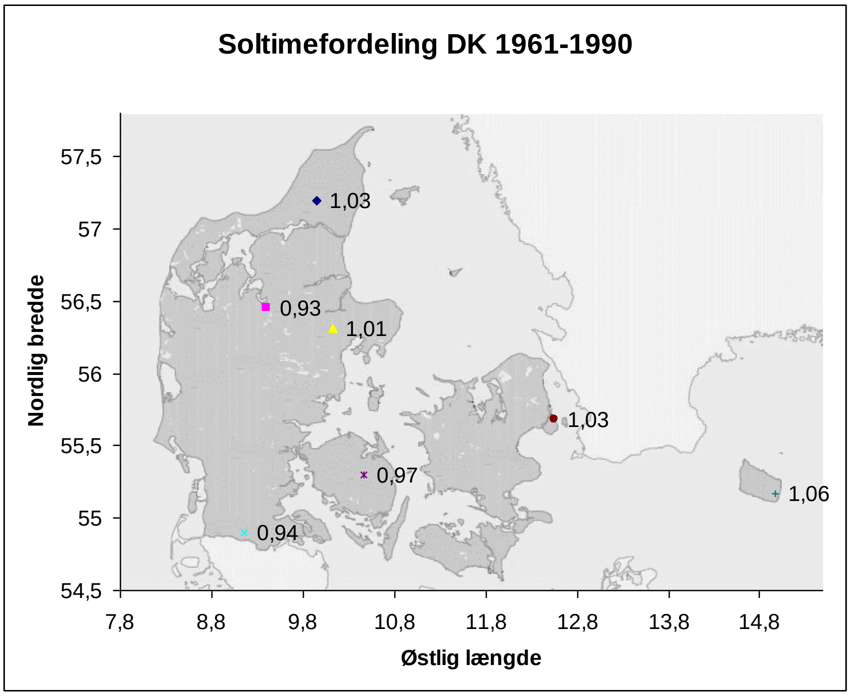
The northern part of Denmark exhibit clearly a relative high variation as mentioned previously with a standard deviation of about 10. The reason for this is not at present fully clear, but an explanation may be indicated by the below graph, again originating from the JRC.

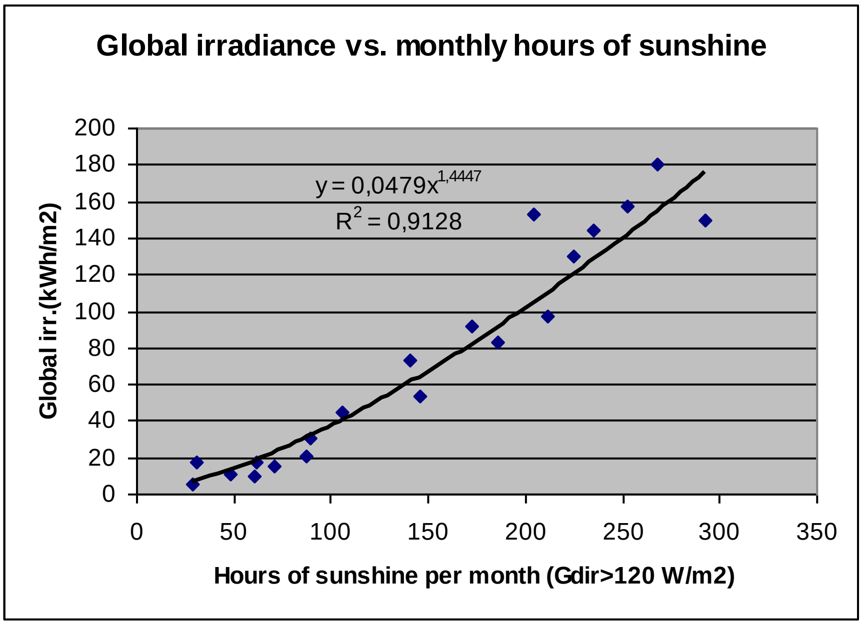


Site number 21 is Northern Jutland and exhibits a rather large variation in insolation values between the six databases. In general it appears from the JRC work, that the three satellite based databases tend to be of higher value than the others.

Historical data of solar irradiance can only be found as sunshine hours, originally being recorded with a solar autograph, which burns a trace in a strip of paper. Sunshine hours are defined by WMO as the number of hours where the direct irradiance level exceeds 120 W/m2. Sunshine hours are still used for weather reports but nowadays electronic sensors are used. The distribution of sunshine hours in

Denmark is seen on the map below for selected measurement stations with long term solar radiation monitoring.

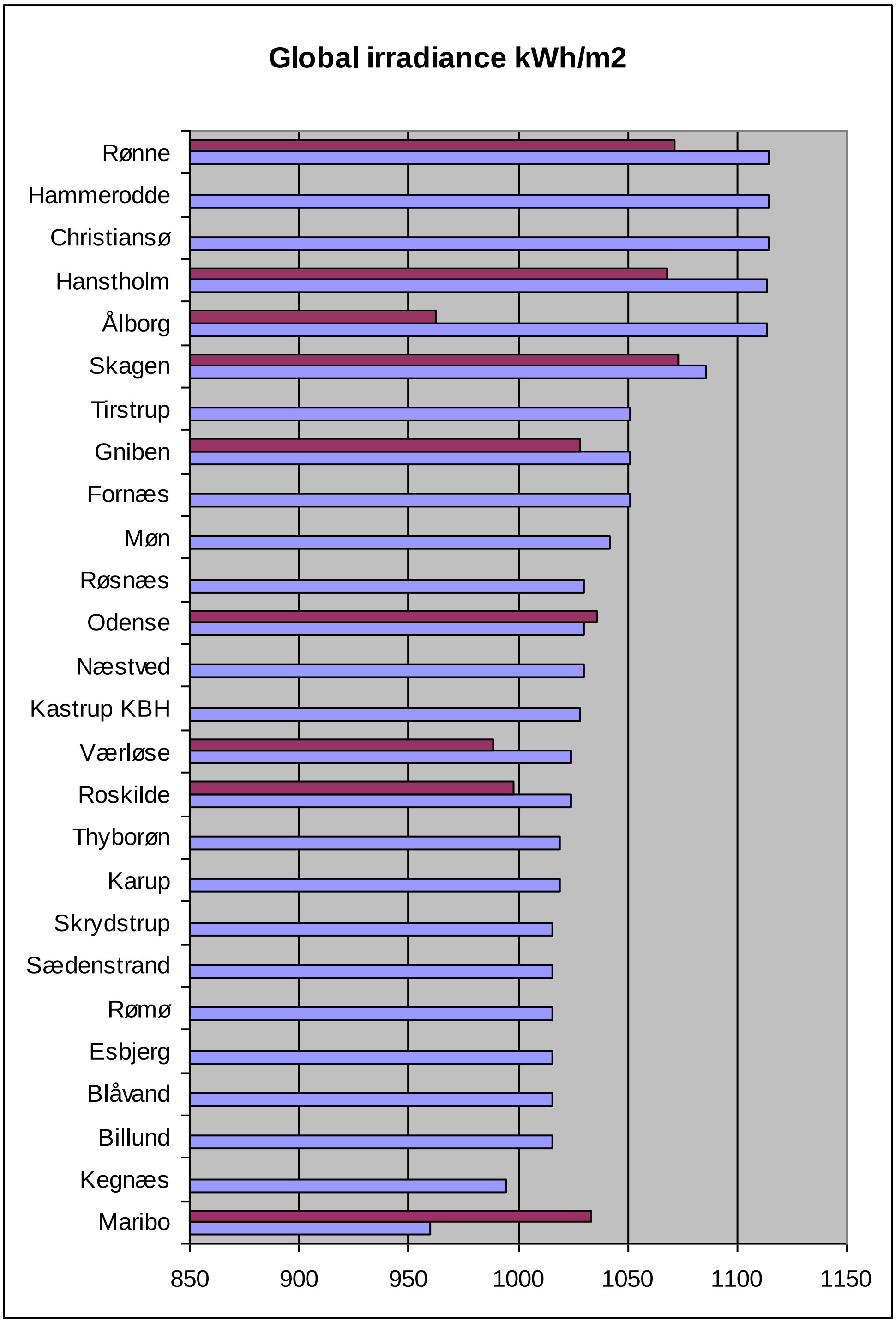




Estimated monthly irradiance based on bright sunshine values is shown above. The graph is based on data from DMI/Skagen 2006-2008

Owners of PV systems or simulation software cannot use this unit directly to estimate the output of a PV system, therefore a simple correlation is proposed in the graph below for the solar irradiance as a function of the monthly sunshine hours. The graph is based on empirical values. It is obviously not showing a perfect fit to the measurements, therefore actual irradiance measurements should always be preferred if they are available for a specific site.

Furthermore insolation data from a number of Danish meteorological stations as presented in the database of the simulation tool RetScreen[9] has been compared to the measured data, se below.



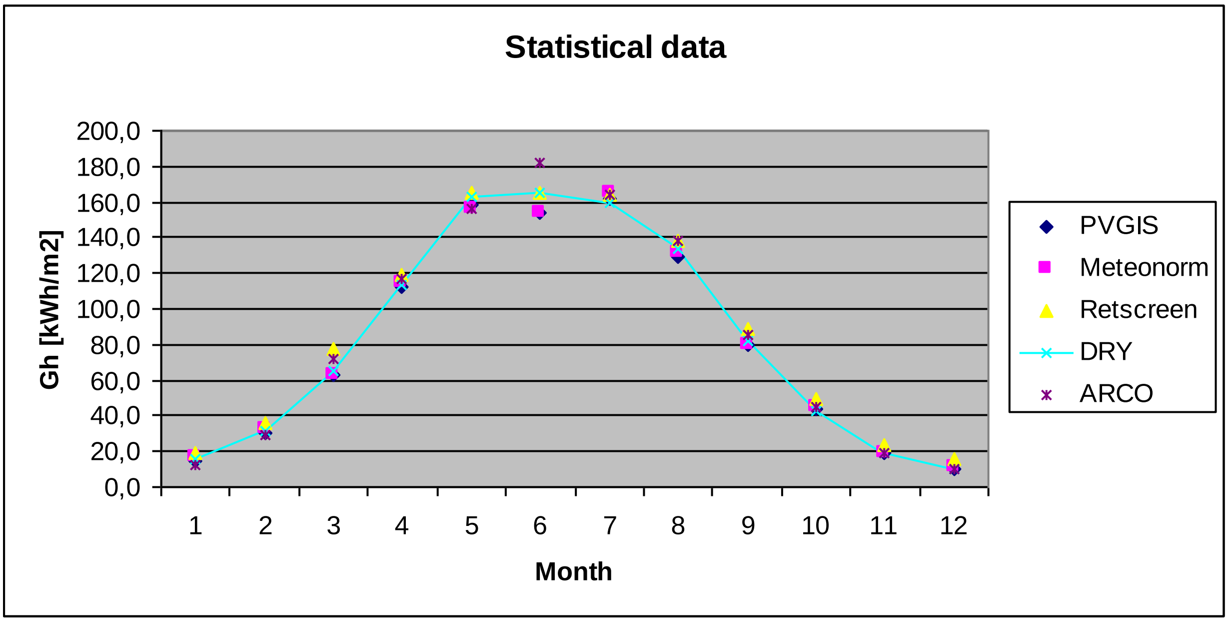
Statistical irradiance from RetScreen (blue) compared with DMI measurements 2007. Most RetScreen values are based on satellite data.

The quite large deviation for some of the stations compared to both the DMI map and 2007 measurements could indicate problems of data quality. Especially the low value in Maribo and the

[9] See: www.retscreen.org

high value in Aalborg are questionable. Probably the explanation is the uncertainty in interpolation between ground based measurements, combined with the less accurate satellite data. It is therefore recommended to check two or three different data sources when planning PV systems of a considerable size.

The monthly distribution of irradiance values is shown on the following graphical representation of DRY data (line) and other statistical data sources (scatter) for Copenhagen:



The relatively large deviation in June is most likely explained by fluctuations in cloud cover in the data series used for generation of the different data sets.

Summary

Solar irradiance is the single most important parameter for evaluation of PV system performance, so for simulation and evaluation purposes it is important to select the best possible data series. The study has shown that the different data sets are not very consistent when it comes to site-specific irradiance.

Though Denmark is a small country, there can be significant geographical variation in irradiance data, in particular between inland and coastal regions. The cloud cover can also cause significant variations of 10-15% from year to year. For simulation of average performance on a specific location, it is therefore suggested to use the DRY data series and subsequently correct the annual values according to the solar map produced by DMI. Other data series can also be used, as long as the annual global irradiance is close to the value on the DMI map. For evaluation of the performance in a specific year, collection of own irradiance data should be preferred, second option would be to download monthly data from the nearest DMI station(s) from www.dmi.dk.

3.2 Operational PV System Data and Their Sources

In Denmark, no compulsory collective scheme is implemented in order to collect, process and file data regarding installed PV systems smaller than 6 kW. This is due to the fact that these plants contribute insignificantly to the total electricity consumption and is allowed to use net metering[10]; thus the data are needed neither for prognosis nor for billing purposes.

However, since the majority of PV plant established in Denmark until 2006 in one way or another has been part of national or international development projects, data are available at least to some extent.

The major project, which has been carried out in order to demonstrate and introduce PV to the Danish marked, are:

- **Sol-30**. Through this project PV plants were retrofitted on 30 family houses in the village Brædstrup in Jutland. Sol-30 was carried out from 1996 to 1999.
- **Sol-300**. As follow-up to Sol-30, Sol-300 was launched in 1998 and went on to 2001. In this project approximately 300 PV plants were established summing up to a total of 750 kWp of installed capacity.
- **Sol-1000**. The final demonstration project in the "Sol-series" were Sol-1000. In this project, some aspect identified in the projects as barriers for utilization of PV in Denmark were addressed.

As part of these projects a total of approximately 1,5 MWp of capacity has been established. The significant value regarding collection and evaluation of operational data was recognised when these projects were launched; and therefore some schemes were implemented in order to collect information regarding operational data and behaviour of PV plants under Danish conditions.

Afterwards, the collection methods from the "Sol" projects are described together with some supplementary data collecting projects, which have been launched in Denmark. The results and knowledge that can be drawn from these activities are described in part 3.3 of this report.

3.2.1 Sol-30

When this project was started in 1996, net metering was not an option and therefore the buildings in question were equipped with meters able to register:

- The amount of electricity delivered from the grid to the house ("incoming electricity" when PV production < momentary consumption in the household).
- The amount of electricity delivered from the house to the grid ("outgoing electricity" when PV production > momentary consumption in the household).

Besides this, also a meter to measure the total production from the PV plant was set up.

In the first 2 years of operation a system for remote reading and storing of these 3 values in quarterly resolution were implemented, whereby it was possible to make these measurements a subject for further analysis.

[10] I.e. the electricity meter reverses in situations when the momentary production exceeds consumption. Thereby all the electricity produced will eventually replace taxed electricity bought from the local power company.

Giving these meters, it is possible to determine:

- The yearly production from the PV plant.
- The amount of electricity, that the household has to pay for, calculated as “incoming electricity“ subtracted “outgoing electricity” (corresponding to net metering).
- The total electricity consumption in the household, calculated as “PV production” added to “incoming electricity“ and subtracted “outgoing electricity”.
- The part of total electricity consumption provided by the PV plant.

Since the installed peak capacity of the plant is known and the yearly production from the plant is measured, it is furthermore possible to calculate the specific performance in kWh/kW_p (please see to part 2.1 for further information). Thereby it is possible to establish a value, that can be compared to other PV plants with the purpose of evaluate it the performance of the plant in question seams satisfactory.

Giving that these plants has been in operation for more than 10 years, an extensive amount of data should be available. Unfortunately, not as much information as expected is available. This is due to the fact that collections of data were only done by remote reading in the first 2 years; hereafter it depends on manual registration carried out by the house owners.

Especially data for PV plant production have in some cases been lacking quality, since this figure are not part of the registration that the grid operator collect in order to make the annual settlement of account.

Giving the steady decrease in data quality and the fact that change of ownership to a large part of the houses has changed recently and that the new owners do not share the same interest in collecting data as the original did caused in 2007 a decision to cease collection of these measurements.

3.2.2 Sol-300

Giving the experiences gathered regarding data collection from Sol-30, it was decided that automatic remote reading of values has to be introduced in order to secure a valid capturing of data.

Thus 264 of the approx. 300 plants in this project were equipped with a measuring station including meters for production as well as sell and purchase to and from the local electricity grid. In each measuring station is a logging device with modem, allowing the measured values to be stored and subsequently transferred to a central computer located at EnergiMidt.

In this case the plants are situated in 8 geographical regions spread throughout the country and it was originally planned to set up one measuring device for irradiation in each of these regions in order to be able to normalise the production from each plant and thereby facilitate comparison between regions and plans. Due to technical difficulties this approach for registration and storing of irradiation data was abandoned, instead data for this purpose was taking from the website of the Danish Meteorological Institute.

The communication from the server to each measuring station was provided through the already present wired telephone lines of the buildings. Although this was considered a sufficient solution in the projecting phase, it proves to be the Achilles' heel of the system and the reason why some of the station are no longer operational. This was partly due to unintended damages of the technical components caused by lightning, rodents such as mice, and partly to the fact that some of the house owners eventually lost interest in the measuring program and therefore did not want to continue to pay for the transmission of data. This was the case in particularly when a house was acquired by a new owner.

Until 2007 approximately 100 of the original measuring stations were in operation and data captured from here made public available via the website “www.Sol-300.dk”. On the website data regarding production, sell and consumption from each installation could be observed in different resolution (day, month and year).

Basically the same information could be drawn from the collected data as described regarding Sol-30, however, since Sol-300 data were collected by remote reading, the quality and availability of data were at a significantly higher level.

Although this measuring scheme was established some 10 years ago and the stations are no longer operational, the data collected in the period of operation still makes up a valuable source regarding operational data for Danish PV systems.

3.2.3 Sol-1000

As part of Sol-1000, the largest demonstration project regarding PV carried out in Denmark, a website “www.solstroem.net” was established as a forum for change of information and experiences between Danish owners of PV plant.

A section of the website was allocated to presenting of unit and production data of Danish PV plants. Information available is provided by the plants owners, which means that the amount and accuracy of data available depend on the reporter.

Approximately 25 users provided production data on regular basis, however, giving that not all data regarding production, sloop, orientating, size etc. were available; it was only to a lesser extent possible to make meaningful comparisons between these plants as well as to deciding whether or not there realised performance could be considered to be on an adequate level.

3.2.4 Measuring station established by Energinet.dk

In Denmark Energinet.dk as the national Transmision system operator (TSO) is responsible for maintaining of the balance between electricity production and – consumption. Energinet.dk has divided the country in 16 regions and in 2006 the company decided to establish a PV plant measuring station in each region.

The motive for this decision was that a future increase in PV utilization eventually could have an influence on the previously mentioned balancing of electricity production and consumption as the case is for wind turbines.

By establishment of data for solar irradiation, Energinet.dk will be able to include solar forecast in there prognosis for future electricity production from renewable sources and thereby decide the amount of electricity, that has to be provided from adjustable central - and decentralise power plants.

The 16 measuring stations have been established in connection with existing PV plants, mainly set up during Sol-1000. Each station consists of 2 calibrated solar cells for capturing irradiation data. One of these are situated in same level (sloop, orientation) as the PV plant in question, while the other calibrated solar cell is situated in horizontal level and thereby can be used as reference.

The picture below shows one of the measuring stations in question during assembling. The two calibrated solar cells are shown at the bottom right.

Each 15 minutes data from the 2 measuring devices are collected and stored in a logger together with values from an electricity meter measuring the AC production delivered from the PV plant. The logger are equipped with a GSM modem, and once every 24 hours a central computer placed at EnergiMidt connect to this modem and collect data stored in the logger.

Since the data from each location includes specific irradiation measuring values, it is possible, besides deduction of the same values regarding absolute production (kWh) and specific performance (kWh/kW$_p$) as mentioned in connection with Sol-30 and Sol-300, furthermore to calculate and compare the annual power ratio of the plant.

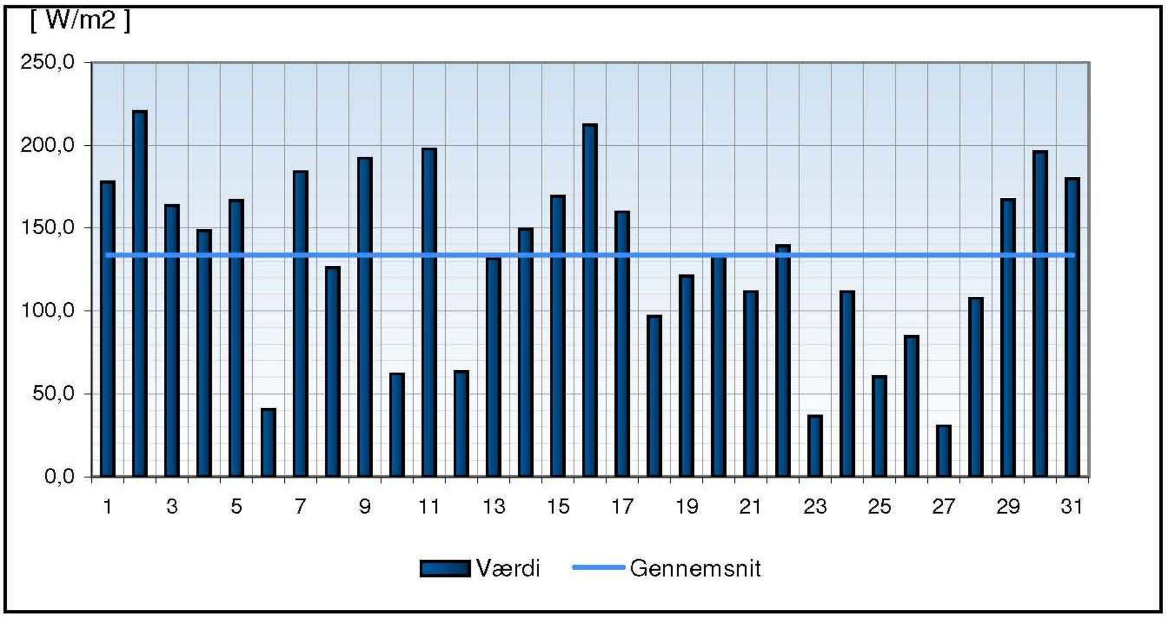
When doing this, data will also be available to determining the division and disparity of solar resources throughout the country.

In the figure inserted next page an example of data presentation from the programme “OmegaEnergi”, which are used as interface to the database, is shown (in Danish).

This particularly graphs show the global irradiation in W/m² measured at the geographic location in question. Besides the graphs, also a table giving some key values is part of this output form.

Målerrapport
Tranekær Solcelleplan w pr m2 - 2008

Månedsrapport - august



Information	
Folder:	Tranekær
Måler:	Tranekær Solcelleplan w pr m2
Beskrivelse:	
Tidspunkt:	august-2008

Periodedata						
	Månedens Værdi [W/m2]	Månedens Budget [W/m2]	Månedens Overskud [W/m2]	Gns. døgn Værdi [W/m2]	Min. døgn Værdi [W/m2]	Max. Døgn Værdi [W/m2]
				133,6	30,8	220,2
Tidspunkt:	august-2008				27-08-08	02-08-08

Udskrevet d. 20-01-09

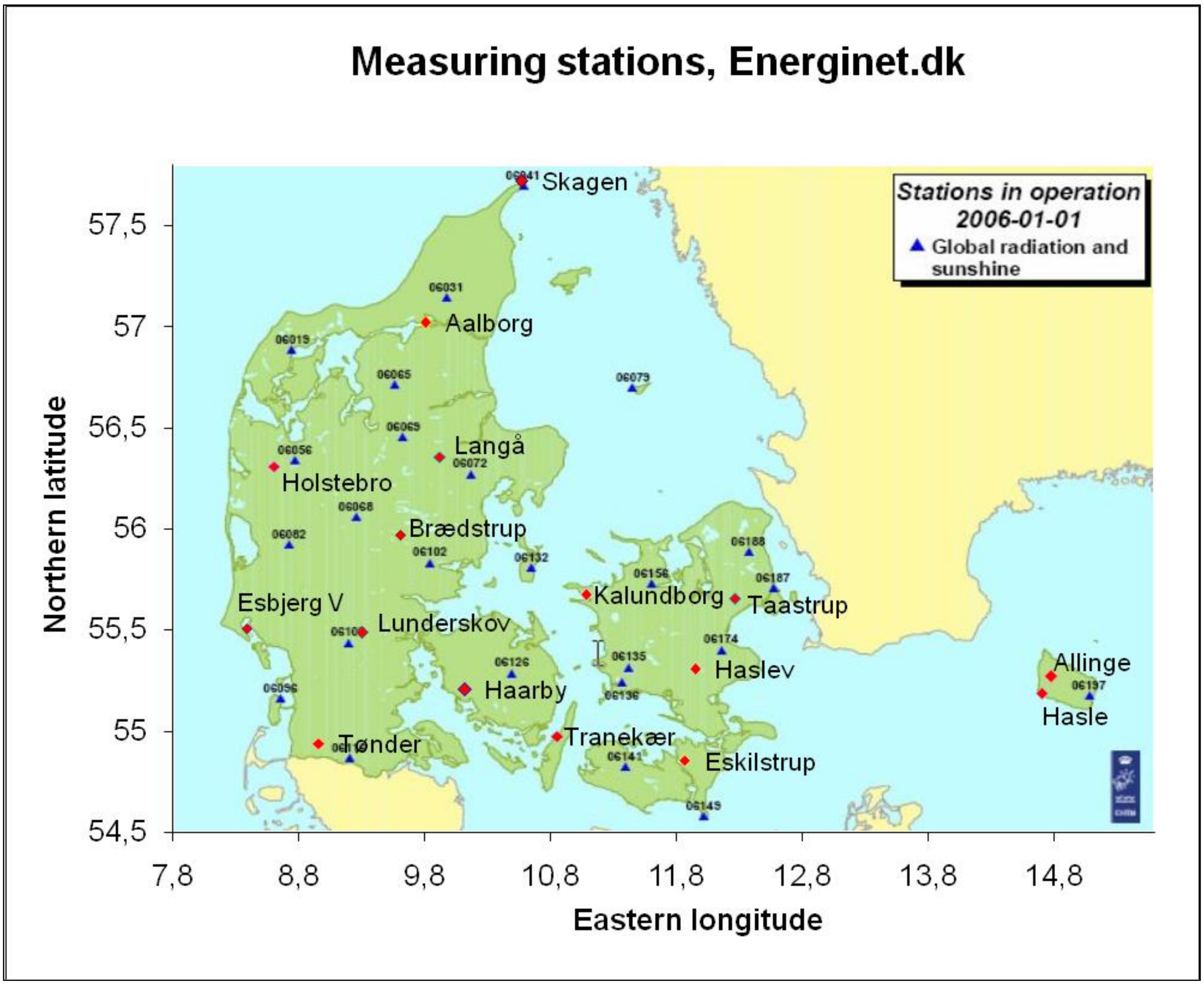
The programme also enable a table output, by which the irradiation in W/m² (global as well as direct) and production in kWh can be presented in numbers in different resolution, for instance averred value per month, day, hour or quarter.

An example of this table output is giving below, in this case showing the values corresponding to the previously presented diagram.

Målerrapport Tranekær Solcelleplan w pr m2 - 2008			
Månedsrapport - august			
Information			
Folder:	Tranekær		
Måler:	Tranekær Solcelleplan w pr m2		
Beskrivelse:			
Tidspunkt:	august-2008		
Periodedata			
	Dato [dd/mm]	**Værdi [W/m2]**	
	01/08	177,9	
	02/08	220,2	
	03/08	163,8	
	04/08	148,3	
	05/08	166,8	
	06/08	40,7	
	07/08	184,1	
	08/08	126,0	
	09/08	192,3	
	10/08	62,2	
	11/08	197,9	
	12/08	63,2	
	13/08	131,6	
	14/08	149,4	
	15/08	169,2	
	16/08	212,1	
	17/08	159,9	
	18/08	96,7	
	19/08	121,1	
	20/08	133,2	
	21/08	111,7	
	22/08	139,2	
	23/08	36,5	
	24/08	111,8	
	25/08	60,3	
	26/08	84,6	
	27/08	30,8	
	28/08	107,7	
	29/08	167,3	
	30/08	196,1	
	31/08	179,9	

Udskrevet d. 20-01-09

The figure below show the location of the measuring stations established by Energinet.dk. These stations are marked with a red rhombus, while the blue triangle indicate the location of measuring stations operated by Danish Metheorological Institute.



3.2.5 *Other sources*

Besides the operation data provided by the sources discussed above, some data are collected from more sporadic and solitary sources. Examples of these could be:

- **Solgården in Kolding**. This 106 kW_p plant was once the largest PV installation in Denmark. In 2006 the inverters on this installation was changed to a new model from Powerlynx (today named "Danfoss Solar Inverters") from which operation data are stored and accessible by remote reading.
- European Database for PV plants, see http://www.sonnenertrag.de/

It is very likely, that quite many statistic data are made locally by owners of larger PV-plants, given the fact that these buyers often share great interest in their PV-plant and that the main part of the inverters suitable for these installations usually store some operational data, which can be viewed locally on a display.

Some of these owners previously announce these operational data through the fore here mentioned website www.solstroem.net, but the major part will just keep these data for their own interest and usually data collected from these sources are not available for anyone besides the owners (this also goes for Solgården).

The site www.solstroem.net was shot down in 2007 due to defects in hardware and lack of financing sources for repair. Thus no voluntarily collection system is now available at national level, however, the fore here mentioned database www.sonnenertrag.de could be used by Danish PV plant owners who would like to share operational data from there system with other interested parts.

3.2.6 Quality of data

In the table on next page, a summary of the available operational data is presented. When this table is compared with the one presented in part 2.2, relevant parameters, it can be seen that some values are missing in order to deduce and calculate the importance of all relevant design parameters for grid connected PV plants.

Although conditions regarding module size, inverter/string layout and other design parameters were known and recorded at the time of instalment, no systematic activities has been implemented in order to keep track of replacement of modules and inverters, changes in layout, extensions etc.

In 10 years time, it is not unlikely that sometimes changing in the environment surrounding the PV plant will cause an influence on the plant production, which is not accounted for when merely observing the production values.

For instance new building and growing trees can cause shading on the modules or change in albedo, which can cause reduction in the yearly production from the PV-plant.

Besides this, unfortunately none of the PV plant in question has been equipped with measuring devices for registration of neither module – nor ambient temperature. Therefore the influence of temperature on the obtainable electricity production cannot be deduced based on available data.

As for the inverter, data regarding the initial model used are know; however it has not always been noted if the original has been replaced due to malfunction. Although the data have some obvious lacking in quantity and quality, it will, however, also be possible to make some important conclusions regarding operational conditions for Danish PV plants on their basic.

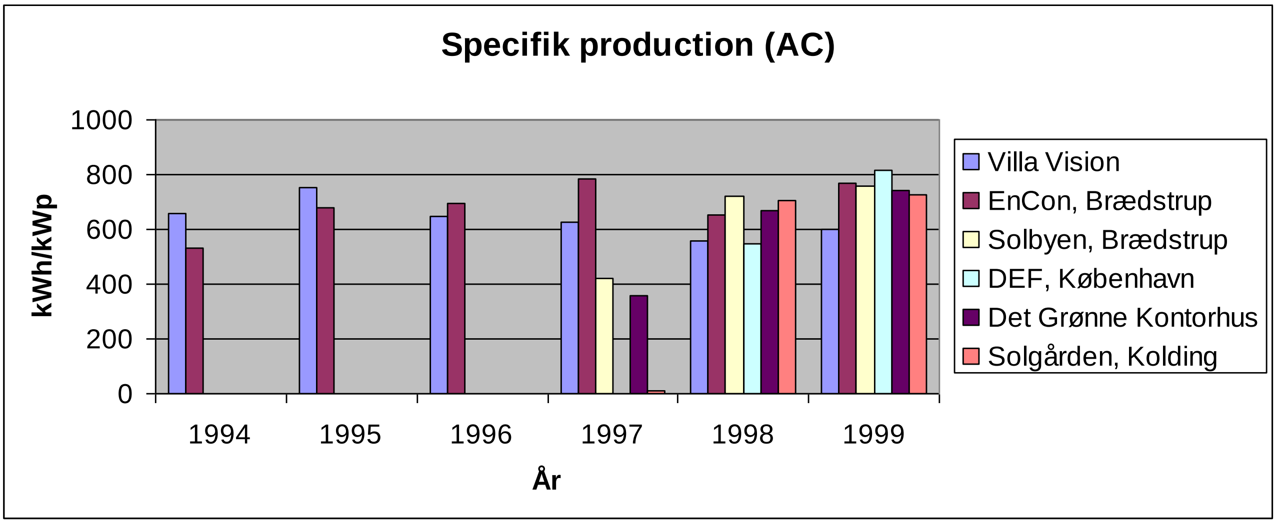
First and foremost, it is possible to calculate a specific performance for each plant, taking into consideration the size, module type, sloop, orientating etc. The specific performance can be supplemented by a power ratio when measuring of irradiation, either from the actual plant or from nearby meteorological stations, are included in the calculation.

Afterwards comparison of specific performance and power ration from plants representing different layouts, geographical locations, module types or other parameters can be carried out and general tendencies, if any, can be concluded. A further analysis of the data according to this description is carried out in part 3.3 to 3.5.

Finally it can be mentioned, that recent studies have indicated that the nominal powers stated on former generation of PV module in some case were overestimated. In the projects forming the basic for these measuring values, no additional test of PV modules has been carried out. As a consequence, when interpreting the results drawn from data collected, it has to be taking into consideration, that some inaccuracy in relation to nominal power might occur, which will have an influence on the final results and conclusions.

Sources for operational data from Danish PV plants						
Source	**Number and location**	**Measuring of**	**Data capturing**	**Data resolution**	**Availability**	**Remarks**
Sol-30	29 private household in Brædstrup, Jutland.	Production from PV plant (kWh), sell to and purchase from electricity grid (kWh)	First 2 years: Remote reading and storing. After that: Manual reading by owners.	First 2 years: Quarterly values. After that: One reading a year.	Data from the first 2 year are available in the report: "Solby projektet". Downloadable at "www.solbyen.dk". Data from recent years reported by EnergiMidt in: "Solby opfølgning 2006".	Started in 1996, ended in 2006 due to decreasing data quality. Plant data are known (size, type of modules, sloop, etc.).
Sol-300	Initially 264 PV plant in 8 geographical regions.	Production from PV plant (kWh), sell to and purchase from electricity grid (kWh).	Remote reading via wired telephone network.	Quarterly values.	Public available via "www.Sol-300.dk".	Started in 1998 and ended in 2007 due to lack of financing sources. Plant data are known (size, type of modules, sloop, etc.).
Sol-1000	Approx. 25 PV plants located throughout Denmark.	Production from PV plant (kWh). Other values depending on the owner.	Manual reading by owners.	Monthly or yearly values.	These registrations are made public available via "www.solstroem.net".	Plant data are known (size, type of modules, sloop, etc.). The website was shut down in 2007 due to lack of financing sources.
Energinet.dk	16 measuring station located throughout Denmark.	Production from PV plant (kWh), irradiation (W/m²) in PV plant - and horizontal level.	Remote reading via GSM network.	Quarterly values.	Available at EnergiMidt with permission from Energinet.dk.	Started successively during 2007. Plant data are known (size, type of modules, sloop, etc.).
Other sources	Unknown.	Usually production from PV plant.	Data stored in inverter. Manually or remote reading		Usually not public available.	

During the period 1994-1999 the first grid connected were monitored by DTI on the basis of manual readings of the electricity meters. The specific performance is shown below:



The plant "Solbyen Brædstrup" is actually a cluster of about 30 individual systems in the same neighbourhood. All the registered plants are more or less south-faced, so the solar irradiance is nearly optimal.

It is obvious that the average performance is somewhat lower than today's standard, some of the explanations might be:

1) Too optimistic power rating of the modules from the factory
2) Higher inverter losses than with new inverter types
3) Mismatch losses due to wider tolerances on electrical data than common today

The performance ratio could not be computed, as irradiance was not measured continuously for most of these plants.

For the SOL300 project, detailed data have been recorded, and in general the performance is very uniform from these plants. The negative deviations can be explained by shadows or periods of disconnection. There is a clear documentation of regional differences in performance.

Denmarks first grid connected PV power plant consisted of a 2,3 kWp PV array in connection with a 1,8 kW Inverter. The PV/Inverter ratio of 1,28 is thus relatively high. An analysis of the total plant efficiency shows an almost linear decrease from the maximum point at around 400 W/m2 solar irradiance. There is no sudden change of efficiency at high irradiance, which could be expected if the inverter was overloaded. The explanation may be a good short-term overload capability due to a high thermal mass in this old-style inverter.

There is a general lack of information regarding the number and installed power of Danish PV plants, as there is no obliged reporting scheme for such installations, nor any central registration of the energy produced. The installers just have to notify that a local power plant has been connected to a given installation. At Danish Technological Institute, the Solar Energy Center collects as much information as possible about new grid connected plants, but it is not a complete list. In order to be able to document the real performance and operational experience, it is highly recommended to support the establishment of a central data base for PV (and perhaps other local) power plants.

It is suggested to register the PV plant data in already existing web sites, already developed for energy registration purposes. There seem to be three options:

a) WWW.elsparefonden.dk Home page of Elsparefonden, where house owners can already register their electrical appliances and electricity consumption (Min Bolig). The addition of PV relevant entries will be needed.
b) WWW.solenergi.dk at Danish Technological Institute already contains a database of most PV plants, but there is no user access for registration of PV performance data. This function could be added with some effort.
c) www.sonnenertrag.eu The European data base for PV systems, driven by Lothar Beer, Germany in the Sonnenertrag Project. The web site includes a chat forum for PV users, and is free and ready to use for Danish plant owners.

When the platform has been selected, it is a matter of man-hours to transfer existing system data and encourage new users to register and exchange data. The data will be very useful for statistical analysis of performance, lifetime, degradation etc. and for comparison with other countries.

3.3 Performance for Typical PV Systems (Roof, Façade and Ground Mounted)

In this and the next section some results from Danish PV plant is presented with the purpose of highlighting typical performance data – and differences – between various installation types (this section) and technologies (section 3.4).

For both sections the data are based on information collected through the fore here mentioned data sources, especially the project Sol-300. In general, these plants were roof top systems using mono- or polycrystalline modules retrofitted on existing roofs.

Giving this, some limitation with respect to the scope of application for the available data sources exist and the fact that the performance data is obtained from plant that was established several years ago is important to keep in mind when interpreting the outcome.

It is thus very likely that contemporary installed installations will provide a higher level of lifetime performance due to the technical progresses obtained in module quality and sorting as well as in inverter performances.

3.3.1 Roof top and facade systems

As described in details previously in this document, the annual yield from a giving PV system depend on several parameters of which some can – and some cannot – be affected by the owner. Giving that the components – panels as well as BOS - are carefully chosen to correspond to each other, the main elements affecting the yield for a non-tracking PV plant at a certain location is the mounting conditions of the PV panels, more precisely to which corner of the world, the panel is directed towards (orientation) and in which sloop (inclination) they are situated.

The optimal orientation will differ according to the geographical location in question, the farther the plant is situated from the Equator the steeper the sloop. In Denmark the optimal sloop varies between 36 and 38°[11].

With respect to direction of the panels, the highest yield is obtained when the plant is directed due south.

Giving these figures is obvious that a facade system with vertically mounted modules will not perform as good as a PV plant with the same capacity mounted in optimal inclination. In design simulation software systems as the once described in chapter 2.3 it can be calculated that the yield of a facade system under Danish condition is usually reduced to approximately 70 – 72 % of the yield obtained at an optimal situated system.

It is worth mentioned; that the yield obtained if modules are mounted in horizontal position, is approximately 85 % compared to the optimal situation. Thus it is considerably more favorable to mount the PV plant in horizontal over vertical position.

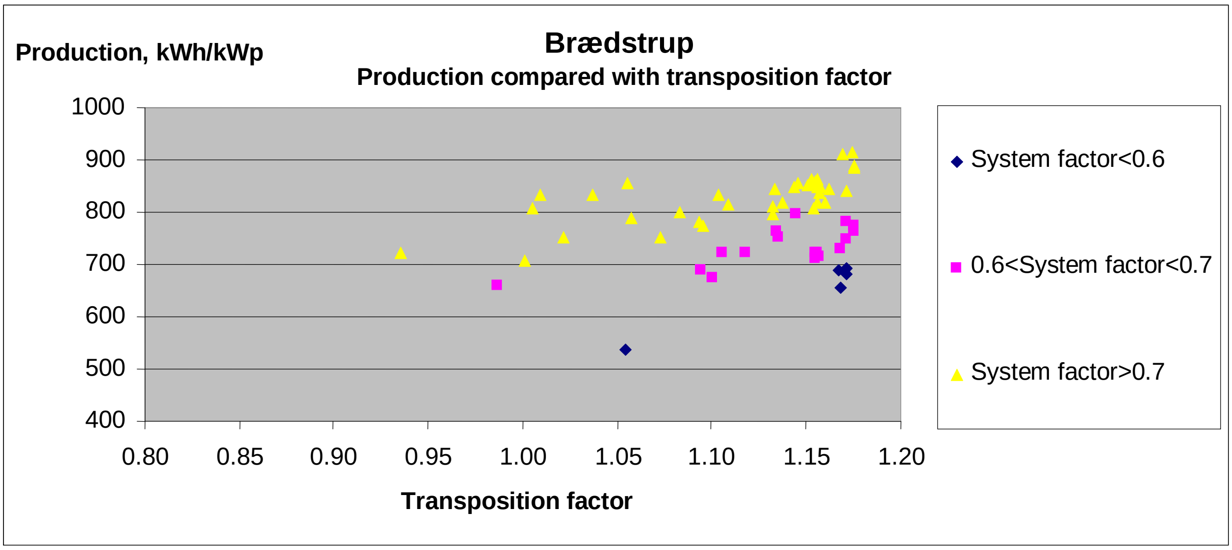
Danish Technological Institute had made an analysis of some of the data collected in the project Sol300, in which the influence of orientation and inclination were investigated. In this, annual productions from 264 plants from 8 geographical areas were compared with the orientation and inclination of the individual plant.

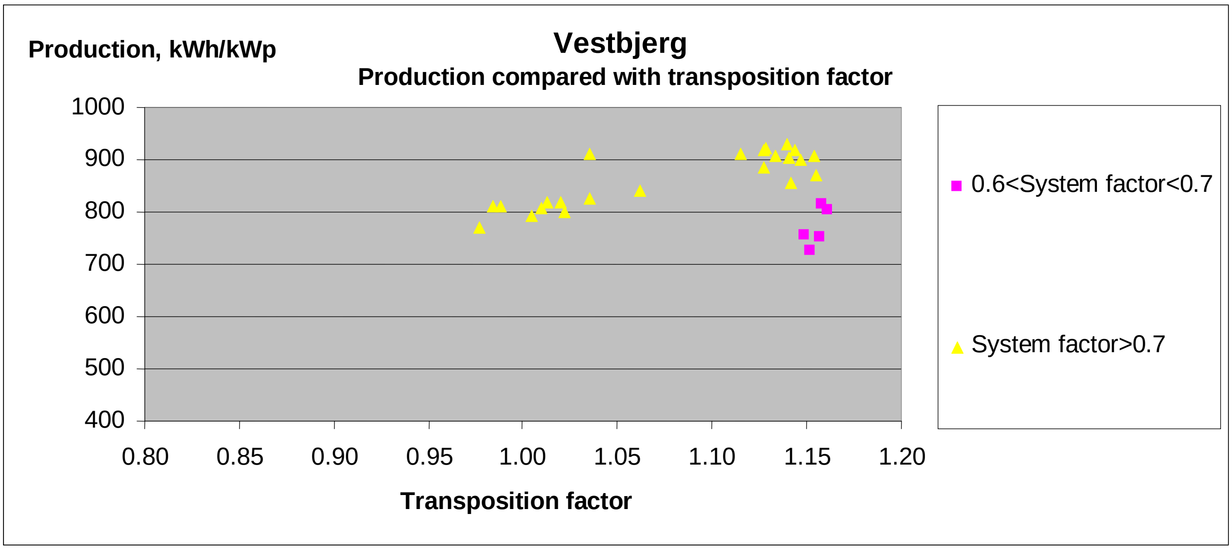
With the purpose of eliminating the influences of differences in efficiency for the various PV modules and inverters involved, a system performance ratio has been calculated for each plant and the results has been ordered according to intervals of theses.

Furthermore, a transposition factor is calculated for each plant, defined as the ratio between irradiation in the level of the PV modules divided by the global irradiation. A high transposition factor indicates that the orientation and inclination of a giving PV plant is close to the optimal situation.

In the diagrams below, the results from two or the areas investigated is shown.

[11] According to: www.jrc.ec.europa.eu/pvgis





For both areas a rising production tendency can be seen with increased transposition factor, clearly stating, that the yield obtained generally decrease when orientation and/or inclination differ from the optimum.

This tendency is present for all intervals of system factor and thereby emphasizes the significance of orientation and inclination. When designing a PV plant to implement on an existing building, theses parameters will be fixed according to the physical conditions of the building in question. The significance of theses parameters, however, is important to have in mind in prediction of the expected yearly production under the circumstances at hand.

3.3.2 Ground mounted systems

No data from ground mounted systems has been available for this study. This is due to the fact that no tradition for establishing free standing PV plant exists in Denmark. In contradiction, some of the world larges solar thermal plants have been established in connection to Danish district heating plants, but as consequents of the conditions applying to PV, is has not been possible to repeat these successes.

Therefore, no operational data is available for this presentation. Theoretically speaking, a ground mounted system would have optimal conditions to obtain high performance, since the plant can be optimized without taking any considerations to existing conditions as the case is for a roof top or facade system.

This means, that a ground mounted system can be set up with optimal parameters with respect to sloop, orientation and cooling conditions, whereas a roof top or facade system has to adapt to the actual orientation and sloop of the building in question.

3.4 Performance for Typical PV Technologies

As previously mentioned crystalline base PV modules account for the lion share of the plants installed in Denmark until now. Theoretically, mono crystalline modules should operate with efficiencies slightly higher than there poly crystalline sibling technology, which again will be more efficient than the various types of thin film technologies.

In the table below, typical values for cell and module efficiency for the most prevailing types of thin film modules and crystalline based modules is shown. Besides the efficiency, also the module area needed in order to establish a PV plant of 1 kW_p is presented.

The area needed is, of cause, directly associated to the efficiency, but has been included anyway since it visualizes the significance of the efficiency in a practical manner.

Module and cell efficiencies for thin film and crystalline base PV modules						
Technology	**Thin film photovoltaic**				**Crystalline based**	
	Amorphous silicon a-Si	Cadmium telluride CdTe	CIS - CIGS	a-Si/μc-Si	Mono crystalline	Poly crystallin e
Module efficiency, %	5 – 7	8 - 11	7 -11	8	13 – 15	12 - 14
Area needed pr. kW_p, m^2	15	11	10	12	App. 7	App. 8

Due to research and development activities the efficiencies of the different technologies has improved over the past years and can be expected to do so on a continuing basis in the years to come. The values presented represent the actual technological stage as of today.

As mentioned in part 2.4.2 "*Studies of the influence of module technology on system performance*" some studies has indicated, that thin film modules could prove to be attractive under Danish conditions giving that – at least for some of the types - a high efficiency under low irradiation situations seemingly occur.

Whether this possible benefit actually can be exploit in general and under Danish condition in particular, still remain to be proved, since no systematic collection of operational data from thin film based PV plant in Denmark yet take place.

To highlight possible differences in performances between mono- and polycrystalline modules, measuring data from some of the plant established in the fore here mentioned development project "Sol 300" can be considered.

In the table inserted on page 49 data from 25 PV plant – 4 with mono crystalline and 21 with poly crystalline modules - is presented. For each plant the values for specific production in kWh/kWp and global insulation in kWh/m² is shown, divided in the years from 2001 to 2003.

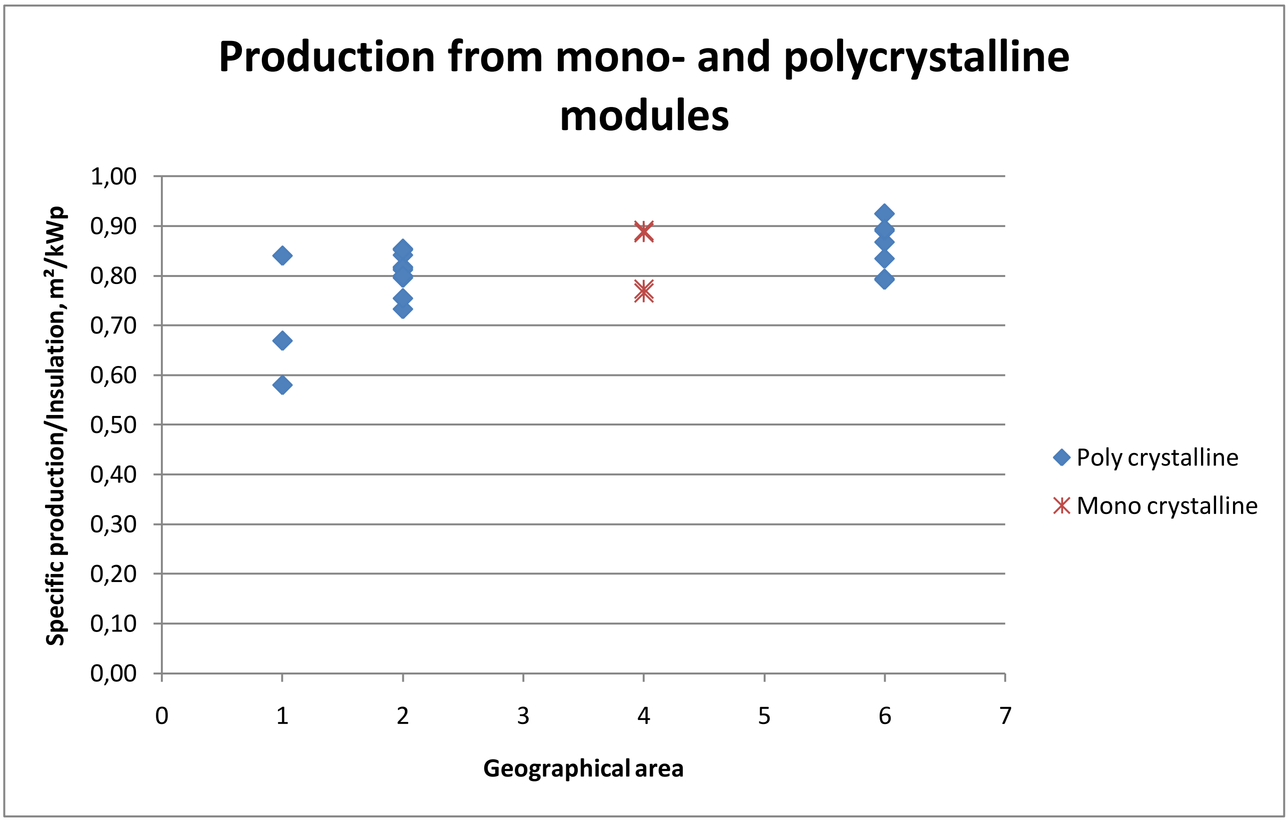
In order to eliminate the influence from the fact that the insulation varies between the areas a performance ratio is calculated, both for the specific years and as an average value. Giving that all of the plant are situated in same orientation (South) with identical inclination (45 °), the data will be comparable.

Comparison of performances of mono- and polycrystalline modules

				Specific production				Global insulation				Specific production/Global insulation			
ID	Area code	Capacity	Module	2001	2002	2003	Average	2001	2002	2003	Average	2001	2002	2003	Average
		Wp		kWh/kWp	kWh/kWp	kWh/kWp	kWh/kWp	kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2	m^2/kWp	m^2/kWp	m^2/kWp	m^2/kWp
894	1	3.000	p-Si	651	723	414	596	1.006	1.005	1.107	1.039	0,65	0,72	0,37	0,58
895	1	2.250	p-Si	708	683	692	694	1.006	1.005	1.107	1.039	0,70	0,68	0,63	0,67
896	1	2.250	p-Si	815	868	938	873	1.006	1.005	1.107	1.039	0,81	0,86	0,85	0,84
910	2	1.800	p-Si	803	842	624	756	1.006	1.005	1.107	1.039	0,80	0,84	0,56	0,73
919	2	1.800	p-Si	794	833	852	826	1.006	1.005	1.107	1.039	0,79	0,83	0,77	0,80
911	2	2.700	p-Si	863	859	800	841	1.006	1.005	1.107	1.039	0,86	0,85	0,72	0,81
913	2	2.700	p-Si	744	874	933	850	1.006	1.005	1.107	1.039	0,74	0,87	0,84	0,82
915	2	2.700	p-Si	823	871	930	875	1.006	1.005	1.107	1.039	0,82	0,87	0,84	0,84
916	2	2.700	p-Si	844	882	936	887	1.006	1.005	1.107	1.039	0,84	0,88	0,85	0,85
917	2	2.700	p-Si	832	882	943	886	1.006	1.005	1.107	1.039	0,83	0,88	0,85	0,85
920	2	2.700	p-Si	803	841	897	847	1.006	1.005	1.107	1.039	0,80	0,84	0,81	0,82
921	2	2.700	p-Si	797	796	901	831	1.006	1.005	1.107	1.039	0,79	0,79	0,81	0,80
912	2	900	P-Si	776	834	733	781	1.006	1.005	1.107	1.039	0,77	0,83	0,66	0,75
1062	6	2.160	p-Si	795	785	864	815	967	1.057	1.059	1.027	0,82	0,74	0,82	0,79
1056	6	1.920	p-Si	883	961	1.007	950	967	1.057	1.059	1.027	0,91	0,91	0,95	0,92
1057	6	1.920	p-Si	885	955	1.010	950	967	1.057	1.059	1.027	0,92	0,90	0,95	0,92
1065	6	2.880	p-Si	840	911	923	891	967	1.057	1.059	1.027	0,87	0,86	0,87	0,87
1066	6	1.080	p-Si	843	675	916	811	967	1.057	1.059	1.027	0,87	0,64	0,86	0,79
1067	6	1.920	p-Si	856	922	966	915	967	1.057	1.059	1.027	0,89	0,87	0,91	0,89
1081	6	2.880	P-Si	808	854	909	857	967	1.057	1.059	1.027	0,84	0,81	0,86	0,83
1085	6	1.920	P-Si	855	921	978	918	967	1.057	1.059	1.027	0,88	0,87	0,92	0,89
991	4	2.040	m-Si	715	760	817	764	974	980	1.039	998	0,73	0,78	0,79	0,77
993	4	3.060	m-Si	827	868	961	885	974	980	1.039	998	0,85	0,89	0,92	0,89
994	4	3.060	m-si	795	946	926	889	974	980	1.039	998	0,82	0,97	0,89	0,89
997	4	3.380	m-Si	540	812	972	775	974	980	1.039	998	0,55	0,83	0,94	0,77

Afterwards a diagram is inserted in which a graphical presentation of the division in performance ratio defined as specific production divided by global insulation is shown.

The plants are grouped according to the local area in which they are installed. The red crosses represent mono crystalline plant whereas the blue dots represent polo crystalline plants.



In the table incerted on page 52 data the modules and inverters used can be seen except for group 4, in which the module type was PB 585 (mono crystalline) and the inverter used was BP GCI 1200.

It is not possible to draw any significant conclusions from the table and diagram with respect to confirmation of the fact that mono crystalline modules should have a higher efficiency. Also the uneven division between the two types in question makes it difficult to use the data to make any valuable statement.

However it can be seen, that the general performace of the plant is rather high, and that a coherency exist between insulation and performance level. The latter can be seen from the fact, that both insulation as well as production peak in 2003.

This confirm, that the insulation level have a significant influences on the performance of a PV plant and that variation must be expected and accounted for both as a result of yearly variations on a certain location and in general diffirencies in available resources from one location to another due to geographical conditions.

3.5 Performance for Different Combinations of Panel and Inverter Capacity

Previously, a rule of thumb stated, that the capacity of the inverter should be slightly undersized compared to the nominal capacity of the PV area. This was due to an assumption that in this way it would be possible to optimize the inverter's power range.

From a technical point of view, undersizing could increase the system performance as it causes the inverter to operate as little time as possible at low partial load efficiency, without application of complex master slave configurations. At the same time, an economically benefit were achieved, since undersizing caused lower balance-of system costs per installed kilowatt peak power.

A disadvantage, however, follows this strategy: When the potential solar supply exceeds the inverter's power rating; only the maximum rated power can be supplied to the grid, whereby situation with very high insulation cannot be fully utilized.

A study giving a throughout explanation of the basic rationales behind this strategy as well as the results from a study carried out to further draw up conclusions regarding guidelines for combination of panels and inverter sizes can be found in[12] .

When using modern equipment, this rule of thumb do not have the same value as previously, giving the fact that modern inverters generally are capable of working at high efficiency over a wide range of input power. Especially the capability of operate with high efficiency at low partial loads has improved significantly, which to a large extent unessential the need for taking special precautions in this respect.

In the table below some values related to PV/Inverter capacity and performance is show for a selection of 18 plant established in Sol 300.

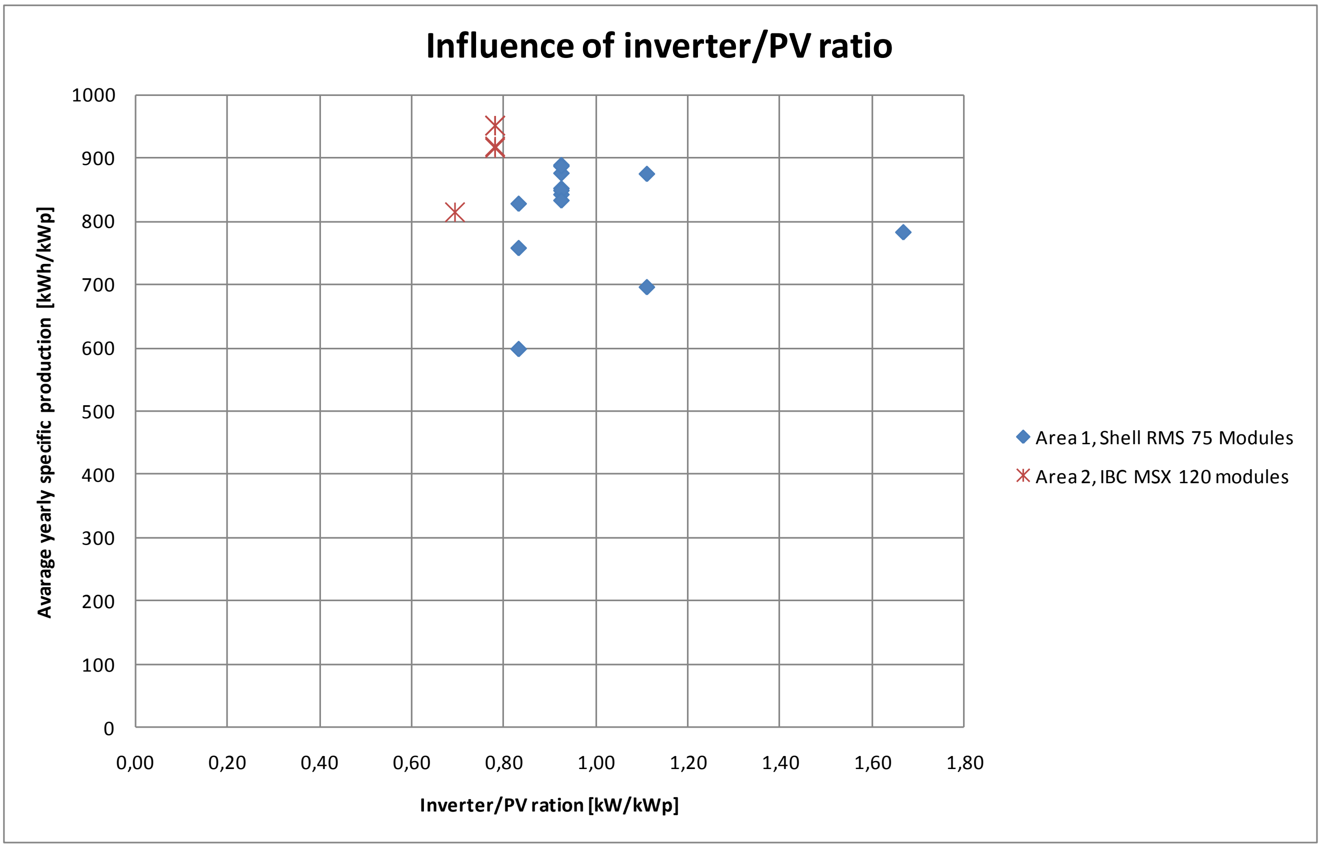
In order to eliminate the influence of sloop, orientation and technology, all the selected plant are facing South, mounted in 45 ° and equipped with poly crystalline modules. The production figures represent data from two geographical areas, denoted Area 1 and Area 2, in which Shell RMS 75 respectively IBC MSX 120 PV modules has been utilized. The production stated are averaged yearly values based on measurement over 3 years from 2001 to 2003.

[12] Undersizing inverters for grid connection – What is the optimum; Saiful Islam e.a., 2006

Data used to compare yearly production and inverter/PV ratio

ID	Area code	Panel type	No. of panels	Capacity	Inverter type	Inverter size	Yearly production 2001	2002	2003	Avarge	Specific prod.	Ratio Inv/PV
				Wp		W	kWh	kWh	kWh	kWh	kWh/kWp	-
894	1	Shell RMS 75W	40	3.000	ASP 2500	2.500	1.953	2.170	1.243	1.789	596	0,83
895	1	Shell RMS 75W	30	2.250	ASP 2500	2.500	1.592	1.536	1.558	1.562	694	1,11
896	1	Shell RMS 75W	30	2.250	ASP 2500	2.500	1.833	1.952	2.111	1.965	873	1,11
910	2	Shell RMS 75W	24	1.800	ASP 1500	1.500	1.445	1.515	1.123	1.361	756	0,83
919	2	Shell RMS 75W	24	1.800	ASP 1500	1.500	1.430	1.499	1.533	1.487	826	0,83
911	2	Shell RMS 75W	36	2.700	ASP 2500	2.500	2.331	2.319	2.161	2.270	841	0,93
913	2	Shell RMS 75W	36	2.700	ASP 2500	2.500	2.010	2.360	2.519	2.296	850	0,93
915	2	Shell RMS 75W	36	2.700	ASP 2500	2.500	2.222	2.351	2.511	2.361	875	0,93
916	2	Shell RMS 75W	36	2.700	ASP 2500	2.500	2.278	2.382	2.528	2.396	887	0,93
917	2	Shell RMS 75W	36	2.700	ASP 2500	2.500	2.247	2.382	2.545	2.391	886	0,93
920	2	Shell RMS 75W	36	2.700	ASP 2500	2.500	2.169	2.272	2.421	2.287	847	0,93
921	2	Shell RMS 75W	36	2.700	ASP 2500	2.500	2.153	2.149	2.433	2.245	831	0,93
912	2	Shell RMS 75W	12	900	ASP 1500	1.500	698	751	660	703	781	1,67
1062	6	IBC MSX 120	18	2.160	Sonnyboy SWR 1500	1.500	1.717	1.696	1.866	1.760	815	0,69
1056	6	IBC MSX 120	16	1.920	Sonnyboy SWR 1500	1.500	1.695	1.845	1.934	1.825	950	0,78
1057	6	IBC MSX 120	16	1.920	Sonnyboy SWR 1500	1.500	1.699	1.834	1.939	1.824	950	0,78
1067	6	IBC MSX 120	16	1.920	Sonnyboy SWR 1500	1.500	1.643	1.771	1.855	1.756	915	0,78
1085	6	IBC MSX 120	16	1.920	Sonnyboy SWR 1500	1.500	1.641	1.769	1.878	1.763	918	0,78

In the diagram below corresponding values for specific production in kWh per kWp based on average yearly production and the inverter/PV ratio is presented.



As can be seen, the highest specific production occur when the inverter/PV ration is approximately 0,8, however, this fact might as well be based in variation in efficiencies for either the PV module or the inverters, which has been tested.

When concentration on the results from Area 1, which all represent PV plant using Shell modules, no definite conclusions can be drawn with respect to identifying an optimum in inverter/PV ratio. It seems, however, that the plants representing a ration of 0,93 perform stable and generally surpass the plant with higher as well as lower ration.

Due to the limited amount of data to which this diagram rest on, it is not possible to draw any substantial conclusion, nevertheless the diagram seems to be in good accordance with the fore here mentioned rule of thumb regarding recommended inverter/PV ratio, which harmonics with the fact, that the PV installations investigated is equipped with inverters of a certain age.

4. Comparison of Danish Operational Data to Simulation Results

It was decided to select three Danish locations, where a more detailed analysis of operational data and simulation results could be carried out. Based on considerations of:

- Closeness to a DMI station
- One of the 16 plants being monitored by EnergiMidt, see also section 3.2
- Reflecting the variety of Danish insolation
- Reflecting a variety of designs
- Sites to be simulated reasonably well

The following sites were selected:

1. Test plant at TI, Taastrup, of nominally 800 W, 700 W inverter, commissioned in 1995
2. Roof-top plant at Haarby, Funen, of nominally 2040 W, 1650 W inverter, commissioned 2004
3. Roof-top plant at Holstebro, Jutland, of nominally 2720 W, 3000 W inverter, commissioned 2003

For all three sites monitoring data for half of 2007 and all 2008 are available; the monitoring programme only started mid 2007.

4.1 Typical Simulation Software Packages in a Danish Context

As mentioned previously a host of datasources for insolation data and simulation software packages are available. Following some preliminary analysis it was decided to use the following in this analysis:

As datasource for insolation data time series from:

1. DMI (Danish Meteorological Institute) recorded data
2. Danish Reference Year (DRY) based on more than 30 years of recorded DMI data
3. Meteonorm software package
4. PVGIS from JRC Ispra
5. RetScreen (basically NASA data)
6. ARCO data (basically FAO agroclimatic data)

As simulation software packages:

1. PVSYST vers. 4.x
2. Retscreen vers. 4.x

3. Homer vers. 2.x

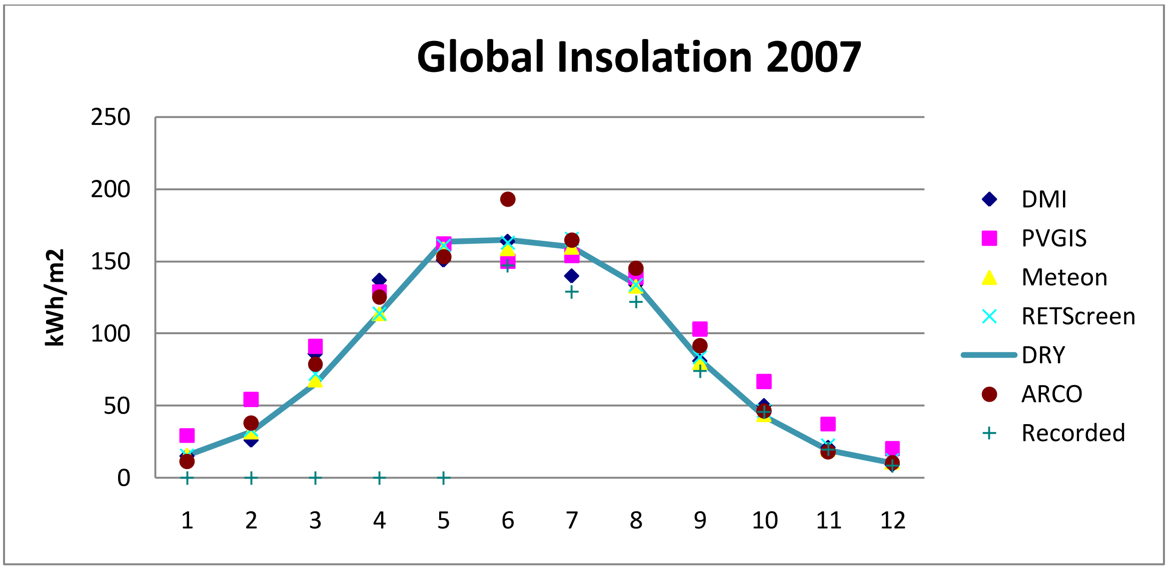
4. PVGIS

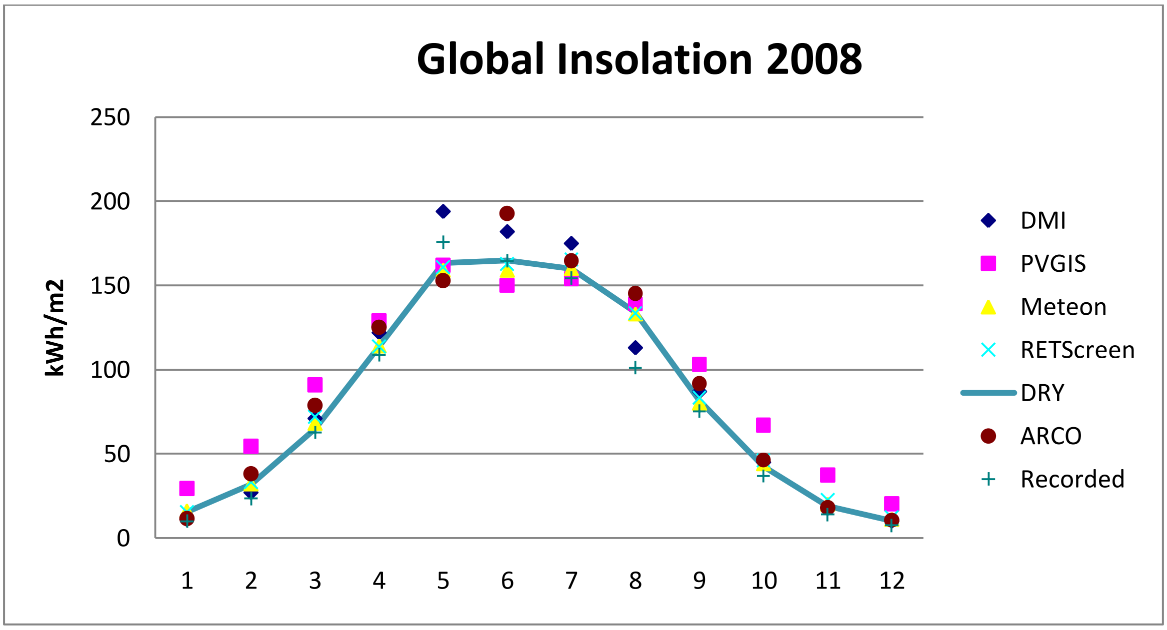
4.2 Comparison of Typical Danish Operational Data to Simulation Results

The spreadsheets containing the basic data of the tre selected plants, the operational data recorded, the insulation data used and the simulation results are found in Annex 6.3. In the following major results are highlighted using graphs based on the above spreadsheets.

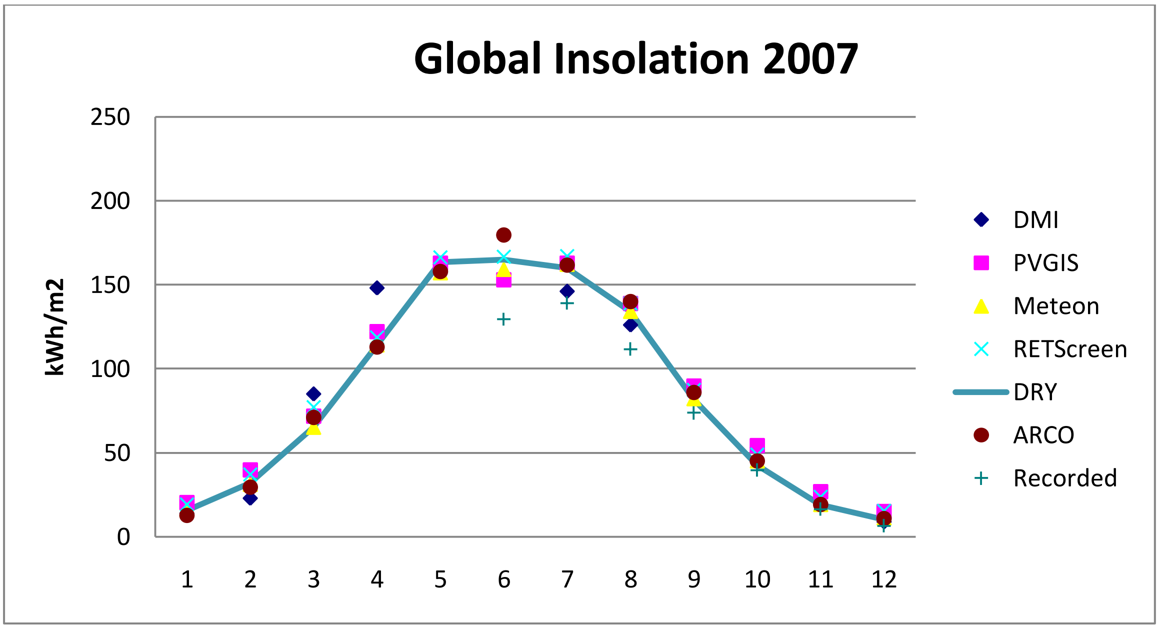
4.2.1 Insolation data

Holstebro





Haarby


Global Insolation 2007
kWh/m2
250
200
150
100
50
0
1
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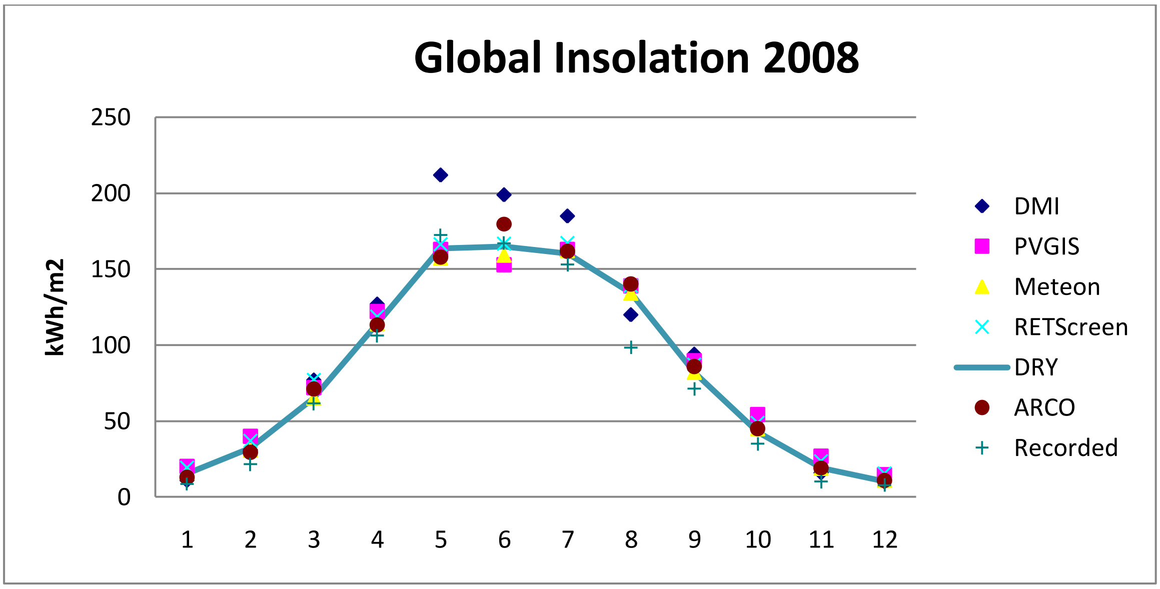
11
12
DMI
PVGIS
Meteon
RETScreen
DRY
ARCO
Recorded


Global Insolation 2008
kWh/m2
250
200
150
100
50
0
1
2
3
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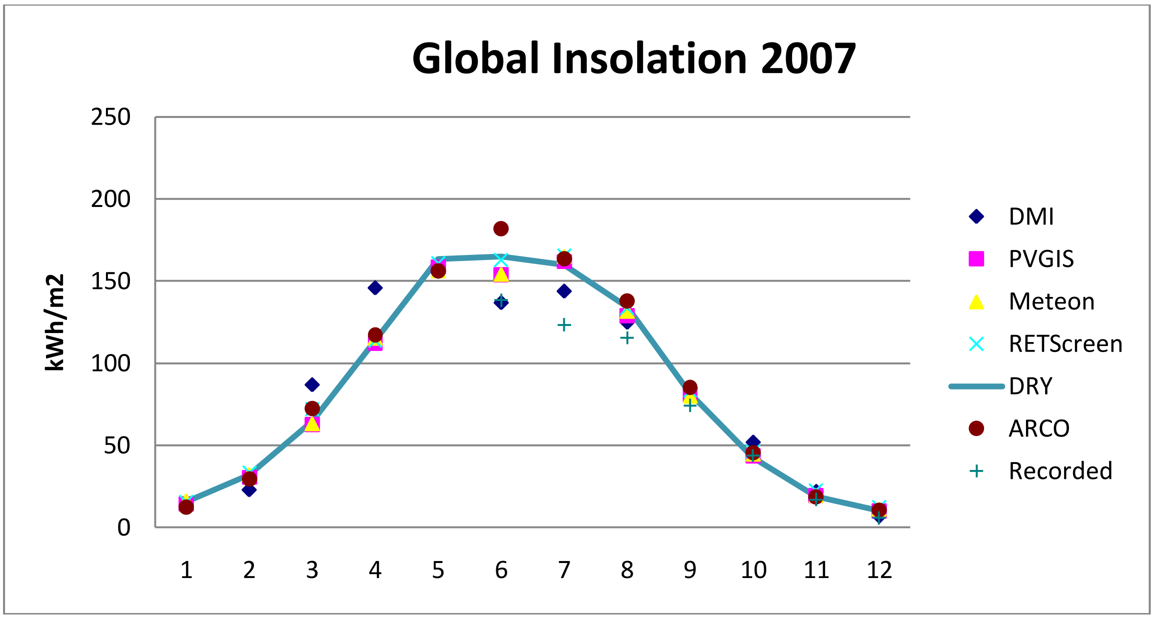
12
DMI
PVGIS
Meteon
RETScreen
DRY
ARCO
Recorded

TI, Taastrup


Global Insolation 2007
kWh/m2
250
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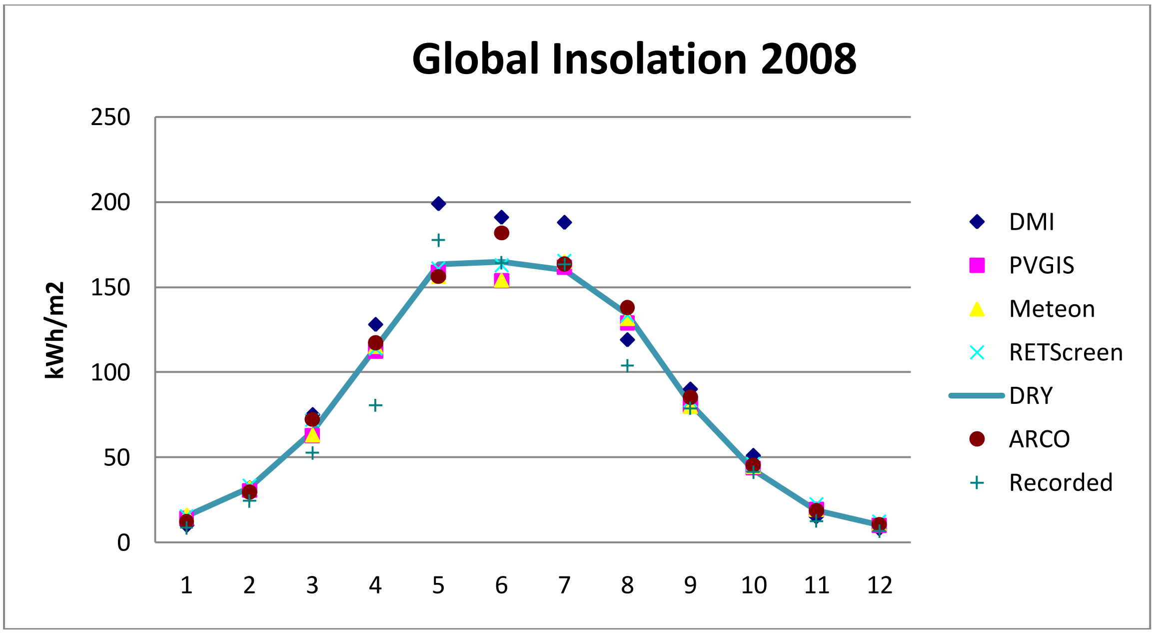
12
DMI
PVGIS
Meteon
RETScreen
DRY
ARCO
Recorded


Global Insolation 2008
kWh/m2
250
200
150
100
50
0
1
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10
11
12
DMI
PVGIS
Meteon
RETScreen
DRY
ARCO
Recorded

Comments

For all three sites there is a relative good coincidence between the various sources of insolation data and the actual recorded values (DMI); the most pronounced differences occur in the summer months. In 2008 for all sites the months of May, June and July exhibit an unusually high insolation in terms of recorded data (DMI). This trend can be found for all DMI stations in 2008, indicating a very sunny summer season.

The recorded insolation data (at the three selected PV plants) exhibit a relative good coincidence with the recorded DMI data; however, in the three summer months in 2008 the plant data and the DMI data differ considerably. As the location of the DMI station and the PV plant for all three sites is almost identical, an obvious explanation for this has not been found[13], but it may have something to do with the angular sensitivity of the insolation sensors – in this case calibrated sol cells. As previously reported by the JRC[14], the angular response of a solar cell is not exactly that of a pyranometer – the usual sensor used by meteorological stations.

For Taastrup in April 2009 – data are missing in the Energinet.dk recordings.

The satellite based data appear in general to be slightly more optimistic than the recorded data. This is in particular true for Holstebro and the PVGIS data. JRC, who has developed and compiled the PVGIS system and data base is aware of a trend to overestimate insolation data in coastal areas with a high share of sea area.

In general terms the DRY data is a good source of data for preliminary design of PV systems. However for larger systems it will be more optimal to use local recorded data reflecting the geographical spread in insolation across Denmark. Furthermore it is recommended to carry out simulations using several sources of insolation data.

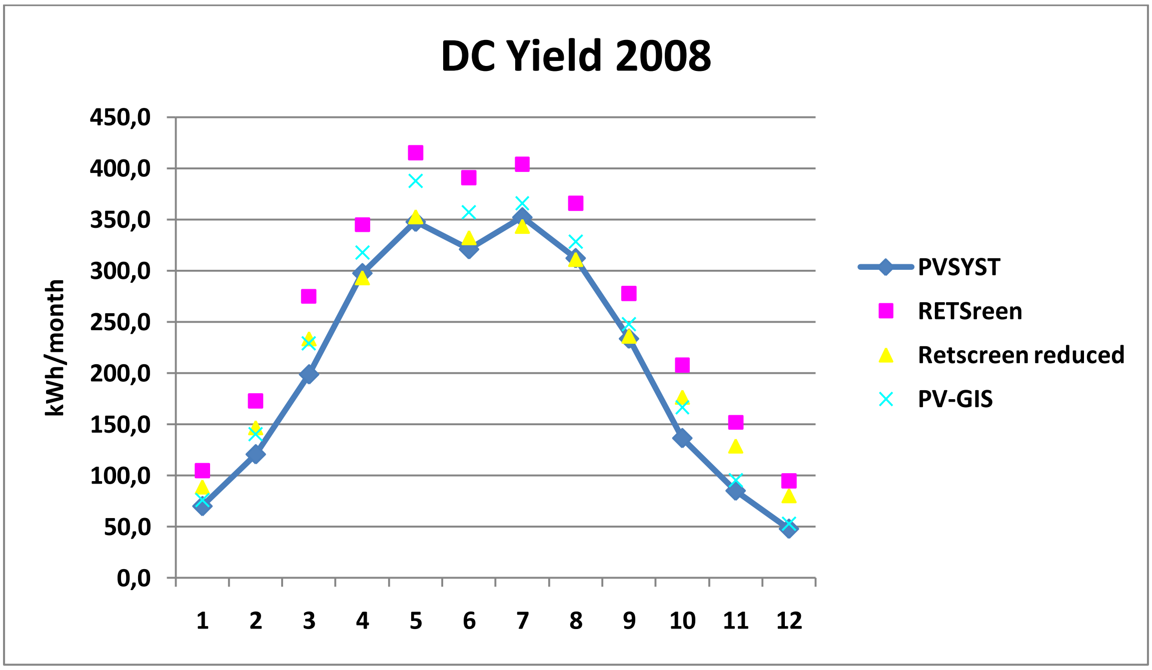
[13] It has not been possible in the project actually to visit and inspect the three selected PV systems; micro-siting issues such as shadowing, temperature, albedo and other reflections may account for the variations.

[14] JRC, Ispra: Analysis of Optical Artefacts observed comparing the ESTI-sensor with a Pyranometer, 1996.

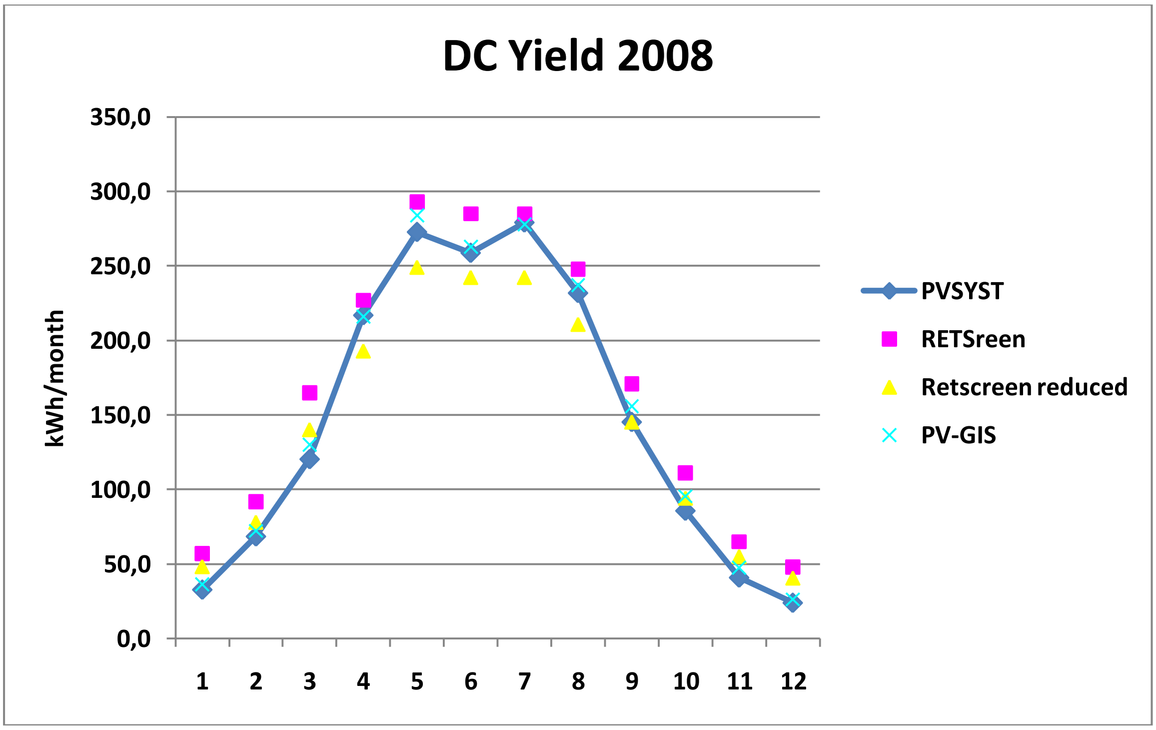
4.2.2 DC Yield using simulation packages

As the PV array DC yield is simulated using the average insolation data as provided by the respective simulation packages, only one year is shown in the following (as all years will be identical).

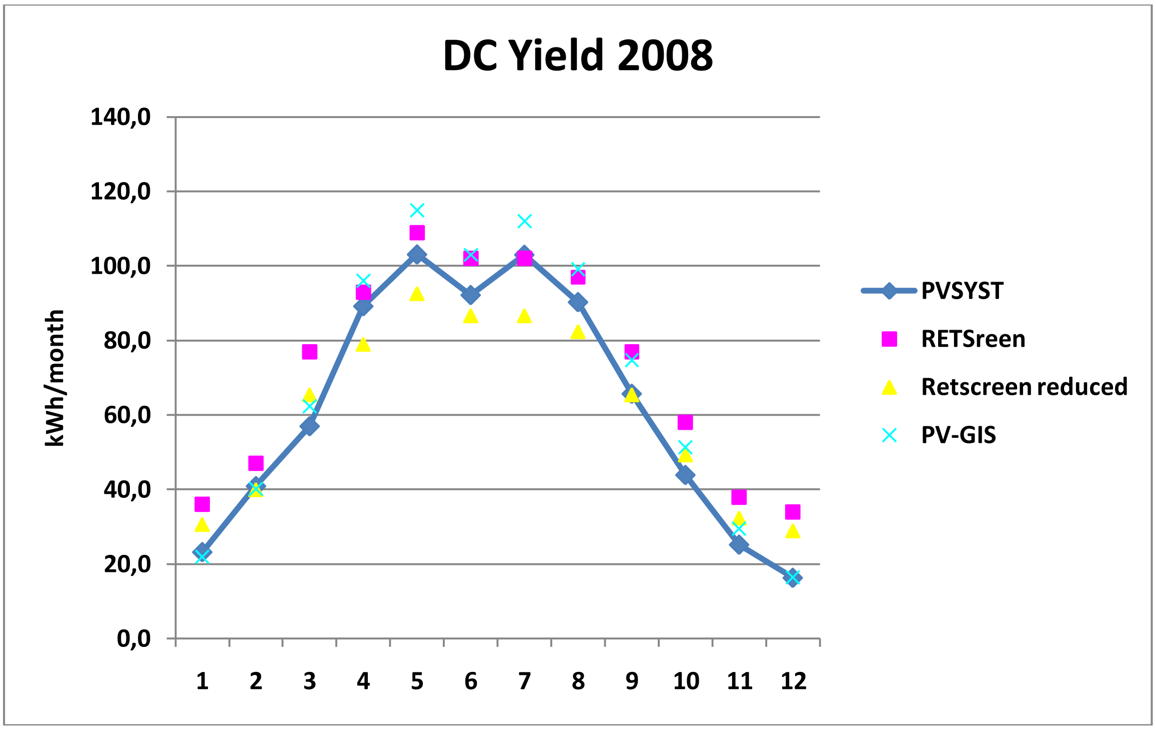
Holstebro



Haarby



TI Tåstrup



Comments

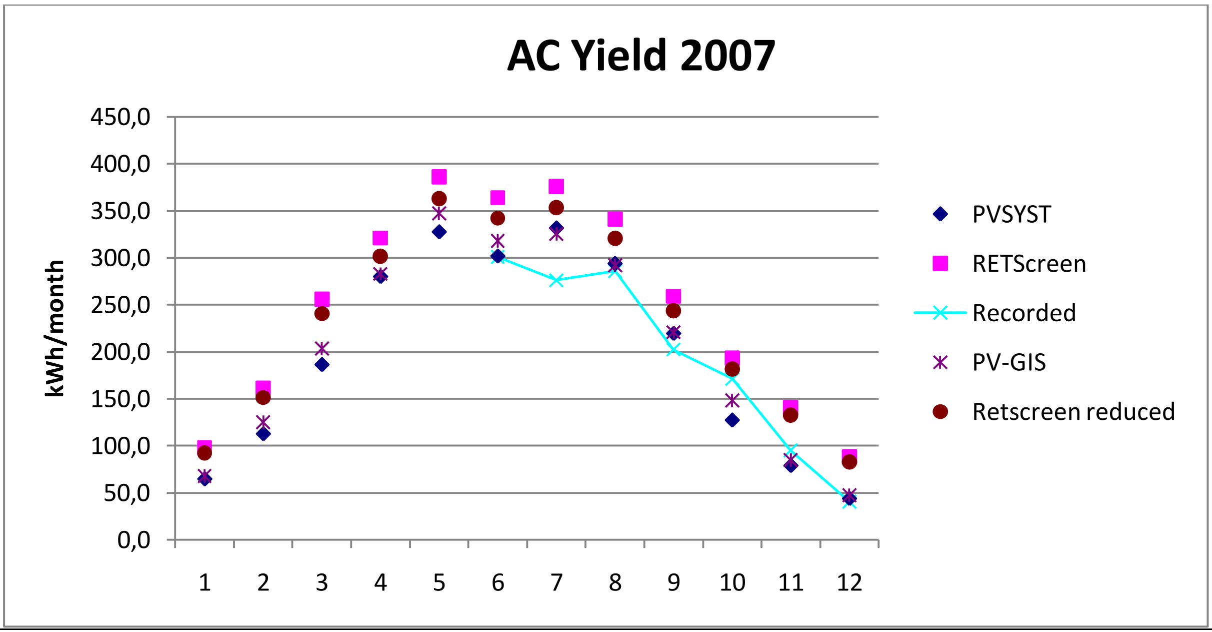
In general terms the various simulation tools predict the PV array DC yield more or less on the same level – however certain differences can be seen.

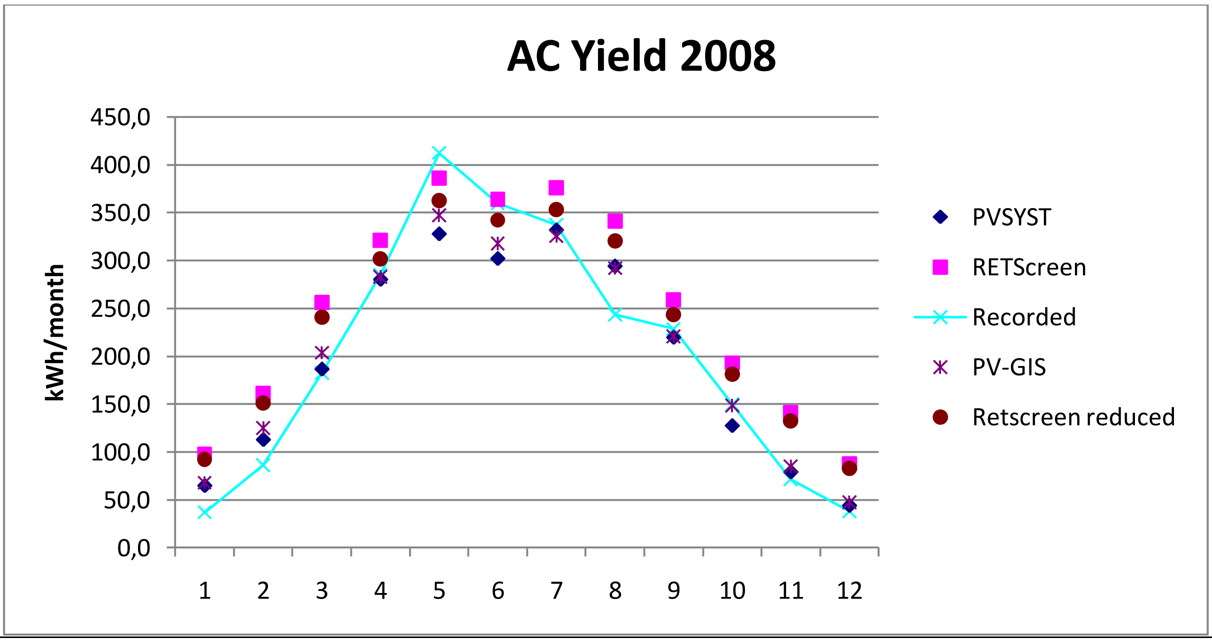
Retscreen is using satellite data, which tends to be high in certain coastal areas (e.g. Holstebro) as mentioned previously. In Retscreen you have to adjust some loss factors from the default, and with additonal losses of about 15 % included (module mismatch, array and ohmic losses) the correlation with the other results are improved (at least for Danish conditions).

The other differences observed can be related to the differences in the insolation data provided by each simulation package as dicussed before.

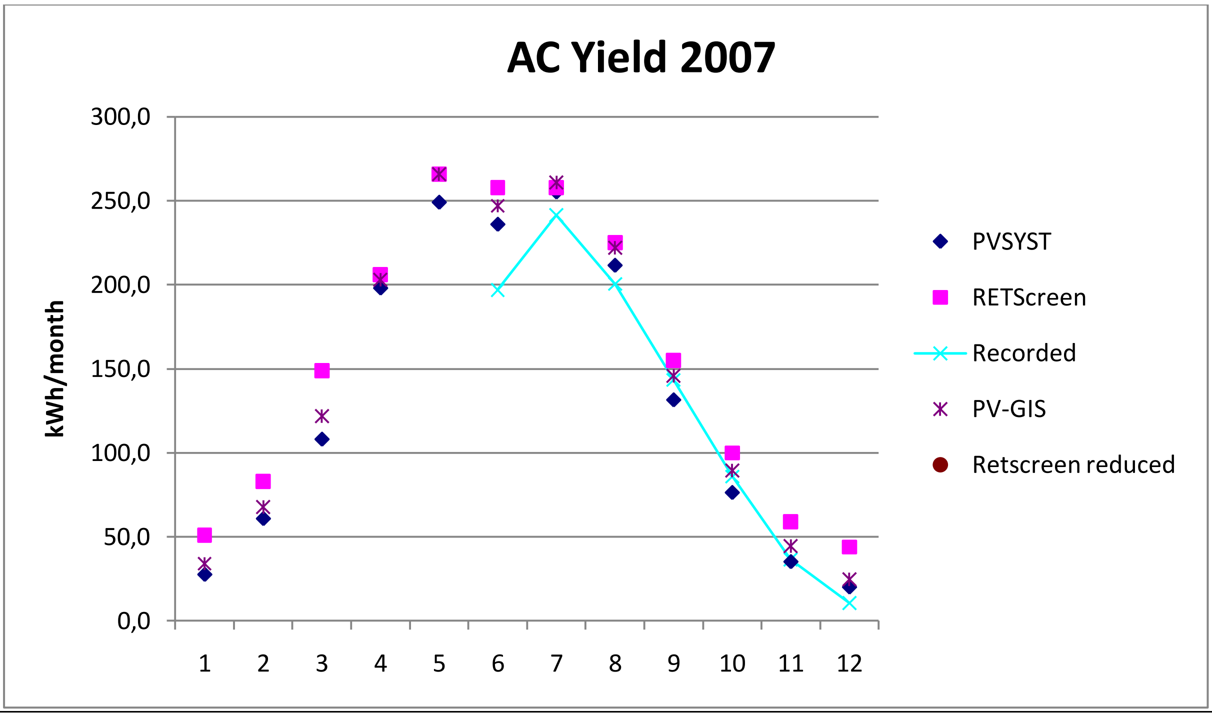
4.2.3 AC Yields using simulation packages and recorded data

<u>Holstebro</u>





Haarby


AC Yield 2007
kWh/month
300,0
250,0
200,0
150,0
100,0
50,0
0,0
1
2
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4
5
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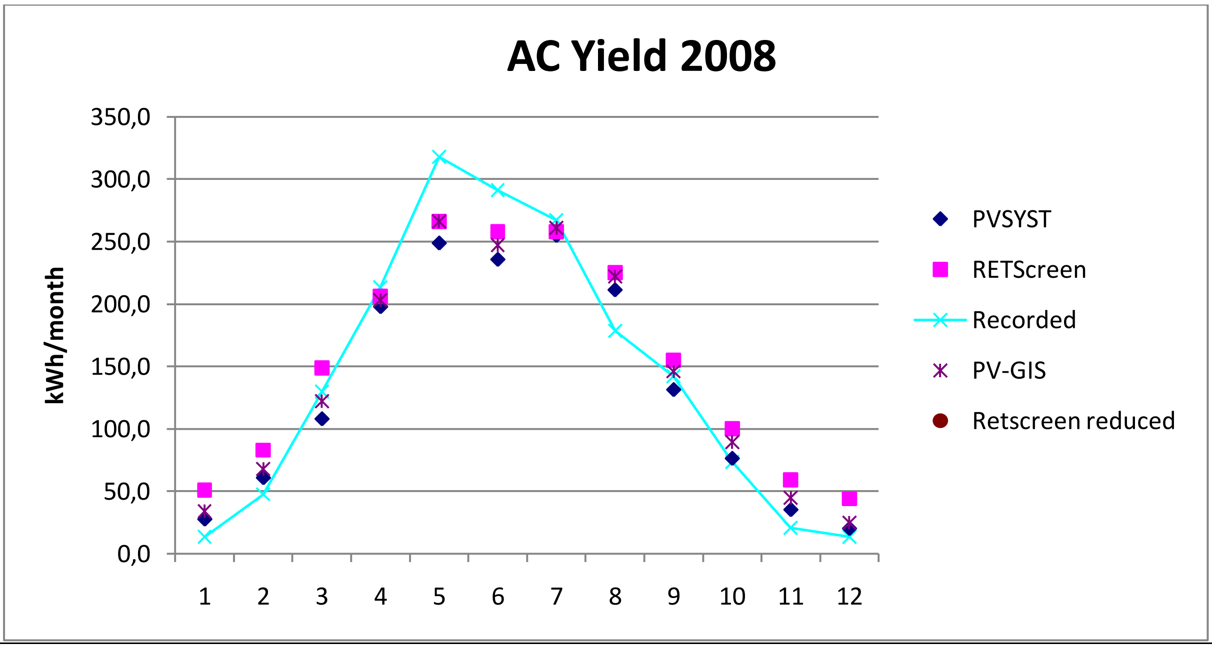
7
8
9
10
11
12
PVSYST
RETScreen
Recorded
PV-GIS
Retscreen reduced


AC Yield 2008
kWh/month
350,0
300,0
250,0
200,0
150,0
100,0
50,0
0,0
1
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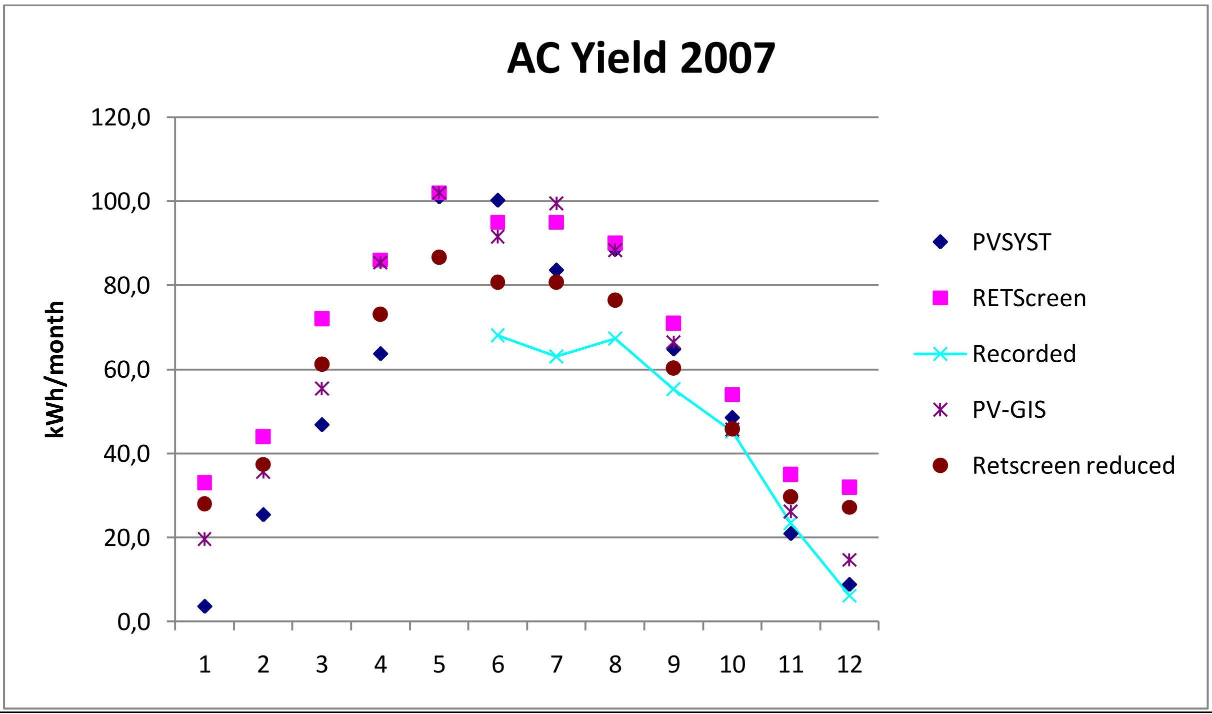
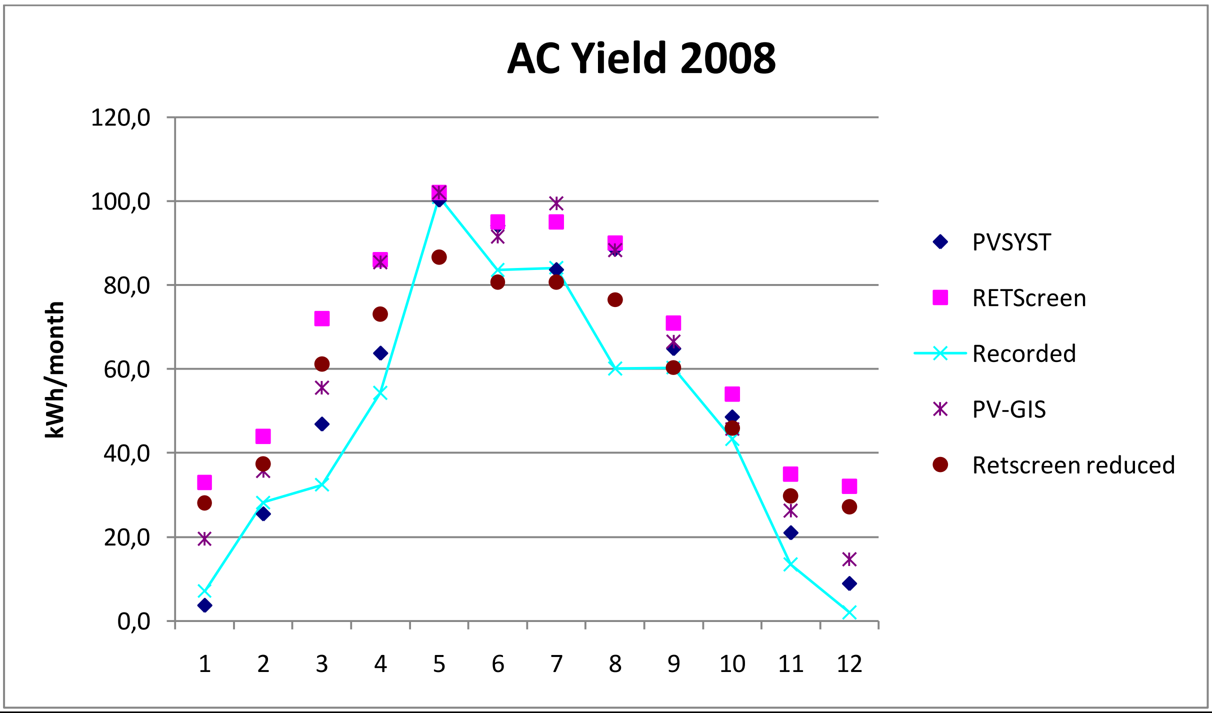
11
12
PVSYST
RETScreen
Recorded
PV-GIS
Retscreen reduced

TI Taastrup


AC Yield 2007
kWh/month
120,0
100,0
80,0
60,0
40,0
20,0
0,0
1 2 3 4 5 6 7 8 9 10 11 12
PVSYST
RETScreen
Recorded
PV-GIS
Retscreen reduced


AC Yield 2008
kWh/month
120,0
100,0
80,0
60,0
40,0
20,0
0,0
1 2 3 4 5 6 7 8 9 10 11 12
PVSYST
RETScreen
Recorded
PV-GIS
Retscreen reduced

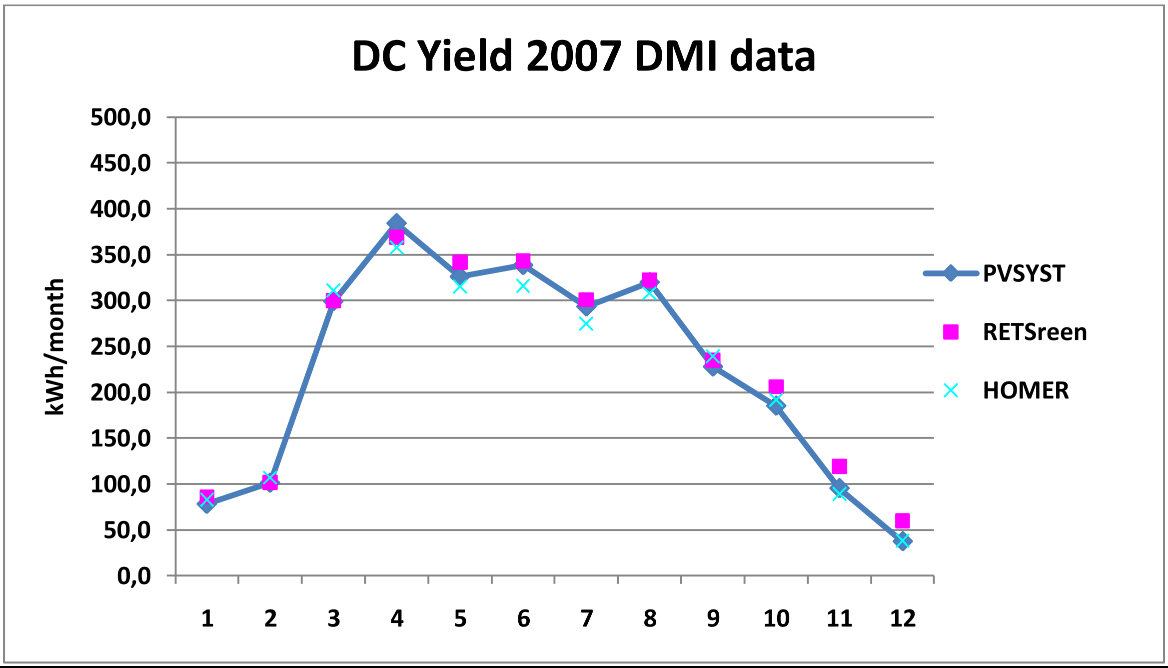
Comments

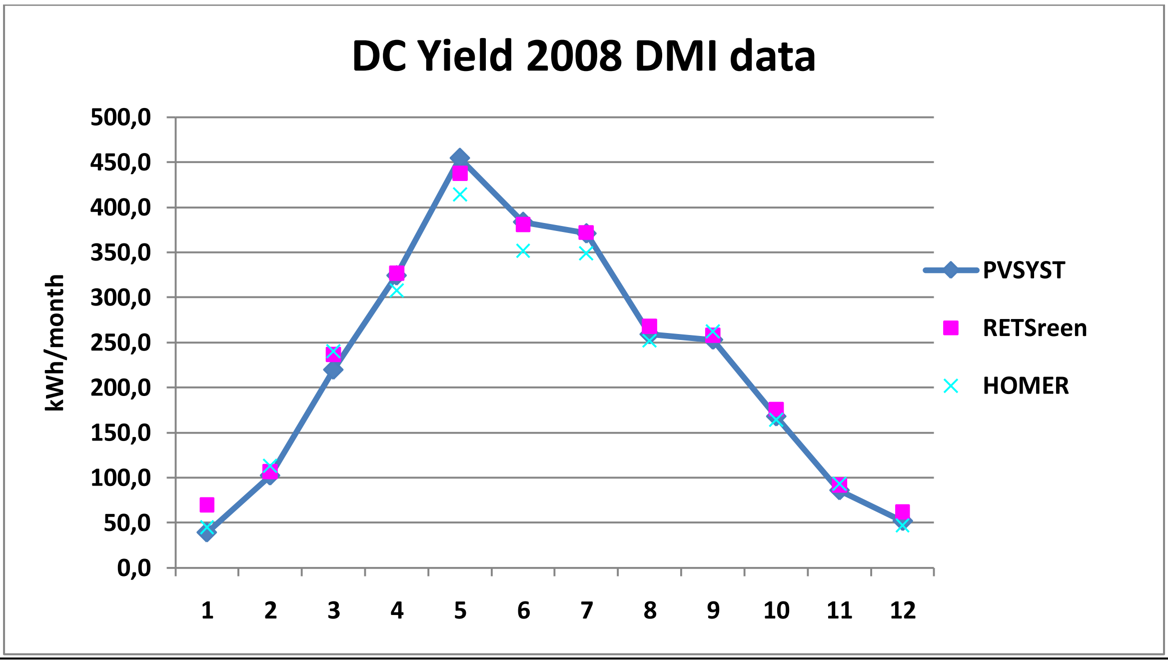
The PV system at Taastrup exhibits relative low recorded data mid 2007 and early 2008 due to gaps in the data recording process. The recorded values are constantly on the low side, but this has been found to be due to old and somewhat degraded modules commisioned in 1995. The two other PV systems are commissioned around 2003-4.

Again the differences are mostly due to the variation in insolation values provided by the different simulation packages.

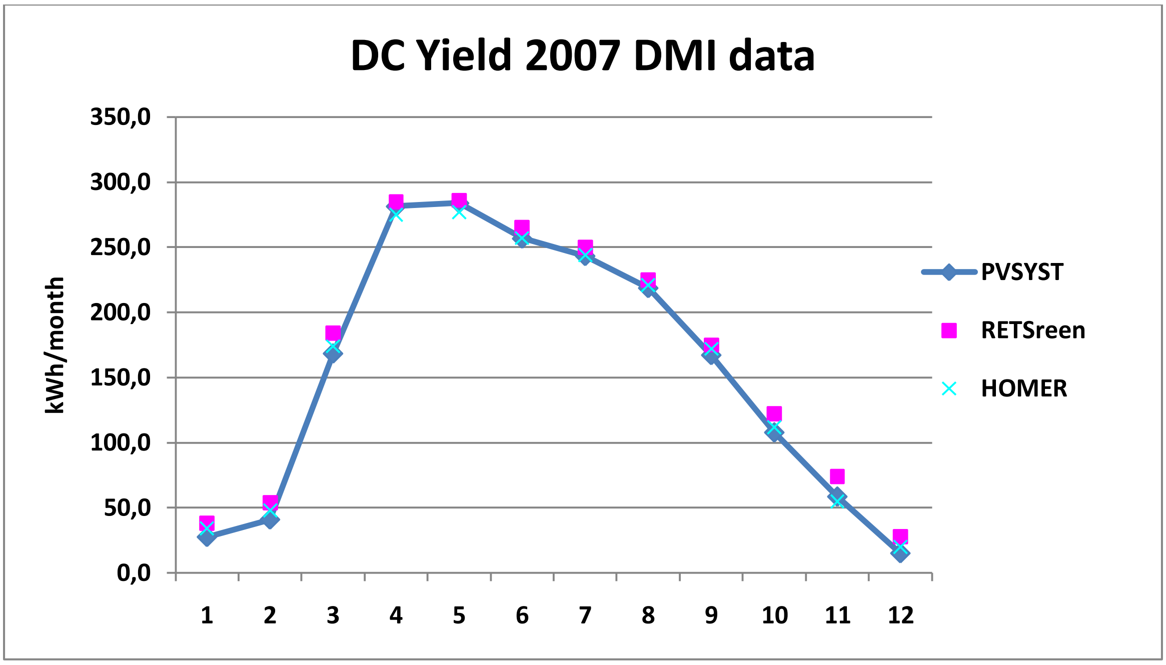
4.2.4 DC Yields using simulation packages and recorded close to site DMI data

<u>Holstebro</u>





Haarby


DC Yield 2007 DMI data
kWh/month
350,0
300,0
250,0
200,0
150,0
100,0
50,0
0,0
1
2
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6
7
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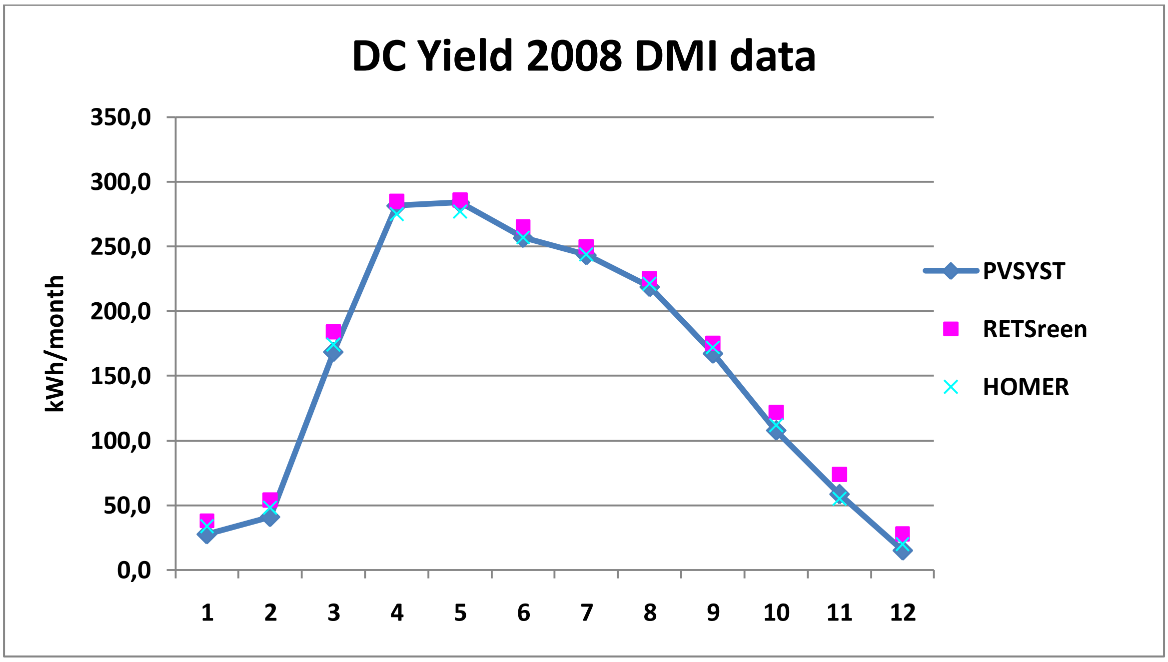
10
11
12
PVSYST
RETSreen
HOMER


DC Yield 2008 DMI data
kWh/month
350,0
300,0
250,0
200,0
150,0
100,0
50,0
0,0
1
2
3
4
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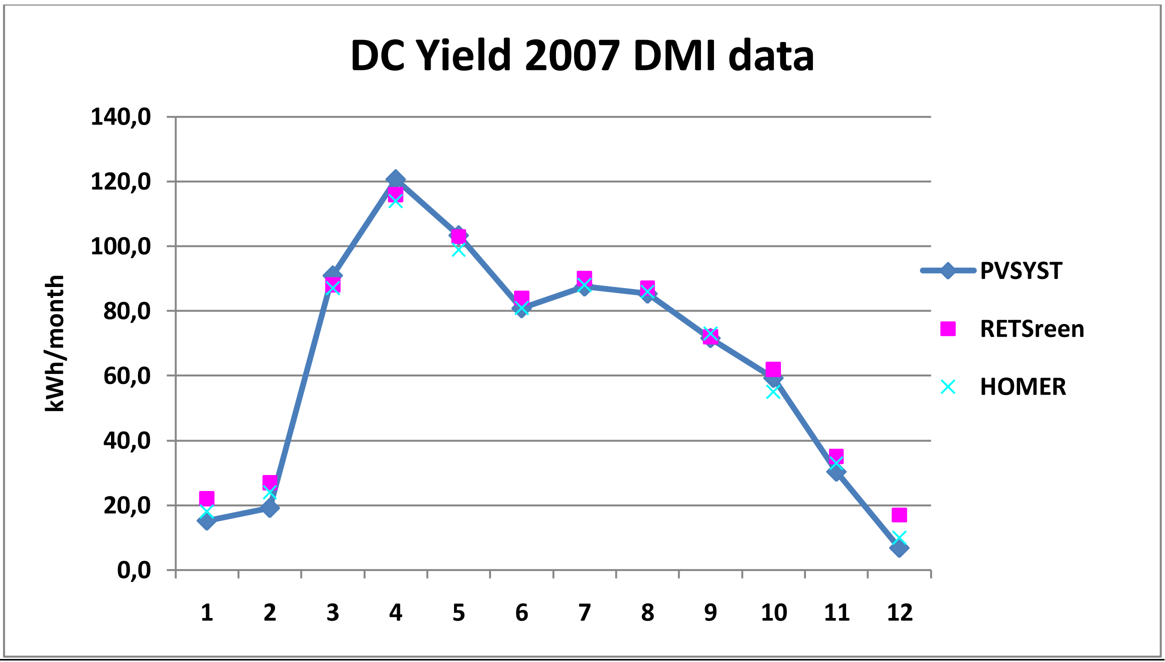
11
12
PVSYST
RETSreen
HOMER

TI Taastrup


DC Yield 2007 DMI data
kWh/month
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
1
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4
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6
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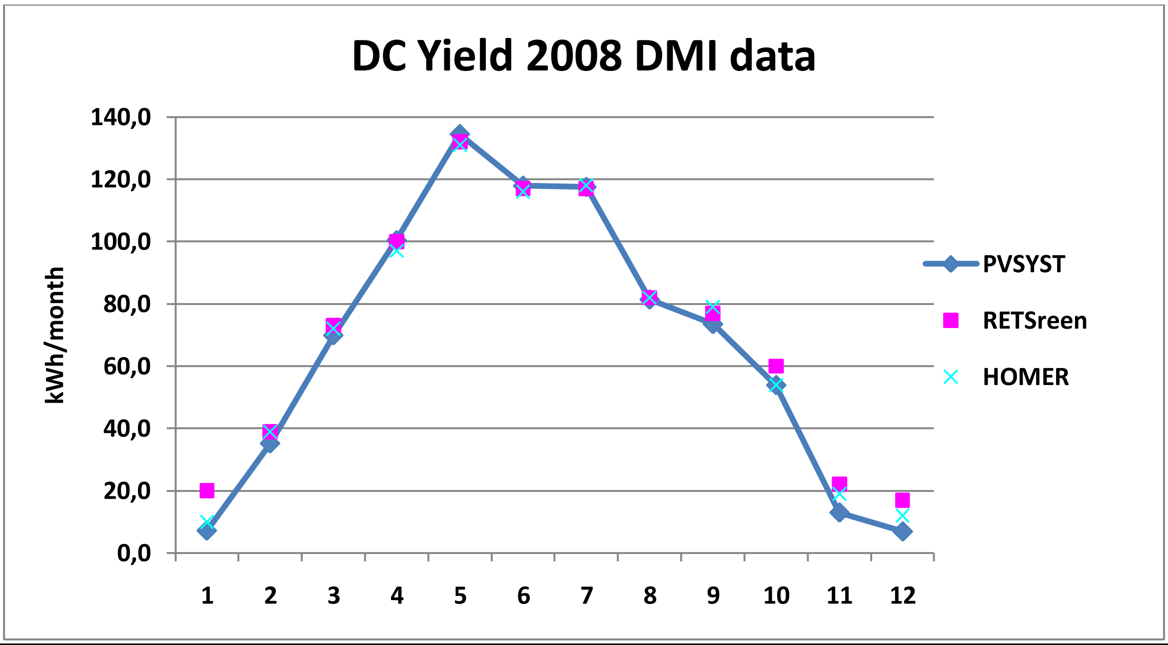
10
11
12
PVSYST
RETSreen
HOMER


DC Yield 2008 DMI data
kWh/month
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
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11
12
PVSYST
RETSreen
HOMER

Comments

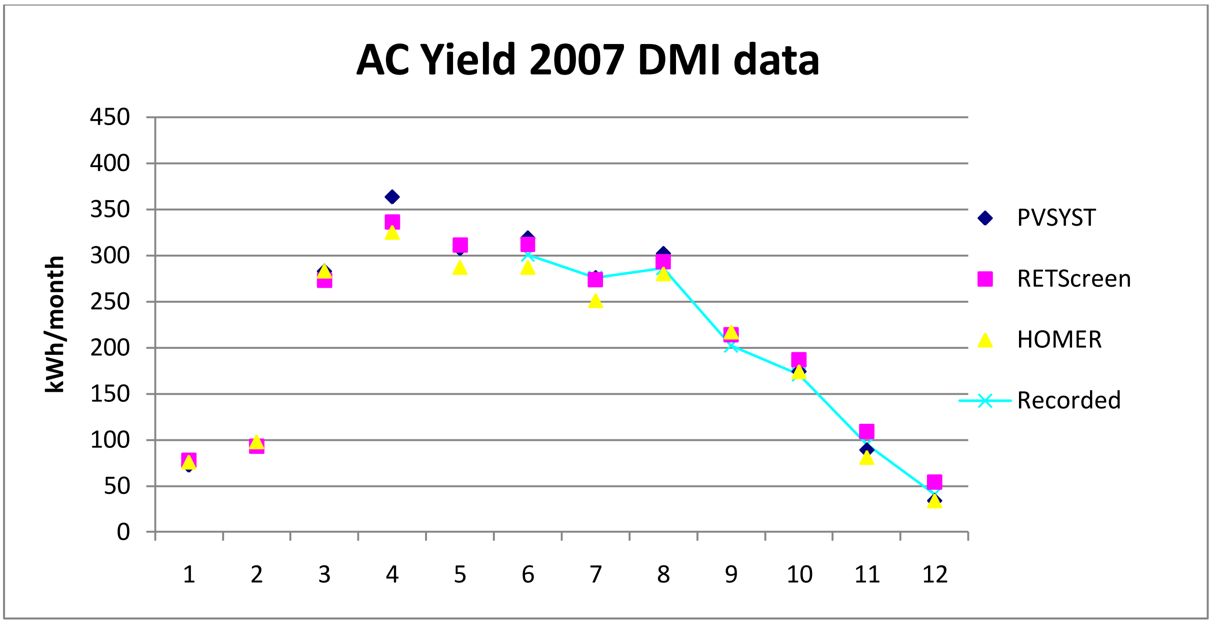
There is a markedly improved correlation in simulated array DC yield for all three sites, when using DMI reorded insolation data from nearby meteorological stations.

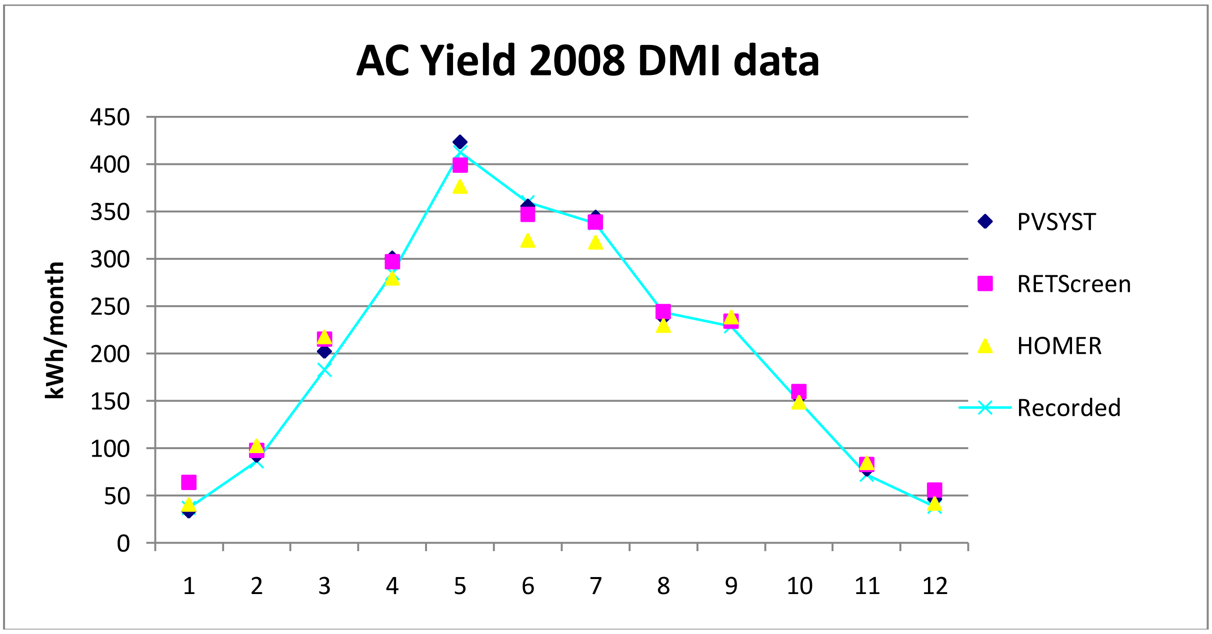
There might be a slight trend for Retscreen to overestimate in the winter months, which might have something to do with the albedo, but the albedo function of Retscreen is not clear.

It is also to be remarked, that the free software packages (with due care) gives the same results as the move advanced commercially available software packages. The degree of freedom in an actual design process is however markedly higher in the commercial softweare packages.

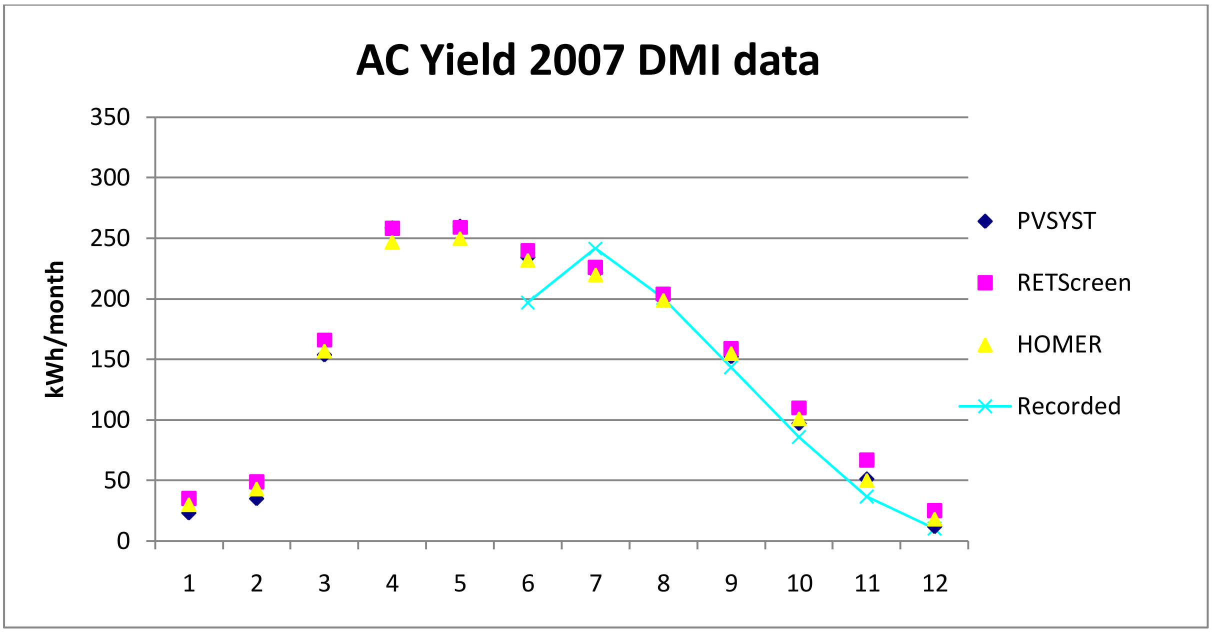
4.2.5 AC Yields usings simulation packages, DMI recorded data and recorded AC data

Holstebro





Haarby


AC Yield 2007 DMI data
kWh/month
350
300
250
200
150
100
50
0
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5
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7
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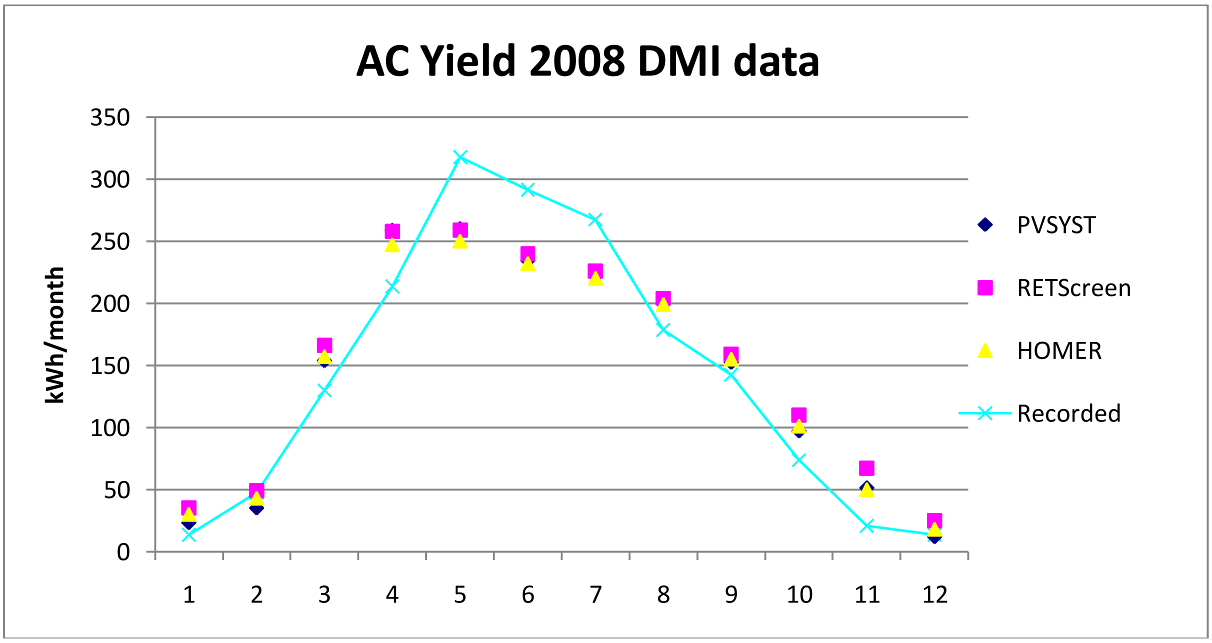
9
10
11
12
PVSYST
RETScreen
HOMER
Recorded


AC Yield 2008 DMI data
kWh/month
350
300
250
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150
100
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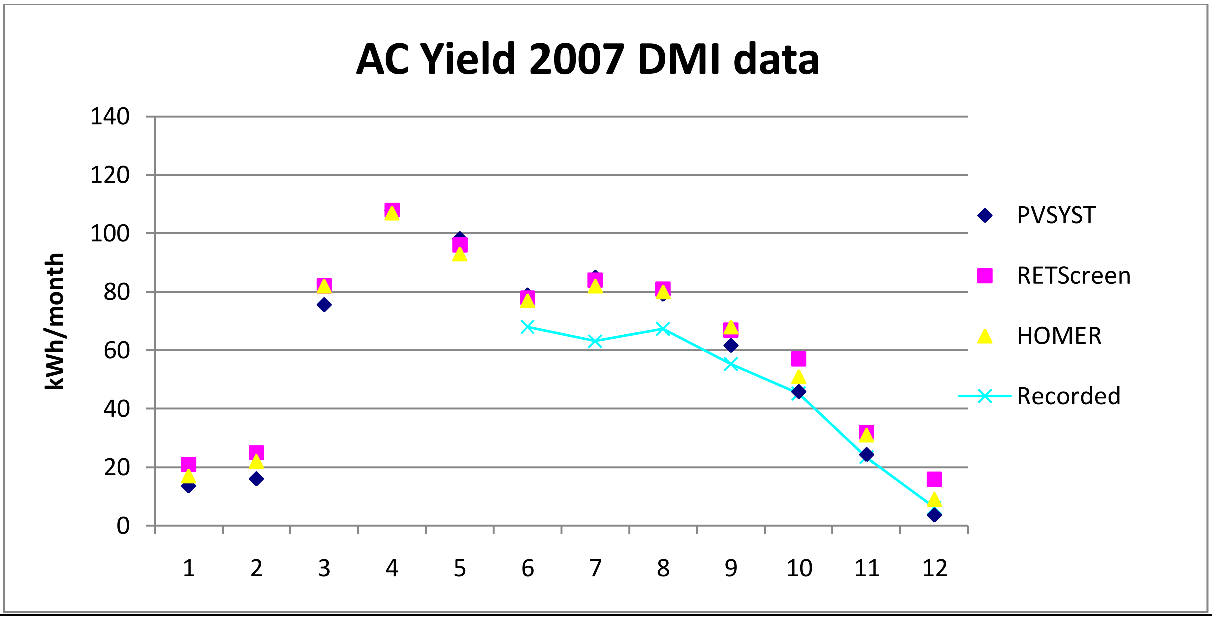
11
12
PVSYST
RETScreen
HOMER
Recorded

TI Taastrup


AC Yield 2007 DMI data
kWh/month
0
20
40
60
80
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120
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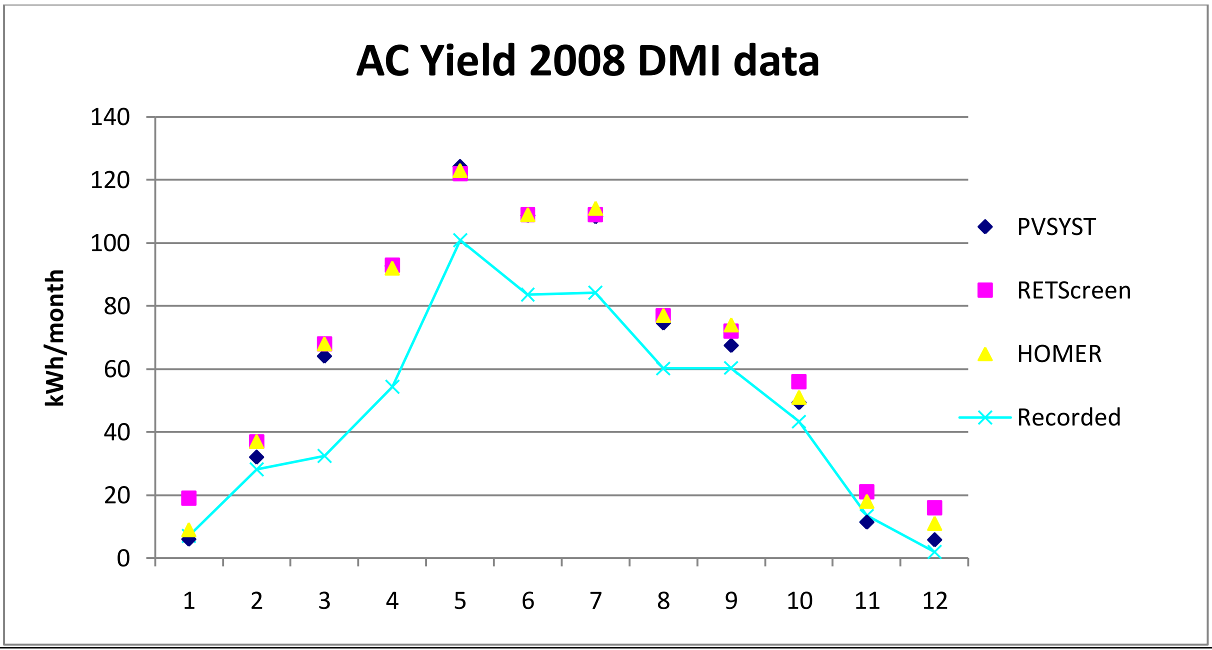
PVSYST
RETScreen
HOMER
Recorded


AC Yield 2008 DMI data
kWh/month
0
20
40
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80
100
120
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PVSYST
RETScreen
HOMER
Recorded

Comments

Similar comments as in section 2.4.2. The advantage of using locally recorded insolation data when possible in stead of the data provided by the simulation packages is evident.

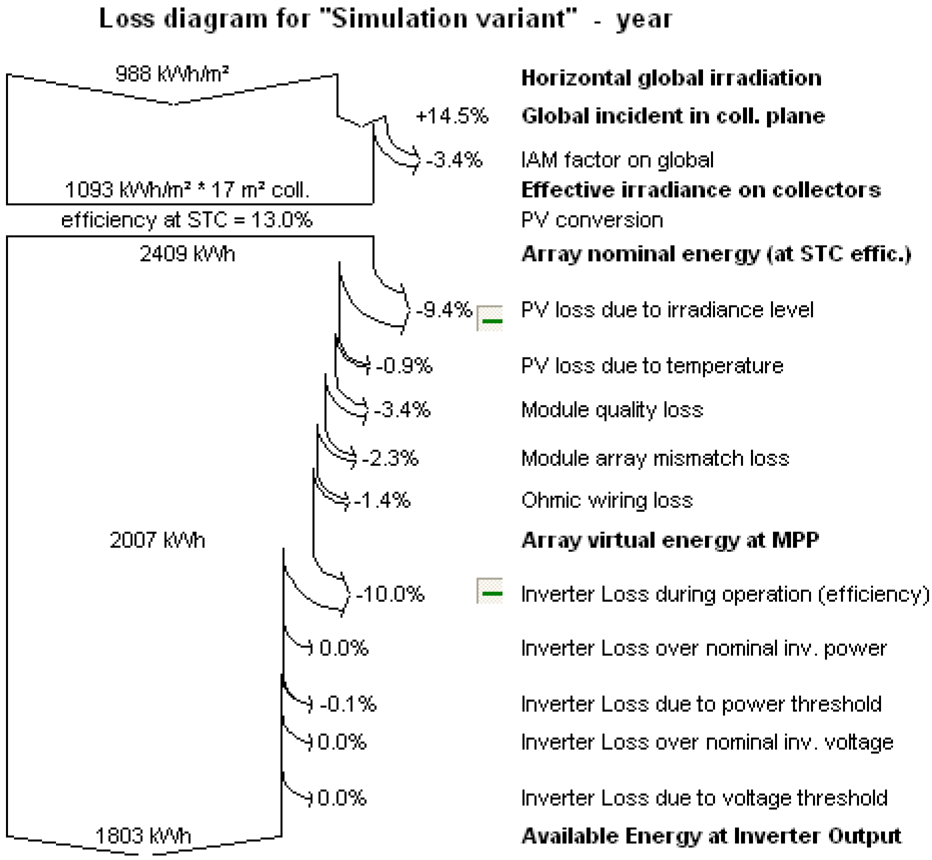
For the site Haarby the recorded AC output in the summer months of 2008 is markedly higher than the simulations. It has not been possible for the PV-OPT project to find a suitable explanation for this phenomenon.

Again the degradation of the modules at the Taastrup site is evident; the array is nominally 800 W, but was in 2007 measured to around 600 W.

5. Recommendations for PV System Design under Danish Conditions

5.1 Critical Design Parametres – Risk Reduction Measures

Type of loss	**Impact**	**How to minimize effect**	**Specific guideline for DK**
Module quality loss	general overestimation of plant performance	check performance warranty	
Module array mismatch loss	Not all modules will operate at maximum power, depending on configuration	Sorting by I_{mpp} in strings and V_{mpp} in parallel	
PV loss due to irradiance	Most modules are less efficient at low irradiance	Check module power curve at low light conditions	See module comparison, chapter….
Ohmic wiring loss	Some of the power is lost before the inverter	Sufficient cable dimension	(table xx)
IAM factor on global irradiance (Optical losses)	Reflection at high angles of incidence	Cover with low reflectance and high transmission properties	
Uneven solar irradiance	Can create hot-spots and significantly reduce current in PV array	Avoid shading, same orientation of all modules in a string	Table xx Horizontal shading
Module loss due to temperature	Loss of voltage due to high temperatures	Use less sensitive modules or ensure sufficient ventilation	
Inverter loss during operation	Conversion losses	Good MPPT algorithm High overall efficiency Correct voltage range	
Inv. Power limit	Lost PV power if inverter power is limited	Correct size	
Inv. Power treshold	Lost power if inverter does not start at low power level	Low cut-in limit	
Inv. Input voltage too high	Cut-out due to over voltage	Wide voltage window	
Inv. Voltage treshold	Insufficient voltage for start-up	Wide voltage window	
Other losses: Dirt and snow on the modules	Lower transmission and uneven solar irradiance	Mount PV modules with a minimum slope of 15 degrees. Avoid edges on the lower part of the module frame.	



Simulation in PVsyst for Denmark (typical polyX modules in standard roof mounting)

The single most important factor is PV loss due to irradiance level. It is typical for many PV modules that their efficiency decreases with decreasing irradiance. For Danish conditions, with a lot of diffuse radiation, it is important to select modules that maintain their nominal efficiency over a wide range of irradiance, or even increase their efficiency at levels below 1000 W/m^2. The temperature affected module derating is almost neutral seen over the entire year in the Danish climate, so this factor is less important, at least in systems with good ventilation.

5.2 Recommended PV Module and Panel Configurations

When projecting a PV system some consideration has to be taking regarding which PV modules are adequate and - for large systems - how to configure these in a sufficient number of parallel strings.

5.2.1 Selection of PV module

At the moment 6 types of PV modules are commercially available, of which 2 types are crystalline based, mono – respectively poly crystalline, and 4 types are thin film based. The latter types being:

- Amorphous silicon (a-Si),
- Micromorphous (a-Si/µc-Si).
- Copper indium gallium selenide (CIGS).
- Cadmium telluride (CdTe).

The crystalline base PV modules account for the lion share of the plants installed in Denmark until now and still hold a marked share of approximately 87 % of new plants installed on worldwide scale in 2008[15].

Theoretically, mono crystalline modules would operate with efficiencies slightly higher than there poly crystalline sibling technology, which again will be more efficient than the various types of thin film. In the table below comparisons of some key characteristic of these 6 types is shown.

Module and cell efficiencies for thin film and crystalline base PV modules						
Technology	**Thin film photovoltaic**				**Crystalline based**	
	Amorphous silicon a-Si	Cadmium telluride CdTe	CIS - CIGS	a-Si/μc-Si	Mono crystalline	Poly crystalline
Cell efficiency, % **Module efficiency, %**	5 – 7	8 - 11	7 -11	8	16 - 19 13 - 15	14 – 15 12 – 14
Area needed pr. kW_p, m²	15	11	10	12	App. 7	App. 8

In the task of selection between these 6 types of modules, 2 major factors will have influence:

1. The overall economic in the lifetime of the plant
2. Architectural aspects

Re. 1. When looking at economical conditions, several elements add up the total economic condition in the plants lifetime. One very important factor is the cost of the modules, which usually account for 55 – 65 % of the total establishment cost.

This should benefit application of thin film modules, which are considerably cheaper per Wp than crystalline modules, however, as can be seen in the table, utilization of thin film modules requires a large area in order to establish a certain capacity.

Therefore, the cost saved in purchasing the modules has to be counterbalanced against the increased cost for salaries and equipment for mounting as well as – if a free standing plant is in question – for purchasing or renting of land.

As a consequence of the increased demand for area, one also has to make sure that the area intended for the PV plant will have sufficient size to host the amount of PV modules needed to establish the intended capacity.

Re. 2. Due to the production process, thin film modules usually have a more homogeneous and discreet visual appearance than the case is for crystalline modules, which make them attractive from an architectural point of view. Thus utilization of thin film can facilitate specialized architectural aspects including building integrated PV which can not be covered using traditional PV modules.

[15] Photon International No. 3, 2009

When selection PV modules to a certain project, it can therefore be very advantageously to collect information regarding available products from several module technologies, giving that the visual appearance can vary considerably from one type to another.

As can be seen, several aspects have to be taking into consideration when selecting modules for a certain project, and therefore it is difficult to give precise and exact recommendations. Eventually, the choice requires a throughout cost-benefit analysis in which all elements infecting the total establishment and operation economic is included together with architectural requirements that may arise.

Some very general aspects, however, can be giving with respect to efficiency and guarantee terms.

Regarding efficiency, it has been shown in the table above, that significant difference exist between the different module technologies, however, also among products in the same technology category the annual yield that can be obtained under a giving condition, can vary considerably.

Thus it is very important to collect and compare efficiency for a number of products produced by manufactures independent from each other in order to maximize the yield of the plant in question, or alternatively to secure that one do not pay a premium price for a minor quality product.

PV modules are not exposed to mechanical wear and tear since no moving parts are involved in the production phase. However, a certain decreasing in the electricity production from a PV plant will inevitable occurs due to a degrading of efficiency of the processes taking place in the single PV cell.

Today, all major producers of PV panels give warranty that the electricity production will be maintained at a high level over time. A common guarantee term is that production level compared to the initial level will be at least 90 % after 10 years of operation and at least 80 % after 25 years of operation.

When choosing a supplier for modules to any giving project, it is important to take into consideration:

1. Which terms of guarantee the supplier offer, and
2. Whether it can be expected, the supplier actually has the strength to be able to fulfil the guarantee terms offered if this should be necessary.

The guarantee terms should at least meet the conditions described above, and with respect to the strength of the supplier, it is important that there is a high degree of certainty that the supplier will remain in business throughout the period of guarantee.

5.2.2 Panel configuration

Most sophisticated PV simulating software systems includes facilities to optimize the panel configuration as well as the interplay between inverter and PV array. The systems that are available free of charge such as Homer and RetScreen, however, do not include such possibilities, and in this case a manual calculation must be carried out.

When doing this, data sheets for PV modules and inverters must be at hand in order to investigate usable configurations that meet the requirement for inverters as well asPV modules. Based on these data sheets, the some information must be provided in order to fulfill the calculation.

With respect to the PV-panel, the following information is needed:

- Nominal power [Wp]
- Open circuit voltage, denoted Voc [V]
- Voltage at MPP, denoted Vmpp [V]

As for the inverter, the following parameter must be available:

- Minimum MPP voltage [V]
- Maximum PV voltage [V]
- Number of separate MPP input strings
- Grid voltage that must be 230 V for mono phased and 400 for triphased model
- Frequency modes, which must be 50 Hz under Danish conditions.

Besides these values, which are essential in order to make the electrical design, also the efficiency as well as purchasing price is important values to know in order to choose between various types that all fit the basic technical purpose.

When these figures are available, a calculation can be made by following these steps:

Based on the desired size of the PV plant in Wp the number of PV modules needed is found by dividing the desired size with the nominal effect of a single module. The number is rounded up or down in order to have an exact number without decimal fractions.

The modules are now divided in a number of strings, each holding an equal numbers of modules. For each string, the operation voltage at MPP as well as in open circuit point is calculated by multiplying respective values for one module with the total number of modules.

When these values are calculated, a sufficient inverter is chosen with respect to size (in W), frequency modes and grid voltage.

Based on the operation specifications of the inverter in question it must now be verified that two conditions are met:

1. The operation voltage at MPP must exceed the inverter's minimum MPP voltage.

2. The open circuit voltage of the array has to stay below the maximum inverter's PV voltage input.

When the desired array configuration doesn't match these requirements, the system is usually not properly sized and therefore an adjustment in number of modules and/or number of strings must be made followed by a new calculation.

A further guidance regarding design of a PV system is presented in part 6.4.

5.3 Recommended PV System Configurations

Under Danish circumstances, PV plants set up by private house owners are - under certain conditions - allowed to use a net metering scheme. Popularly speaking, this allows the production to be “parked” on the electricity grid in period where the local production surpasses the momentary consumption.

From an economic point of view it is usually not beneficial to install a PV plant by which the production exceeds the consumption of the installation in question, since the net metering scheme is not valid in this situation. **Therefore it is recommended, that the size of the PV system will not cause this to provide annual yields that exceed the average electricity consumption of the building in question.**

Besides the overall size of PV plant in term of nominal installed capacity, it is very important that careful consideration is addressed towards the interplay between the PV array and the inverter.

Previously, a rule of thumb stated, that the capacity of the inverter should be slightly undersized compared to the nominal capacity of the PV area. This was due to an assumption that in this way it would be possible to optimize the inverter's power range.

From a technical point of view, undersizing could increase the system performance as it causes the inverter to operate as little time as possible at low partial load efficiency, without application of complex master slave configurations. At the same time, an economically benefit were achieved, since undersizing caused lower balance-of system costs per installed kilowatt peak power.

A disadvantage follows this strategy: When the potential solar supply exceeds the inverter's power rating; only the maximum rated power can be supplied to the grid, whereby situation with very high insulation cannot be fully utilized.

Nowadays the value of undersizing the inverter is not ascribed as high as previously, giving the fact that the efficiency of modern inverters has increased considerably, included also the ability to function with high efficiency throughout the working interval.

However, from an economical point of view, it will still be beneficial to choose an inverter, which is not oversized, giving that this will have a negative influence on the fiscal situation due to the increased purchase price following a larger inverter.

Having this in mind, a practical approach can be to select an inverter that is undersized 15 – 20 % relative to the array power. In the case that the PV-array is not situated in optimum position with respect to sloop and orientation, a further undersizing of the inverter can be relevant.

Special concern must be addressed if parts of the PV array are exposed to shadows in order to minimize the damage with respect to decreased yield this otherwise will cause. This can be done either by using several inverters or by using an inverter with multiple MPP trackers and then make sure, that the array is sub-divided in such a way, that the parts that are exposed to shadows at certain times of days are collected together in separate groups connected to separate inverter or MPP tracker.

A final point, that must be highlighted, is the fact that long distance of DC cables preferably shall be avoided due to the fact that in order to maintain voltage drop at an acceptable level the cross section of the cable will increase rapidly when the distance is increased.

It is therefore recommended, that the inverter is placed as close to the PV area as possible with regard to the fact, that the requirement set by the manufacture is met, for instance the protection class (IP xx) and ambient temperature levels.

5.3.1 Consideration regarding thin film modules

When thin film modules are used, special consideration has to be addressed toward that the inverter type intended for the system is adequate. The voltage output from a thin film PV area is usually higher than the case is for a crystalline PV area, which must be taking into account when choosing inverter – or inverters – to the system.

As mentioned previously, corrosion of the modules TCO layer have in some cases been emerged when thin film modules have been combined with transformer less inverters, causing that a number of thin film module manufactures have state that they will not accept warranty claims unless there products are used with invertes with transformers.

Another very important aspect to keep in mind during the projection phase is that new thin film modules will typically have an even higher voltage than stabilized modules. It is therefore crucial to select an inverter type that can tolerate the situations with the highest obtainable voltage, which will be open circuit voltage for new modules in clear and cold weather.

It is difficult to give precise and universal advice with respect to system design for thin film modules, giving the fact that the requirements vary considerably from manufacture to manufacture. **In any cases the requirements of the component manufactures have to be scrutinized and followed.**

5.4 Guidelines for PV System Design and Use of Simulation Software Packages incl. Generic Design Examples

Based on the previous chapters a guideline for PV system design and use of various kind of simulation software is giving. In Annex 6.4 a practical example of the use of this guideline is demonstrated including print of results from simulation software.

Besides the guideline, some general points that have to be taking into consideration when examine the possibility for implemented a PV installation on a certain location is presented in part 5.4.2.

5.4.1 Guidelines for implementing PV systems

1. Make on-site inspection

Make an in depth examination of the location in which the PV system is expected to be implemented. Be aware of the following aspect:

- Determine size, orientation, and sloop (tilt) of the location. Exact values for these are essential in order to be able to make accurate prediction of the expected yield from the PV system. Besides this, also the general lighting conditions on the location in question, known as the “albedo”, is often taking into consideration in simulation software. The size of the albedo is determinate on the reflectance of the prevailing materials in the surrounding environment and varies between 0.04 in very dark materials such as asphalt and charcoal

Typical albedo for different surfaces

Surface	Typical albedo
Fresh asphalt	0.04
Conifer forest (Summer)	0.08 to 0.15
Worn asphalt	0.12
Deciduous trees	0.15 to 0.18
Bare soil	0.17
Green grass	0.25
Desert sand	0.40
New concrete	0.55
Fresh snow	0.80–0.90
Ocean Ice	0.5–0.7

and 0.90 in fresh snow. In the table on the right examples of albedo values in different cases are given.

- Notice how the modules shall be mounted. Will they be retrofitted on top of an existing roof or building integrated? This is important in order to determinate the degree of ventilation of the modules and thereby the influence of temperature on the efficiency of the system.

- Will the roof, facades or other building element intended for the PV plant have the necessary structural strength to carry the weight of the PV modules and mounting equipment?

- Keep in mind, that it might occasionally be necessary to manually inspect and/or clean the PV modules. Giving this, if possible it should be avoided to install PV systems on surfaces, which afterwards will be complicated to access without utilization of special equipments.

- The mounting equipment needed to fasten the modules varies considerably according to the conditions present, for instance the roofing material in question (tile, slate, roofing felt etc.). Make an accurate determination of the conditions in question in order to be able to purchase the correct mounting equipment.

- Module manufactures usually provide a detailed specification and instructions with respect to the conditions where there products may – and may not – be used. These instructions have to be fulfilled, otherwise the warranty of the product might expel.

- An important aspect is to determine whether there is objects causing shadows on the modules, since shadows on PV modules have a highly negative influence on the production from the system. When observing the shadow situation, notice that significant differences occur in wintertime compared to summertime due to the altitude of the sun.

- With respect to shadows, also consider if there is any indications that new buildings, trees or other element out of the control of the PV owner could be expected to cause shadows on the plant in the future. Local district plans can be a valuable source of information in this context.

2. Make a preliminary evaluation

Based on the on-site inspection a preliminary evaluation of the plant can be carried out. The following procedure, adapted to the resources at ones disposal, can be recommended. The guiding is denoted for a rooftop system; however, the same points will have to be considered for any other mounting conditions.

- Collect data sheets for a number of different PV modules available in order to obtain information with respect to size, expected yields, visual appearance etc.

- Make a drawing in nominal plane of projection of the roof in question and use this to establish the number of modules that can be placed using the various types available. Be aware of architectural and visual aspects to ensure that the building will end up with a symmetrical visual appearance.

- When the number of modules fixable for each type is determinate, calculate the nominal capacity by multiplying the number of modules by the nominal capacity for one module.

- Calculate a preliminary value for expected annual yield in each case by multiply the nominal capacity of the plant (kWp) by 850[16] kWh/kWp.

- If the expected annual yield is too high, a recalculation is made with a proportionally fewer number of modules for each type. If by contrast the expected annual yield for all the modules taking into investigation is lower than preferred, try to locate either a PV module with higher nominal capacity per square meter or another/a supplementary location for the PV plant in order to increase the area.

- Calculate the expected price for each of the installation alternatives in question and select which of these will fulfill the needs and expectations. Since PV modules are available in many different sizes, colors, qualities and price levels, the selection will usually be based on a compromise with respect to desirable visual appearance, cost of installation and expected annual yield.

3. Make a simulation of the plant

When the basic outline of the plant is established, it is beneficial to carry out a more detailed simulation with the purpose - 1) partly to have a more precise and detailed picture of the size and annual division of the electricity production of the plant and - 2) partly to decide on the optimum design of the system layout with respect to inverter size and coupling in parallel strings.

Concerning the firstly mentioned issue, several free of charge simulation software systems can be used, for instance PVGIS and RETScreen, these systems, however, do not include facilities to optimize electrical layout of the plant.

For the latter more sophisticated software systems have to be employed, for instance PVSYST, which include a comprehensive database with parameters (size, weight, capacity, efficiency etc.) for almost all commercially available modules and inverters on the marked.

Systems like PVSYST are commercial products which are updated on regularly basis in order to incorporate new products. As so, they are not free of charge but have to be purchased from the developer. Often, however, it is possible to try products like these for a limited period of time before a license has to be bought.

In Annex 6.4 an example of practical design of a PV system is presented using PVGIS and PVSYST. If simulation and design system like PVSYST is not at ones disposal, a manual design procedure can be carried out as described below:

1) Choose type and numbers of modules based on the on-site evaluation and preliminary evaluation and divide these into a suitable number of parallel strings.

2) Ensure that maximum system voltage stated on the modul is not supassed in the configuration choosen. If this is the case, reconfigure the system layout, either by reducing the total number of modules or by increasing the number of parallel strings.

[16] This value is based on experiences and express, that under average Danish weather conditions 850 kWh of electricity can be expected to be delivered from the inverter for each kWp of installed capacity.

3) Calculate the nominel effect of the system by mulitplying the number of modules with the nominel effect of one module.

4) Choose a sufficient inverter. In this process, keep the following aspect in mind:

   - Undersize the inverter with 15-20% relative to the array power.
   - Ensure that the inverter MPP voltage range is sufficient for the maximum and minimum array operating voltage (-10°C/1000 W/m^2 and 80°C/100 W/m^2).
   - In case that part of the PV-array is exposed to shadows then use an inverter with multiple MPP tracker or alternatively use several inverters.
   - In the case of vertical or east/west oriented systems, the inverter may be 30% undersized.

5) If it is not possible to identify an inverter that meets the requirement mentionen, go bach to step 1 and adjust the number of modules or make a further division in parallel strings. Repeat this procedure until all requirements are met and it is possible to match the PV area with an inverter.

6) Finaly measure the distance between the PV area and the installation location of the inverter in order to be able to dimension the DC cabeling in such a way, that that the voltage drop is not critical.

5.4.2 General aspects of importance

Giving the objective of this project, the main focus of this report are targeted towards technical aspect, however, some general points of importance also has to be taking into consideration when examine the possibility for implemented a PV installation on a certain location. Afterwards a brief introduction to some of these is giving.

Before the plant is implemented, these points should be taking into consideration:

- Sometime local conditions in district plans as well as preservation and listing prohibit implementation of a PV plant on a certain building. Before starting planning and projecting tasks, make sure that no such legal boundaries prevent installment of the PV plant on the intended location.
- Confer with the insurance company in question regarding the influence on the insurance policy for the building if a PV plant is implemented as well as regards the conditions of insurance for the PV plant. Usually insurance companies do not require additional charge on account on a PV plant; it is, however, important to verify the actual condition with the company in question.
- A PV plant has to be connected to the electricity grid by an authorized electrician, whom is obliged to inform the local power supplying company about the installation of the plant.
- A mentioned, PV plant set up in Denmark, are under certain circumstances allowed to use a net metering scheme. This, however, necessities that the electricity meter can measure

inbound as well as outbound power traffic. If this is not the case, the local power supplying company will have to change the meter, which they usually do free of charge.

If a PV plant is set up, attention should be giving to the following aspects:

- If a production meter is available – often this is integrated in the inverter – it is beneficially to read and notice the realized production yield on a regularly basis, for instance on a certain day once a week. By doing this, the owner will eventually gets to know the characteristic production size under any giving time of the year, weather conditions etc. When this knowledge is obtained, any irregularities will swiftly be identified and can be mended before it causes significant reduction of the production yield.

- A possibility to keep track of the production from a PV plant is provided through a German website Sonnenertrag (http://sonnenertrag.eu). Every owner of a PV plant can – free of charge - open an account on this site and type in measurement from the plant in question. Afterwards the measurement are presented on the website in different user-friendly designs, giving the owner the possibility to monitor his or hers data as well as compare the yields with other plants throughout Europe.

Various related print-outs and examples are shown in Annex 6.4.

6. Annexes

6.1 Simulation variants of Performance Ratio for different PV modules under same typical Danish conditions

6.2 Omega data analyse (recordings from 16 PV plants in Denmark)

6.3 Spreadsheet of comparison operational data with simulation results

6.4 Simulation printouts etc.

Annex 6.1

Simulation variants of different PV modules in same plant configuration and under same typical Danish conditions

Simulation variant

Normalized Performance Coefficients

	Yr kWh/m².day	Lc	Ya kWh/kWp/d.	Ls	Yf kWh/kWp/d.	Lcr	Lsr	PR
January	30.00	0.172	8.80	0.105	0.69	0.177	0.108	0.714
February	52.04	0.268	16.90	0.173	1.42	0.144	0.093	0.763
March	77.89	0.363	22.84	0.228	1.92	0.145	0.091	0.765
April	133.87	0.613	40.57	0.348	3.50	0.137	0.078	0.785
May	156.04	0.744	45.76	0.392	3.90	0.148	0.078	0.774
June	143.43	0.744	43.46	0.385	3.65	0.156	0.080	0.764
July	159.90	0.804	46.89	0.397	3.96	0.156	0.077	0.767
August	138.74	0.702	40.69	0.349	3.42	0.157	0.078	0.765
September	100.46	0.528	30.44	0.276	2.54	0.158	0.082	0.760
October	69.74	0.356	20.45	0.194	1.70	0.158	0.086	0.756
November	39.41	0.217	11.94	0.124	0.97	0.165	0.094	0.741
December	25.59	0.146	7.50	0.083	0.60	0.177	0.100	0.722
Year	1127.10	0.473	28.07	0.255	2.36	0.153	0.083	0.764

Simulation for 2x55 Wp Würth CIS modules and Soladin 120 inverter

Simulation variant
Normalized Performance Coefficients

	Yr kWh/m².day	Lc	Ya kWh/kWp/d.	Ls	Yf kWh/kWp/d.	Lcr	Lsr	PR
January	30.00	0.192	8.80	0.105	0.67	0.198	0.109	0.693
February	52.04	0.221	16.90	0.176	1.46	0.119	0.095	0.786
March	77.89	0.186	22.84	0.239	2.09	0.074	0.095	0.831
April	133.87	0.391	40.57	0.362	3.71	0.088	0.081	0.831
May	156.04	0.465	45.76	0.407	4.16	0.092	0.081	0.827
June	143.43	0.435	43.46	0.401	3.95	0.091	0.084	0.825
July	159.90	0.530	46.89	0.411	4.22	0.103	0.080	0.817
August	138.74	0.473	40.69	0.361	3.64	0.106	0.081	0.814
September	100.46	0.380	30.44	0.284	2.68	0.113	0.085	0.802
October	69.74	0.315	20.45	0.199	1.74	0.140	0.088	0.771
November	39.41	0.242	11.94	0.126	0.95	0.184	0.096	0.720
December	25.59	0.199	7.50	0.082	0.54	0.241	0.099	0.659
Year	1127.10	0.337	28.07	0.263	2.49	0.109	0.085	0.806

Simulation for 2x55 Wp Kaneka a-Si modules and Soladin 120 inverter

Simulation variant
Normalized Performance Coefficients

	Yr	Lc	Ya	Ls	Yf	Lcr	Lsr	PR
	kWh/m².day		kWh/kWp/d.		kWh/kWp/d.			
January	30.00	0.184	8.80	0.103	0.68	0.190	0.107	0.703
February	52.04	0.287	16.90	0.172	1.40	0.154	0.092	0.753
March	77.89	0.396	22.84	0.226	1.89	0.158	0.090	0.752
April	133.87	0.709	40.57	0.342	3.41	0.159	0.077	0.765
May	156.04	0.909	45.76	0.381	3.74	0.181	0.076	0.744
June	143.43	0.923	43.46	0.373	3.49	0.193	0.078	0.729
July	159.90	1.022	46.89	0.384	3.75	0.198	0.074	0.727
August	138.74	0.895	40.69	0.337	3.24	0.200	0.075	0.725
September	100.46	0.652	30.44	0.268	2.43	0.195	0.080	0.725
October	69.74	0.427	20.45	0.189	1.63	0.190	0.084	0.726
November	39.41	0.245	11.94	0.122	0.95	0.187	0.093	0.721
December	25.59	0.157	7.50	0.082	0.59	0.190	0.099	0.710
Year	1127.10	0.569	28.07	0.248	2.27	0.184	0.080	0.735

Simulation for 2x55 Wp Photowatt polyX-Si modules and Soladin 120 inverter

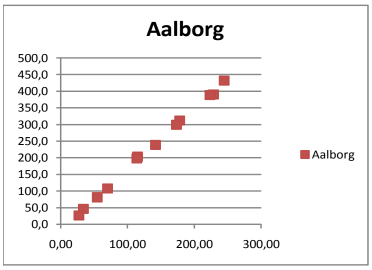
Simulation variant
Normalized Performance Coefficients

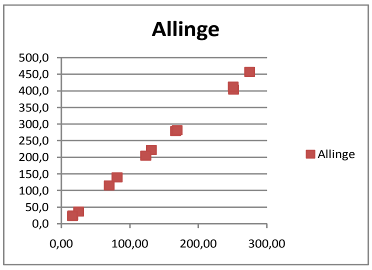
	Yr	Lc	Ya	Ls	Yf	Lcr	Lsr	PR
	kWh/m².day		kWh/kWp/d.		kWh/kWp/d.			
January	30.00	0.210	8.80	0.100	0.66	0.217	0.103	0.679
February	52.04	0.325	16.90	0.168	1.37	0.175	0.090	0.735
March	77.89	0.445	22.84	0.221	1.85	0.177	0.088	0.735
April	133.87	0.766	40.57	0.336	3.36	0.172	0.075	0.753
May	156.04	0.969	45.76	0.374	3.69	0.192	0.074	0.733
June	143.43	0.981	43.46	0.367	3.43	0.205	0.077	0.718
July	159.90	1.076	46.89	0.379	3.70	0.209	0.073	0.718
August	138.74	0.944	40.69	0.331	3.20	0.211	0.074	0.715
September	100.46	0.695	30.44	0.264	2.39	0.208	0.079	0.713
October	69.74	0.461	20.45	0.184	1.60	0.205	0.082	0.713
November	39.41	0.273	11.94	0.116	0.92	0.208	0.089	0.704
December	25.59	0.178	7.50	0.077	0.57	0.216	0.093	0.691
Year	1127.10	0.612	28.07	0.243	2.23	0.198	0.079	0.723

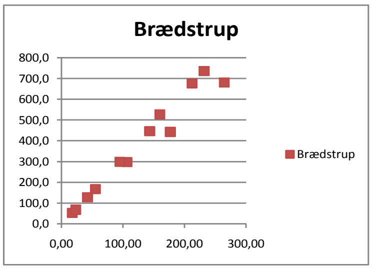
Simulation for 2x55 Wp BP monoX-Si modules and Soladin 120 inverter

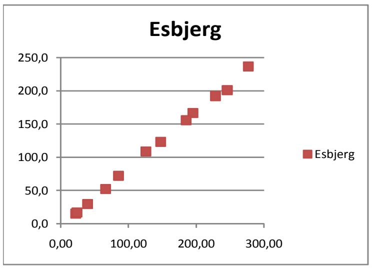
Check of consistency of recorded data at 16 PV plants in Denmark **Annex 6.2**

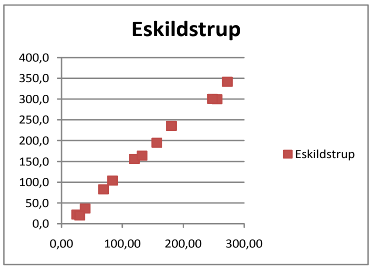
X-axis: global insolation [W/m^2]; Y-axis plant production [kWh]

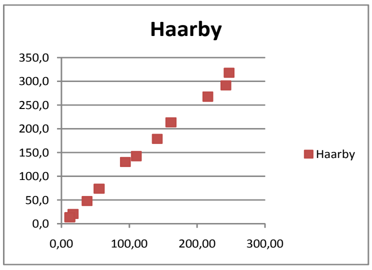


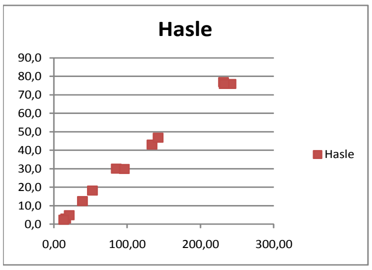


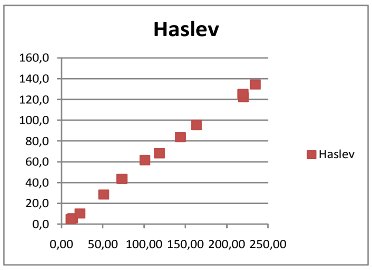


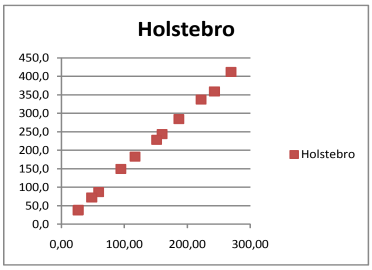


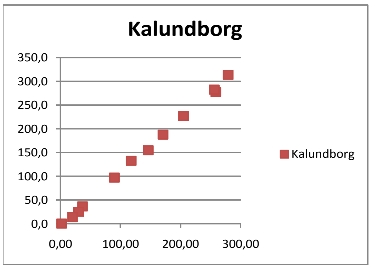


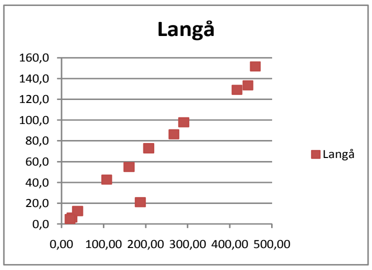


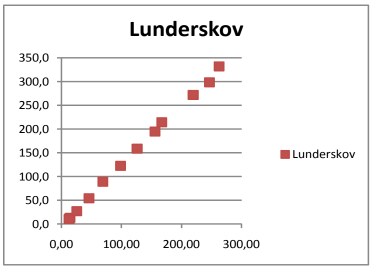


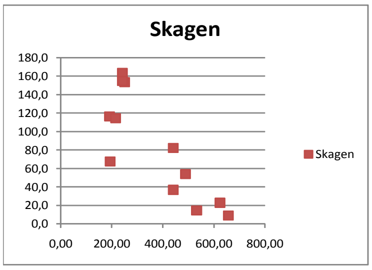


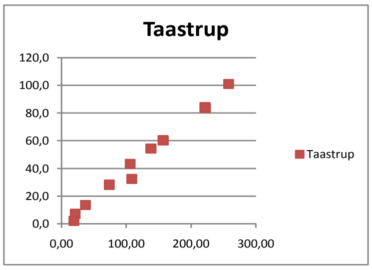


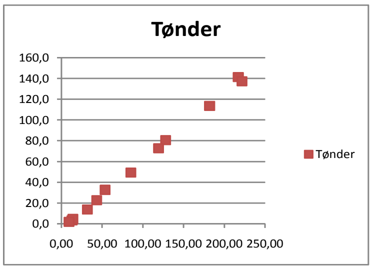


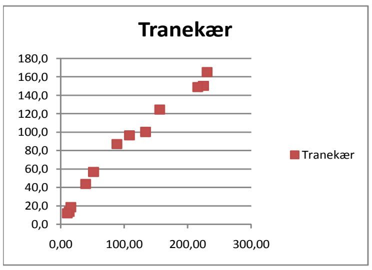












Spreadsheet DK Comparisons and Simulation Annex 6.3

6.3.1 Holstebro

Comparison of Danish PV Plants	0,50	0,105	2,46	0,098	2,19
	1,19	0,173	5,02	0,161	4,46
Basic plant data	2,32	0,275	7,39	0,256	6,57
Commissio 28.10.03	3,79	0,345	10,6	0,321	9,43
El. design 1 string	5,19	0,415	12,5	0,386	11,2
Module typ Si-mono BP 170 W	5,43	0,391	11,9	0,364	10,6
Panel yield 2.720 W	5,34	0,404	11,8	0,376	10,5
Inverter 3 kW Fronius Maxi	4,31	0,366	10,6	0,341	9,42
Azimuth syd	2,78	0,278	8,27	0,259	7,36
Tilt, ° 45	1,49	0,208	5,38	0,193	4,79
Location: 56° 39' N 8° 58' E	0,75	0,152	3,18	0,141	2,83
Roof mounted system with free field towards South	0,40	0,095	1,71	0,088	1,53
				0	

Global Irradiance, Holstebro

Year	Period: Month	Days	DMI data 2007/2008 (Mejrup): Temp °C	Wind m/s	Irradiation kWh/m²/d	Irradiation kWh/m2	Com-ments	PVGIS Irradiation kWh/m2	Skrydstr. Meteonorm Irradiation kWh/m²	Karup RETscreen Irradiation kWh/m²	DRY Irradiation kWh/m²	ARCO Irradiatio kWh/m²
2007	1	31	5	7,7	0,48	15		29,3	16	15,5	15,5	11,4
2007	2	28	1,9	5,8	0,93	26		54,5	32	33,3	32,0	38,0
2007	3	31	6,3	5,8	2,77	86		91,0	68	71,9	65,0	78,7
2007	4	30	9,4	5,1	4,57	137		129,0	114	113,7	114,0	125,2
2007	5	31	10,5	4,2	4,87	151		162,0	159	160,9	163,4	153,0
2007	6	30	15,7	3,4	5,47	164		150,0	159	162,9	164,9	192,9
2007	7	31	15,1	4,7	4,52	140		154,0	160	165,5	160,0	164,8
2007	8	31	16,4	4,7	4,32	134		139,0	133	133,6	134,0	145,3
2007	9	30	12,5	5,8	2,70	81		103,0	80	83,4	81,7	91,7
2007	10	31	8,7	3,9	1,61	50		66,9	44	46,2	42,6	46,3
2007	11	30	5,3	5,6	0,70	21		37,3	20	22,5	18,9	18,0
2007	12	31	4	4,6	0,29	9		20,4	11	12,4	10,3	10,6
	Average	30,4	9,23	5,11	2,77	84,50		94,7	83	85,2	83,53	89,66
	Ttotal	365			33,23	1014		1136,4	996	1021,87	1.002,37	1075,9
2008	1	31	4,2	7,4	0,35	11		29,3	16	15,5	15,5	11,4
2008	2	28	4,9	7	0,96	27		54,5	32	33,3	32,0	38,0
2008	3	31	3,3	5,7	2,29	71		91,0	68	71,9	65,0	78,7
2008	4	30	7,4	3,9	4,07	122		129,0	114	113,7	114,0	125,2
2008	5	31	12,5	3,5	6,26	194		162,0	159	160,9	163,4	153,0
2008	6	30	14,6	4,9	6,07	182		150,0	159	162,9	164,9	192,9
2008	7	31	17,5	4	5,65	175		154,0	160	165,5	160,0	164,8
2008	8	31	15,7	4,2	3,65	113	*)	139,0	133	133,6	134,0	145,3
2008	9	30	12,2	3,9	2,90	87		103,0	80	83,4	81,7	91,7
2008	10	31	9,1	5	1,45	45		66,9	44	46,2	42,6	46,3
2008	11	30	5,5	5,4	0,60	18		37,3	20	22,5	18,9	18,0
2008	12	31	2,1	4	0,32	10		20,4	11	12,4	10,3	10,6
	Average	30,4	9,08	4,91	2,88	87,92		94,7	83	85,2	83,53	89,66
	Total	365			34,57	1055		1136,4	996	1021,87	1.002,37	1075,9

Recorded irradiation and AC yields (Source: Energinet.DK)

Year	Month	Global irr. W/m²	Panel irr. W/m²	Global irr. kWh/m2	Panel irr. kWh/m2	Global irr. kWh/m2/d	Panel irr. kWh/m2/d	AC yield kWh	Record Year	
2007	1			0,0	0,0	0,00	0,00			
2007	2			0,0	0,0	0,00	0,00			
2007	3			0,0	0,0	0,00	0,00			
2007	4			0,0	0,0	0,00	0,00			
2007	5			0,0	0,0	0,0	0,0			
2007	6	204,2	209,6	147,0	150,9	4,90	5,03	300,8	2007	start
2007	7	173,2	178,7	128,9	133,0	4,16	4,29	276,1	2007	
2007	8	163,8	189,4	121,9	140,9	3,93	4,55	286,0	2007	
2007	9	102,7	135,8	73,9	97,8	2,46	3,26	202,4	2007	
2007	10	61,3	109,5	45,6	81,5	1,47	2,63	171,1	2007	
2007	11	27,4	63,0	19,7	45,4	0,66	1,51	95,3	2007	
2007	12	11,2	28,4	8,3	21,1	0,27	0,68	40,8	2007	
	Average	62,0	76,2	45,4	55,9	1,49	1,83	1373		
	Ttotal	744	914	545	671	17,9	21,9	1.373		
2008	1	13,3	26,5	9,9	19,7	0,32	0,64	37,1	2008	
2008	2	34,9	59,2	23,5	39,8	0,84	1,42	86,3	2008	
2008	3	84,2	117,2	62,6	87,2	2,02	2,81	182,8	2008	
2008	4	150,9	186,6	108,6	134,4	3,62	4,48	284,9	2008	
2008	5	236,2	269,4	175,7	200,4	5,7	6,5	412,4	2008	
2008	6	228,5	243,0	164,5	175,0	5,48	5,83	359,6	2008	
2008	7	207,4	221,9	154,3	165,1	4,98	5,33	337,2	2008	
2008	8	135,9	159,9	101,1	119,0	3,26	3,84	243,6	2008	
2008	9	104,5	151,2	75,2	108,9	2,51	3,63	228,5	2008	
2008	10	49,5	94,3	36,8	70,2	1,19	2,26	149,7	2008	
2008	11	19,3	48,2	13,9	34,7	0,46	1,16	71,8	2008	
2008	12	10	26,8	7,4	19,9	0,24	0,64	38,2	2008	
	Average	106,2	133,7	77,8	97,8	2,55	3,21	2432		
	Total	1.275	1.604	934	1.174	30,6	38,5	2.432		

Simulated panel yield [DC]

Year	Month	Panel yield using software data: Pvsyst kWh	RETscreen kWh	Re redt kWh	PVGIS kWh	Panel yield using DMI data: Pvsyst kWh	RETscreen kWh	HOME kWh
2007	1	69,9	105,0	89,3	76,3	78,1	86,0	83,0
2007	2	120,6	173,0	147,1	140,6	101,2	102,0	107,0
2007	3	198,7	275,0	233,8	229,1	299,1	300,0	311,0
2007	4	297,6	345,0	293,3	318,0	384,3	369,0	358,0
2007	5	347,8	415,0	352,8	387,5	326,0	342,0	315,0
2007	6	321,0	391,0	332,4	357,0	338,6	343,0	316,0
2007	7	352,2	404,0	343,4	365,8	293,4	301,0	275,0
2007	8	312,3	366,0	311,1	328,6	320,0	322,0	308,0
2007	9	233,6	278,0	236,3	248,1	227,9	235,0	239,0
2007	10	136,4	208,0	176,8	166,8	185,2	206,0	192,0
2007	11	85,0	152,0	129,2	95,4	95,3	119,0	89,0
2007	12	47,8	95,0	80,8	53,0	37,4	60,0	38,0
	Average	210,2	267,3	227,2	230,5	223,9	232,1	219,3
	Ttotal	2.523	3.207	1.630	2.766	2.687	2.785	2.631
2008	1	69,9	105,0	89,3	76,3	39,1	70,0	45,0
2008	2	120,6	173,0	147,1	140,6	102,3	107,0	113,0
2008	3	198,7	275,0	233,8	229,1	219,7	237,0	240,0
2008	4	297,6	345,0	293,3	318,0	324,3	327,0	308,0
2008	5	347,8	415,0	352,8	387,5	454,7	438,0	414,0
2008	6	321,0	391,0	332,4	357,0	383,7	381,0	352,0
2008	7	352,2	404,0	343,4	365,8	371,0	372,0	349,0
2008	8	312,3	366,0	311,1	328,6	259,0	268,0	252,0
2008	9	233,6	278,0	236,3	248,1	253,0	258,0	262,0
2008	10	136,4	208,0	176,8	166,8	167,9	176,0	164,0
2008	11	85,0	152,0	129,2	95,4	85,9	92,0	93,0
2008	12	47,8	95,0	80,8	53,0	51,8	62,0	47,0
	Average	210,2	267,3	227,2	230,5	226,0	232,3	219,9
	Total	2.523	3.207	1.630	2.766	2.712	2.788	2.639

Simulated yield to grid [AC]

Year	Month	Simulated yield using software data: Pvsyst kWh	RETscreen kWh	Res re kWh	PVGIS kWh	Yield (DMI data): Pvsyst kWh	RETscreen kWh	HOME kWh
2007	1	64,7	98,0	92,1	67,9	72,6	78,0	76
2007	2	112,8	161,0	151,3	124,9	94,3	93,0	98
2007	3	186,5	256,0	240,6	203,7	282,6	273,0	283
2007	4	280,3	321,0	301,7	282,9	363,1	336,0	325
2007	5	327,9	386,0	362,8	347,2	307,2	311,0	287
2007	6	302,1	364,0	342,2	318,0	318,7	312,0	287
2007	7	332,0	376,0	353,4	325,5	275,7	274,0	251
2007	8	294,2	341,0	320,5	292,0	301,8	293,0	280
2007	9	219,7	259,0	243,5	220,8	214,4	214,0	217
2007	10	127,4	193,0	181,4	148,5	174,1	187,0	174
2007	11	79,0	141,0	132,5	84,9	89,1	109,0	81
2007	12	43,9	88,0	82,7	47,4	34,2	54,0	34
	Average	197,5	248,7	233,7	205,3	210,7	211,2	199,4
	Ttotal	2.371	2.984	1.630	2.464	2.528	2.534	2.393
2008	1	64,7	98,0	92,1	67,9	33,8	64,0	41
2008	2	112,8	161,0	151,3	124,9	92,6	98,0	103
2008	3	186,5	256,0	240,6	203,7	202,4	215,0	218
2008	4	280,3	321,0	301,7	282,9	300,8	297,0	280
2008	5	327,9	386,0	362,8	347,2	423,2	399,0	377
2008	6	302,1	364,0	342,2	318,0	355,6	347,0	320
2008	7	332,0	376,0	353,4	325,5	343,9	339,0	318
2008	8	294,2	341,0	320,5	292,0	238,2	244,0	230
2008	9	219,7	259,0	243,5	220,8	233,8	234,0	239
2008	10	127,4	193,0	181,4	148,5	153,9	160,0	149
2008	11	79,0	141,0	132,5	84,9	77,9	83,0	85
2008	12	43,9	88,0	82,7	47,4	46,6	56,0	42
	Average	197,5	248,7	233,7	205,3	208,6	211,3	200,2
	Total	2.371	2.984	1.630	2.464	2.503	2.536	2.402

*) data not complete

6.3.2 Haarby

Comparison of Danish PV Plants		0,50	0,105	2,46	0,098	2,19
		1,19	0,173	5,02	0,161	4,46
Basic plant data		2,32	0,275	7,39	0,256	6,57
Commissio	2004	3,79	0,345	10,6	0,321	9,43
El. design		5,19	0,415	12,5	0,386	11,2
Module type	BP	5,43	0,391	11,9	0,364	10,6
Panel yield 2040 W	12 * 170 W	5,34	0,404	11,8	0,376	10,5
Inverter 1650/1760 W	Fronius Midi Plus, nominel-/maxeffekt	4,31	0,366	10,6	0,341	9,42
Azimuth South/South-West		2,78	0,278	8,27	0,259	7,36
Tilt, °	15	1,49	0,208	5,38	0,193	4,79
Location: 55° 224' N 10° 124' E		0,75	0,152	3,18	0,141	2,83
		0,40	0,095	1,71	0,088	1,53

Global Irradiance, Haarby

Year	Period		DMI data 2007/2008 (Mejrup)					PVGIS	Meteonorr Skrydstr.	RETscreen Karup	DRY	ARCO
	Month	Days	Temp °C	Wind m/s	Irradiation kWh/m²/d	Irradiation kWh/m2	Com-ments	Irradiation kWh/m2	Irradiation kWh/m²	Irradiation kWh/m²	Irradiation kWh/m²	Irradiatio kWh/m²
2007	1	31	5,1	7,0	0,45	14		20,2	16	19,2	15,5	12,8
	2	28	2,6	4,7	0,82	23		39,9	31	37,0	32,0	29,6
	3	31	6,5	5,3	2,74	85	G*	71,8	65	77,2	65,0	71,0
	4	30	9,8	4,3	4,93	148		122,0	114	118,8	114,0	113,1
	5	31	11,9	3,6	5,23	162		163,0	157	166,2	163,4	157,8
	6	30	15,8	3,0	5,17	155		153,0	159	166,8	164,9	179,6
	7	31	16,1	4,1	4,71	146	T* G*	163,0	162	167,1	160,0	161,8
	8	31	16,7	3,7	4,06	126		139,0	134	138,9	134,0	140,1
	9	30	12,8	4,6	2,97	89		89,7	82	87,3	81,7	85,7
	10	31	8,6	2,9	1,71	53		54,1	45	49,0	42,6	45,2
	11	30	4,8	4,4	0,87	26		26,8	19	23,7	18,9	19,1
	12	31	3,4	4,0	0,29	9		14,9	11	15,5	10,3	10,8
	Average	30,4	9,5	4,3	2,83	86	0	88,1	82,9	88,9	83,5	85,5
	Ttotal	365	114,1	51,6	33,95	1036	0	1057,4	995	1066,6	1002,3	1026,6
2008	1	31	4,1	6,2	0,35	11		20,2	16	19,2	15,5	12,8
	2	28	4,5	5,6	1,11	31		39,9	31	37,0	32,0	29,6
	3	31	3,8	5,1	2,48	77		71,8	65	77,2	65,0	71,0
	4	30	7,4	3,2	4,23	127		122,0	114	118,8	114,0	113,1
	5	31	12,4	2,6	6,84	212		163,0	157	166,2	163,4	157,8
	6	30	14,5	4,2	6,63	199		153,0	159	166,8	164,9	179,6
	7	31	17,0	3,8	5,97	185		163,0	162	167,1	160,0	161,8
	8	31	16,2	4,0	3,87	120	G*	139,0	134	138,9	134,0	140,1
	9	30	12,7	3,2	3,13	94		89,7	82	87,3	81,7	85,7
	10	31	9,3	4,3	1,65	51		54,1	45	49,0	42,6	45,2
	11	30	6,0	4,9	0,53	16		26,8	19	23,7	18,9	19,1
	12	31	2,7	3,3	0,32	10		14,9	11	15,5	10,3	10,8
	Average	30,4	9,22	4,20	3,09	94,42	0	88,1	82,9	88,9	83,5	85,5
	Total	365	110,6	50,4	37,1	1133	0	1057,4	995	1066,58	1002,3	1026,6

Recorded irradiation and AC yields (Source: Energinet.DK)

Year	Month	Global irr. W/m²	Panel irr. W/m²	Global irr. kWh/m2	Panel irr. kWh/m2	Global irr. kWh/m2/d	Panel irr. kWh/m2/d	AC yield kWh	Record Year	
2007	1									
	2									
	3									
	4									
	5									
	6	179,9	185,8	129,5	133,8	4,32	4,46	196,8	2007	start
	7	187,0	195,2	139,1	145,2	4,49	4,68	241,6	2007	
	8	150,2	161,7	111,7	120,3	3,60	3,88	200,5	2007	
	9	102,4	116,3	73,7	83,7	2,46	2,79	143,4	2007	
	10	53,4	64,3	39,7	47,8	1,28	1,54	85,9	2007	
	11	22,9	30,2	16,5	21,7	0,55	0,72	36,6	2007	
	12	8,7	10,0	6,5	7,4	0,21	0,24	10,5	2007	
	Average	100,6	109,1	73,8	80,0	2,42	2,62	130,8		
	Ttotal	704,5	763,5	516,8	560,1	16,91	18,32	915,3		
2008	1	11,5	12,8	8,6	9,5	0,28	0,31	13,4	2008	
	2	32,0	38,0	21,5	25,5	0,77	0,91	47,6	2008	
	3	82,7	94,2	61,5	70,1	1,98	2,26	129,8	2008	
	4	147,4	161,5	106,1	116,3	3,54	3,88	213,4	2008	
	5	231,6	247,0	172,3	183,8	5,56	5,93	317,7	2008	
	6	232,0	242,4	167,0	174,5	5,57	5,82	291,4	2008	
	7	205,5	215,6	152,9	160,4	4,93	5,17	267,4	2008	
	8	132,3	141,2	98,4	105,1	3,18	3,39	178,6	2008	
	9	99,0	110,6	71,3	79,6	2,38	2,65	142,2	2008	
	10	47,1	55,7	35,0	41,4	1,13	1,34	73,6	2008	
	11	14,1	17,4	10,2	12,5	0,34	0,42	20,6	2008	
	12	10,5	12,4	7,8	9,2	0,25	0,30	13,5	2008	
	Average	103,8	112,4	76,1	82,3	2,49	2,70	142,4		
	Total	1.246	1.349	913	988	29,9	32,4	1.709		

Simulated panel yield [DC]

Year	Month	Panel yield using software data: Pvsyst kWh	RETscreen kWh	Re redt kWh	PVGIS kWh	Panel yield using DMI data: Pvsyst kWh	RETscreen kWh	HOME kWh
2007	1	32,9	57,0		36,4	27,6	38,0	34,0
	2	68,6	92,0		72,3	41,0	54,0	48,0
	3	120,4	165,0		130,0	168,5	184,0	174,0
	4	216,9	227,0		216,0	281,5	285,0	275,0
	5	272,7	293,0		284,0	284,0	286,0	277,0
	6	258,7	285,0		263,0	256,8	265,0	257,0
	7	279,1	285,0		278,0	243,4	250,0	244,0
	8	231,8	248,0		237,0	218,8	225,0	221,0
	9	145,3	171,0		156,0	167,3	175,0	172,0
	10	85,8	111,0		95,5	107,9	122,0	112,0
	11	41,0	65,0		47,6	58,6	74,0	55,0
	12	24,1	48,0		26,3	15,1	28,0	20,0
	Average	148,1	170,6		153,5	155,9	165,5	157,4
	Ttotal	1.777	2.047		1.842	1.871	1.986	1.889
2008	1	32,9	57,0		36,4	27,6	38,0	34,0
	2	68,6	92,0		72,3	41,0	54,0	48,0
	3	120,4	165,0		130,0	168,5	184,0	174,0
	4	216,9	227,0		216,0	281,5	285,0	275,0
	5	272,7	293,0		284,0	284,0	286,0	277,0
	6	258,7	285,0		263,0	256,8	265,0	257,0
	7	279,1	285,0		278,0	243,4	250,0	244,0
	8	231,8	248,0		237,0	218,8	225,0	221,0
	9	145,3	171,0		156,0	167,3	175,0	172,0
	10	85,8	111,0		95,5	107,9	122,0	112,0
	11	41,0	65,0		47,6	58,6	74,0	55,0
	12	24,1	48,0		26,3	15,1	28,0	20,0
	Average	148,1	170,6		153,5	155,9	165,5	157,4
	Total	1.777	2.047		1.842	1.871	1.986	1.889

Simulated yield to grid [AC]

Year	Month	Simulated yield using software data: Pvsyst kWh	RETscreen kWh	Res re kWh	PVGIS kWh	Yield (DMI data): Pvsyst kWh	RETscreen kWh	HOME kWh
2007	1	27,7	51,0		34,1	23,3	35,0	30
	2	60,9	83,0		67,7	35,1	49,0	43
	3	108,1	149,0		122,0	153,7	166,0	157
	4	198,0	206,0		203,0	258,5	258,0	247
	5	249,0	266,0		266,0	259,8	259,0	250
	6	235,9	258,0		247,0	234,2	240,0	232
	7	255,1	258,0		261,0	221,6	226,0	220
	8	211,5	225,0		222,0	199,3	204,0	199
	9	131,5	155,0		146,0	152,3	159,0	155
	10	76,4	100,0		89,4	97,1	110,0	101
	11	35,3	59,0		44,6	51,3	67,0	50
	12	20,2	44,0		24,6	12	25,0	18
	Average	134,1	154,5		144,0	141,5	149,8	141,8
	Ttotal	1.610	1.854		1.727	1.698	1.798	1.702
2008	1	27,7	51,0		34,1	23,3	35,0	30
	2	60,9	83,0		67,7	35,1	49,0	43
	3	108,1	149,0		122,0	153,7	166,0	157
	4	198,0	206,0		203,0	258,5	258,0	247
	5	249,0	266,0		266,0	259,8	259,0	250
	6	235,9	258,0		247,0	234,2	240,0	232
	7	255,1	258,0		261,0	221,6	226,0	220
	8	211,5	225,0		222,0	199,3	204,0	199
	9	131,5	155,0		146,0	152,3	159,0	155
	10	76,4	100,0		89,4	97,1	110,0	101
	11	35,3	59,0		44,6	51,3	67,0	50
	12	20,2	44,0		24,6	12	25,0	18
	Average	134,1	154,5		144,0	141,5	149,8	141,8
	Total	1.610	1.854		1.727	1.698	1.798	1.702

6.3.3. TI Taastrup

Comparison of Danish PV Plants	0,50	0,04	2,46	0,098	2,19
	1,19	0,05	5,02	0,161	4,46
Anlæggets stamdata	2,32	0,08	7,39	0,256	6,57
Commissio 1995	3,79	0,09	10,6	0,321	9,43
El. design 2 strenge á 4 moduler	5,19	0,11	12,5	0,386	11,2
Module ty| Solel mono-X si 100W, heraf 4 bifacielle	5,43	0,10	11,9	0,364	10,6
Panel yield 800 W	5,34	0,10	11,8	0,376	10,5
Inverter 700 W SMA Sunny Boy 700	4,31	0,10	10,6	0,341	9,42
Azimuth syd	2,78	0,08	8,27	0,259	7,36
Tilt, ° 45	1,49	0,06	5,38	0,193	4,79
Location: 55° 39' N 12° 16' E	0,75	0,04	3,18	0,141	2,83
Open system with free field towards South	0,40	0,03	1,71	0,088	1,53

Global Irradiance, Taastrup

Year	Period		DMI data 2007/2008 (Køge/Herfølge)					PVGIS	Meteonorr	RETscreen	DRY	ARCO
			Temp	Wind	Irradiation	Irradiation	Com-	Irradiation	Irradiation	Irradiation	Irradiation	Irradiatio
	Month	Days	°C	m/s	kWh/m²/d	kWh/m2	ments	kWh/m2	kWh/m²	kWh/m²	kWh/m²	kWh/m²
2007	1	31	4,5	6,1	0,45	14		14,3	16,3	15,5	15,5	12,2
2007	2	28	2,0	4,7	0,82	23		30,5	32,2	33,3	32,0	29,6
2007	3	31	6,0	4,3	2,81	87		62,6	63,1	71,9	65,0	72,3
2007	4	30	8,7	3,7	4,87	146		112,2	115,1	113,7	114,0	117,2
2007	5	31	12,0	3,2	5,03	156		158,7	156,1	160,9	163,4	156,2
2007	6	30	16,0	3,0	4,57	137		153,9	154	162,9	164,9	181,8
2007	7	31	16,1	3,8	4,65	144		161,8	165	165,5	160,0	163,5
2007	8	31	17,1	3,3	4,03	125		129,0	131,5	133,6	134,0	138,0
2007	9	30	13,0	4,2	2,83	85		80,1	79,9	83,4	81,7	85,4
2007	10	31	8,4	2,7	1,68	52		43,7	44,6	46,2	42,6	45,4
2007	11	30	4,6	4,1	0,73	22		19,5	19,4	22,5	18,9	18,8
2007	12	31	3,4	4,0	0,23	7		10,2	11,1	12,4	10,3	10,6
	Average	30,4	9,3	3,9	2,72	83		81,4	82,4	85,2	83,5	85,9
	Ttotal	365			32,69	998		976,5	988,3	1021,9	1002,4	1031,1
2008	1	31	3,8	5,6	0,32	10		14,3	16,3	15,5	15,5	12,2
2008	2	28	4,5	5,0	1,14	32		30,5	32,2	33,3	32,0	29,6
2008	3	31	3,6	4,6	2,42	75		62,6	63,1	71,9	65,0	72,3
2008	4	30	7,2	3,0	4,27	128		112,2	115,1	113,7	114,0	117,2
2008	5	31	12,1	2,7	6,42	199		158,7	156,1	160,9	163,4	156,2
2008	6	30	14,7	3,5	6,37	191		153,9	154	162,9	164,9	181,8
2008	7	31	17,4	3,2	6,06	188		161,8	165	165,5	160,0	163,5
2008	8	31	16,8	3,8	3,84	119		129,0	131,5	133,6	134,0	138,0
2008	9	30	13,2	3,3	3,00	90		80,1	79,9	83,4	81,7	85,4
2008	10	31	9,4	3,9	1,65	51		43,7	44,6	46,2	42,6	45,4
2008	11	30	6,0	4,5	0,50	15		19,5	19,4	22,5	18,9	18,8
2008	12	31	2,6	3,2	0,26	8		10,2	11,1	12,4	10,3	10,6
	Average	30,4	9,28	3,86	3,02	92,17		81,4	82,4	85,2	83,5	85,9
	Total	365			36,2	1106		976,479	988,3	1021,87	1002,367	1031,1

Recorded irradiation and AC yields

Year	Month	Source: Energinet.DK								
		Global irr.	Panel irr.	Global irr.	Panel irr.	Global irr.	Panel irr.	AC yield	Record	
		W/m²	W/m²	kWh/m2	kWh/m2	kWh/m2/d	kWh/m2/d	kWh	Year	
2007	1									
2007	2									
2007	3									
2007	4									
2007	5									
2007	6	192,2	185,5	138,4	133,6	4,61	4,45	68,1	2007	start
2007	7	165,8	164,8	123,4	122,6	3,98	3,96	63,1	2007	
2007	8	155,2	175,5	115,5	130,6	3,72	4,21	67,3	2007	
2007	9	103,1	144,8	74,2	104,3	2,47	3,48	55,3	2007	
2007	10	58,8	112,6	43,7	83,8	1,41	2,70	45,3	2007	
2007	11	23,5	59,4	16,9	42,8	0,56	1,43	23,5	2007	
2007	12	7,9	19,0	5,9	14,1	0,19	0,46	6,2	2007	
	Average	58,9	71,8	43,2	52,6	1,41	1,72	27,4		
	Ttotal	706,5	861,6	518,0	631,7	16,96	20,68	328,7		
2008	1	11,5	21,3	8,6	15,8	0,28	0,51	7,1	2008	
2008	2	36,3	73,7	24,4	49,5	0,87	1,77	28,2	2008	
2008	3	70,7	108,8	52,6	80,9	1,70	2,61	32,4	2008	
2008	4	111,9	138,1	80,6	99,4	2,69	3,31	54,4	2008	
2008	5	238,7	257,9	177,6	191,9	5,73	6,19	100,9	2008	
2008	6	228,1	222,2	164,2	160,0	5,47	5,33	83,6	2008	
2008	7	219,6	221,5	163,4	164,8	5,27	5,32	84,1	2008	
2008	8	139,5	157,3	103,8	117,0	3,35	3,78	60,1	2008	
2008	9	109,4	156,6	78,8	112,8	2,63	3,76	60,3	2008	
2008	10	55,6	106,0	41,4	78,9	1,33	2,54	43,3	2008	
2008	11	17,4	36,9	12,5	26,6	0,42	0,89	13,4	2008	
2008	12	9,1	19,3	6,8	14,4	0,22	0,46	2,0	2008	
	Average	104,0	126,6	76,2	92,7	2,50	3,04	47,5		
	Total	1.248	1.520	915	1.112	29,9	36,5	570		

Simulated panel yield [DC]

Year	Month	Panel yield using software data				Panel yield using DMI data		
		Pvsyst	RETscreen	Re redt	PVGIS	Pvsyst	RETscreen	HOME
		kWh	kWh	kWh	kWh	kWh	kWh	kWh
2007	1	23,2	36,0	30,6	22,0	15,3	22,0	18,0
2007	2	40,9	47,0	40,0	40,1	19,2	27,0	24,0
2007	3	57,0	77,0	65,5	62,3	90,9	88,0	87,0
2007	4	89,2	93,0	79,1	96,0	120,6	116,0	114,0
2007	5	103,1	109,0	92,7	115,0	103,3	103,0	99,0
2007	6	92,2	102,0	86,7	103,0	80,8	84,0	81,0
2007	7	103,0	102,0	86,7	112,0	87,5	90,0	88,0
2007	8	90,3	97,0	82,5	99,2	85,3	87,0	86,0
2007	9	65,7	77,0	65,5	74,7	71,6	72,0	73,0
2007	10	43,9	58,0	49,3	51,3	59,3	62,0	55,0
2007	11	25,2	38,0	32,3	29,5	30,4	35,0	33,0
2007	12	16,3	34,0	28,9	16,5	6,9	17,0	10,0
	Average	62,5	72,5	61,6	68,5	64,3	66,9	64,0
	Ttotal	750	870	740	822	771	803	768
2008	1	23,2	36,0	30,6	22,0	7,2	20,0	10,0
2008	2	40,9	47,0	40,0	40,1	35,2	39,0	39,0
2008	3	57,0	77,0	65,5	62,3	69,9	73,0	72,0
2008	4	89,2	93,0	79,1	96,0	100,4	100,0	97,0
2008	5	103,1	109,0	92,7	115,0	134,5	132,0	131,0
2008	6	92,2	102,0	86,7	103,0	117,9	117,0	116,0
2008	7	103,0	102,0	86,7	112,0	117,5	117,0	118,0
2008	8	90,3	97,0	82,5	99,2	81,4	82,0	82,0
2008	9	65,7	77,0	65,5	74,7	73,5	77,0	79,0
2008	10	43,9	58,0	49,3	51,3	53,9	60,0	54,0
2008	11	25,2	38,0	32,3	29,5	13,0	22,0	19,0
2008	12	16,3	34,0	28,9	16,5	6,9	17,0	12,0
	Average	62,5	72,5	61,6	68,5	67,6	71,3	69,1
	Total	750	870	740	822	811	856	829

Simulated yield to grid [AC]

Year	Month	Simulated yield using software data				Yield (DMI data)		
		Pvsyst	RETscreen	Res re	PVGIS	Pvsyst	RETscreen	HOME
		kWh	kWh	kWh	kWh	kWh	kWh	kWh
2007	1	3,6	33,0	28,1	19,6	13,7	21,0	17
2007	2	25,4	44,0	37,4	35,7	16,1	25,0	22
2007	3	46,8	72,0	61,2	55,5	75,6	82,0	82
2007	4	63,7	86,0	73,1	85,4	107,9	108,0	107
2007	5	135,6	102,0	86,7	102,0	98,2	96,0	93
2007	6	94,1	95,0	80,8	91,5	78,9	78,0	77
2007	7	83,6	95,0	80,8	99,5	85	84,0	82
2007	8	88,5	90,0	76,5	88,3	79,2	81,0	80
2007	9	64,8	71,0	60,4	66,5	61,7	67,0	68
2007	10	48,5	54,0	45,9	45,7	45,9	57,0	51
2007	11	20,9	35,0	29,8	26,2	24,4	32,0	31
2007	12	8,8	32,0	27,2	14,7	3,7	16,0	9
	Average	57,0	67,4	57,3	60,9	57,5	62,3	59,9
	Ttotal	684	809	688	731	690	747	719
2008	1	3,6	33,0	28,1	19,6	6,1	19,0	9
2008	2	25,4	44,0	37,4	35,7	32,1	37,0	37
2008	3	46,8	72,0	61,2	55,5	64,1	68,0	68
2008	4	63,7	86,0	73,1	85,4	92,7	93,0	92
2008	5	135,6	102,0	86,7	102,0	124,2	122,0	123
2008	6	94,1	95,0	80,8	91,5	108,7	109,0	109
2008	7	83,6	95,0	80,8	99,5	108,3	109,0	111
2008	8	88,5	90,0	76,5	88,3	74,6	77,0	77
2008	9	64,8	71,0	60,4	66,5	67,5	72,0	74
2008	10	48,5	54,0	45,9	45,7	49,4	56,0	51
2008	11	20,9	35,0	29,8	26,2	11,5	21,0	18
2008	12	8,8	32,0	27,2	14,7	5,9	16,0	11
	Average	57,0	67,4	57,3	60,9	62,1	66,6	65,0
	Total	684	809	688	731	745	799	780

Simulation Print Out, examples, etc. **Annex 6.4**

Appendix 6.4 Example of design of PV plant

Afterwards 3 examples are giving on designing of a PV plant for retrofitting on a roof of a single house. The roof is foreseen to be orientated south-east and having a sloop (an inclination) of 30°. Furthermore it is foreseen, that a plant of approximately 1.8 kWp can be placed on the roof and that no shading affects the plant at any time of day and year.

In the example mono crystalline module BP275F will be combined with an inverter of the type Fronius IG15. These products are all commercially available and represent equipment of high standard. Afterward data sheets of the modules and inverter is inserted.

In the examples the expected annual yield is calculated using 3 different methods:

- A manual calculation based on data sheets for modules and inverter, which are inserted afterward.
- The web-based software program PVGIS, developed by Joint Research Centre of the European Commission. PVGIS is provided free of charge and can be utilized via the website http://re.jrc.ec.europa.eu/pvgis/index.htm
- The software system PVSYST. This system is a professional program, to which a license has to be purchased. Further information can be found on the website: www.pvsyst.com .

BP SOLAR

SOLAR MODULES

BP280F & BP275F

SOLAR MODULES

PRODUCT FEATURES

- High efficiency monocrystalline silicon cells.
- Designed for maximum reliability and minimum maintenance.
- Produced using in-house technology in cell manufacturing and encapsulation.
- Highly resistant to water, abrasion, hail impact and other environmental factors.
- Lightweight anodised aluminium frame or laminate version only.
- All proven products. Only materials with extensive field experience used.
- Designed and manufactured to comply with European and International standards. European specification ESTI503.
- 20 year product warranty

CELL SPECIFICATIONS

36 series connected, 125 mm monocrystalline silicon pseudo square cells.

APPLICATIONS

GRID-CONNECT

Rain-screen Façades

Sun-shade & Balcony Products

Roofing Products

Domestic/Residential Roof Products

Multi-Kilowatt and Megawatt Power Stations

Generator-type Power for centralised locations.

TELECOMS

Microwave Repeaters and Terminals.

VHF/UHF Radio Systems and Repeaters.

Mobile Radio Systems.

HF/SSB Radio Transceivers

TV Translators

Radio Telephones & Telemetry.

Radio Navigational Aids

Fibre Optic Repeaters

Miscellaneous Packages DC Loads

RURAL INFRASTRUCTURE

Community/Village Water Pumping

Community/Village Water Purification

Community/Village Refrigeration, Medical and Domestic

Community/Village Lighting

Community/Village Television & Video

Individual House Power

Community/Village Power

SPECIALIST

Cathodic Protection

Aircraft Obstruction Lighting

Lighthouse Lighting Systems

Racon Systems

Beacon Buoy Lighting Systems

Fog Warning Systems

TECHNICAL SPECIFICATIONS

Module Catalogue Number	**BP280**	**BP275**
Nominal Peak Power (Pmax)	**80.00W**	**75.00W**
Voltage @ maximum power (V mp)	**17.00V**	**17.00V**
Current @ maximum power (I mp)	**4.70A**	**4.45A**
Short-circuit current (I sc)	**5.0A**	**4.75A**
Open-circuit Voltage (V oc)	**21.8V**	**21.40V**

Dimensions F=Framed L=Laminate

BP275/280F	Length 1188 mm	Width 530 mm
	Depth 43.5 mm	Weight 7.5 kg
BP275/280L	Length 1183 mm	Width 525 mm
	Depth 4 mm (±1 mm)	Weight 5.5 kg

HIGH EFFICIENCY BP280F/BP275F MODULES

POWER SPECIFICATIONS

All performance specifications given are as measured at the standard test conditions.

VOLTAGE/CURRENT CURVE (Nominal)

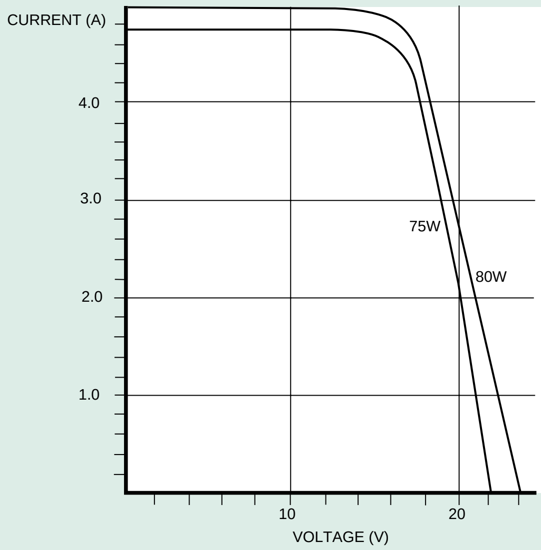
The graph below details module performance at an insolation of 1000 W/m^2, air mass 1.5 D

Standard Test Conditions

Description	Parameter	Value
Intensity of illumination	Insolation (W/m^2)	1000
Special Density	Air Mass (AM)	1.5
Operating Temperature	Cell Temperature (°C)	25

Description of performance parameters

P max	Maximum power of a module. The point on the curve where the IV is at a maximum
V_{mp}	Voltage at the maximum power point
I_{mp}	Current at the maximum power point
I_{sc}	The short circuit current of a PV module
V_{oc}	The open circuit voltage of a PV module
P_{min}	Minimum guaranteed power of a module



Tolerance – Minimum power, the peak power of all high power modules is normally supplied within minus 5watts actual of the nominal value, for further details contact BP Solar.

Coefficient of Voltage	-0.0022 V/cell/°C
Coefficient of Current	8.9 mA/cm^2/°C

CEC APPROVAL SPECIFICATION NO.503

BP Solar modules have been tested and qualified to the Commission of European Communities specification number 503 at the CEC Joint Research Centre in Ispra, Italy. The qualification tests are designed to demonstrate the module's suitability for use in field conditions.

- 200 thermal cycles from -40°C to 85°C.
- 10 humidity/freeze cycles from 85°C at 85% relative humidity to -40°C.
- Ice ball impact test.
- Ultra violet exposure.
- Outdoor exposure.
- Damp heat.
- Hot spot endurance (to simulate partial shading).
- Mechanical endurance, to simulate wind loads of up to 225 km/h.

Power specifications are measured at Standard BP Solar Test Conditions. For further information on module performance contact BP Solar.

Approved by TÜV Rheinland Group for use as Class II equipment, Schutzklasse II.

CONSTRUCTION

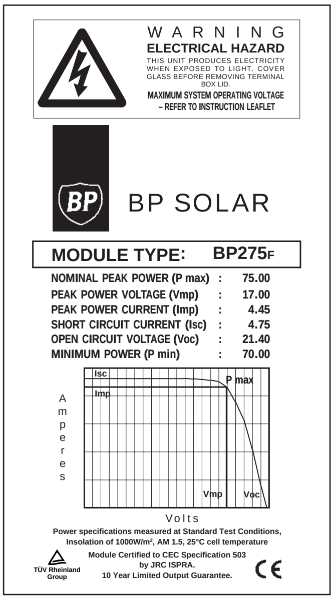
BP280 & BP275 modules are manufactured using industry-standard materials and lamination techniques. Stainless steel fasteners are used throughout. The junction box is bonded directly to the laminate to facilitate both framed and laminate only module products.

Materials are as follows:

Front Cover:	Toughened glass, 3mm, high light transmission (c 92%)
Encapsulant:	Ethylene-vinyl-acetate (EVA)
Rear Cover:	Tri-laminate of PVF/Polyester/PVF
Frame:	Extruded Aluminium, Anodised
Frame Sealant:	High strength bonding tape
Junction Box:	Glass filled polycarbonate

Electrical connections to the module are made via screw terminals within the junction box. One cable gland is fitted and 3 further knockouts (suitable for glands or conduit) are provided to facilitate series and/or parallel connection.

Rear Module Label



Home Branches Catalogue

Fronius IG 15 / 20 / 30

The reliable PV inverter series.

The Fronius IG series has proven itself to be powerful, user-friendly and highly reliable. Equipped for every size of PV system, especially for smaller systems (e.g. on the roof of one-family houses). The combination of different types available for selection is limitless. The ingenious processor control combined with the powerful HF transformer extracts the maximum energy yield from all types of modules.

Technical Data

Fronius IG	15	20	30
Input Data			
MPP voltage range	150 - 400 V	150 - 400 V	150 - 400 V
Max. input voltage (at 1000 W/m²; - 10° C)	500 V	500 V	500 V
PV system output	1300 - 2000 Wp	1800 - 2700 Wp	2500 - 3600 Wp
Max. input current	10,8 A	14,3 A	19 A
Output Data			
Nominal output	1300 W	1800 W	2500 W
Max. power output	1500 W	2000 W	2650 W
Max. efficiency	94,2 %	94,3 %	94,3 %
Euro efficiency	91,4 %	92,3 %	92,7 %
Mains voltage / frequency	230 V / 50 Hz (60 Hz)		
Distortion factor	< 3,5 %		
Power factor	1		
Power consumption at night	0 W		
General Data			
Size l x w x h	366 x 344 x 220 mm (500 x 435 x 225 mm)		
Weight	9 kg (12 kg)		
Cooling	controlled forced-air cooling		
Protection class (housing)	IP 21 (IP 45)		
Ambient temperature range	- 20 ... 50° C		
Permissible humidity	0 ... 95 %		
Protective Devices			
DC insulation measurement	warning when Riso< 500 k Ohm		
Polarity reversal protection	built-in		
Behaviour on DC overload	displacement of operating		

6.4.1 Manual calculation

In part 5.4.1 of the report a procedure for manual design and calculation of a PV system is giving. Afterward a practical use of this method is presented based on the previously mentioned assumptions with respect to size and equipment.

As can be seen from the data sheet for the solar module, the nominal peak power is 75 W. The number of modules necessary to have a total installed capacity of 1.8 kWp can be found by dividing the total capacity by the nominal power of a single module:

$$\text{Number of modules} = \frac{1{,}800\ \text{W}}{75\ \text{W}} = 24$$

Giving that no shading affect the plant, it is not necessary to take any special consideration when dividing the number of modules in strings, and therefore these is expected to be divided in 2 strings each holding 12 modules. Based on the calculation made afterwards, it will be tested if the outcome of this expectation will meet the demand set up by the inverter manufacture.

According to the module data sheet, the following voltage specifications exist:

- Voltage at maximum power point, Vmpp: 17.0 V
- Open circuit voltage, Voc: 21.4 V

Giving that 12 modules are connected in series, the total values of a string will add up to:

- Voltage at maximum power point, Vmpp: 12 * 17.0 V = 204.0 V
- Open circuit voltage, Voc: 12 * 21.4 V = 256.8 V

In the selection of inverter for the system, the size is undersized by approximately 25 % due to the fact that the orientation and inclination differ from the optimum situation. Therefore an inverter with a nominal output of 1300 W has been chosen.

According to the data sheet, the following specifications exist:

- Operation voltage: 150 – 400 V
- Max. input voltage: 500 V
- PV system output: 1,300 – 2,000 Wp

It must now be confirmed, that:

1. The operation voltage at MPP must exceed the inverter's minimum MPP voltage. Since the actual value of Vmpp of 204,0 V is higher than 150 V this condition is fulfilled.

2. The open circuit voltage of the array has to stay below the maximum inverter's PV voltage input. Since the actual value of Voc of 256,8 V is less than the maximum input voltage of 500 V this condition is also fulfilled.

It can therefore be concluded, that the combination of 24 BP275F modules divided in two strings holding 12 modules each can be combined with the Fronius IG 15 inverter. With respect to the annual yield that can be expected, a rule of thumb can be utilized, stating that 1 kWp of installed capacity on average will produce approximately 850 kWh a year, giving that ideal values of orientation and inclination.

As so, the yield from the plant used for this example will amount to 1.8 * 850 kWh/year = 1,530 kWh/year. This yield, however, has to be slightly reduced, since the values for orientation and inclination is not ideal. Below a table is inserted showing the expected yield for modules situated in a “non-optimized position” as a percentage of what can be achieved have they been in optimized position.

Significance of orientation and inclination, percentage of maximum

	Orientation						
	West	W-SW	S-SV	South	S-SE	E-SE	East
Inclination							
0 °	86	86	86	86	86	86	86
15 °	84	89	93	94	93	90	85
30 °	91	90	97	99	97	91	82
45 °	77	89	97	100	98	90	79
60 °	72	85	93	97	94	86	73
75 °	65	77	86	89	86	78	66
90 °	57	67	75	77	75	68	58

Source: Solceller I Danmark, Energistyrelsen, June 2000

Based on the table it can be seen, that the value calculated above has to be reduced by approximately 5 %, giving an expected annual yield of approximately 0,95 * 1,530 kWh/year = 1,455 kWh/year.

6.4.2 PVGIS

Afterwards a calculation using PVGIS is shown. The first page shows the input parameters whereas the next page presents the results.

PVGIS benefits from being easy to use and free of charge and as so is a handy way of providing an overview of what yield can be expected from a PV plant divided by each month of the year. The program, however, does not contain a database with specification of modules and inverters etc, but rather depends on standard values for the basic categories of modules.

In order to include losses in inverters and cables etc., a loss factor has to be defined by the user during the input process. As default, this value is set at 14 %.

One very valuable facility in PVGIS is that the software can show the optimal orientation and inclination of any giving location in Europe, and as so are able to calculate the exact influence of any variations caused by the actual conditions appearing on the location in question.

It can be seen, that according to PVGIS the expected annual yield will be approximately 1,490 kWh/year, which is only slightly higher then what has been found according to the manual calculation.

JRC EUROPEAN COMMISSION

Photovoltaic Geographical Information System - Interactive Maps

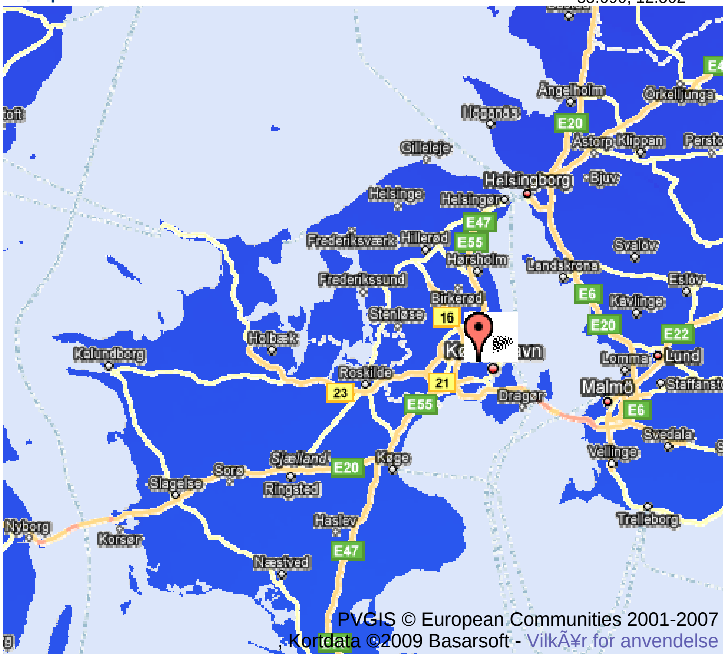
EUROPA > EC > JRC > IES > RE > SOLAREC > PVGIS > Interactive maps >

Contact Important legal notice

Europe Africa

e.g., "Ispra, Italy" or "45.256N, 16.9589E" Search

cursor position: 56.408, 13.436
selected position: 55.690, 12.502



Solar radiation **Temperature** **Other maps** 200 650 1100 1550 2000 [kWh/m²]

PV Estimation | Monthly radiation | Daily radiation

Performance of Grid-connected PV

PV technology: Crystalline silicon

Installed peak PV power 1.8 kWp

Estimated system losses [0;100] 14 %

Fixed mounting options:

Mounting position: Free-standing

Slope [0;90] 30 ° ☐ Optimize slope

(Azimuth angle from -180 to 180. East=-90, South=0)

Azimuth -45 ° ☐ Also optimize azimuth

Tracking options:

☐ Vertical axis Slope [0;90] 0 ° ☐ Optimize

☐ Inclined axis Slope [0;90] 0 ° ☐ Optimize

☐ 2-axis tracking

Output options

☐ Show graphs ☐ Show horizon

○ Web page ○ Text file ◉ PDF

Calculate [help]

Performance of Grid-connected PV

PVGIS estimates of solar electricity generation

Location: 55°41'23" North, 12°30'8" East, Elevation: 16 m a.s.l.,
Nearest city: Koebenhavn, Denmark (10 km away)

Nominal power of the PV system: 1.8 kW (crystalline silicon)
Estimated losses due to temperature: 7.7% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 3.3%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 23.2%

	Fixed system: inclination=30 deg., orientation=-45 deg.			
Month	**Ed**	**Em**	**Hd**	**Hm**
Jan	1.01	31.3	0.68	21.2
Feb	2.19	61.2	1.49	41.7
Mar	3.47	108	2.41	74.6
Apr	5.89	177	4.18	125
May	7.26	225	5.33	165
Jun	6.88	206	5.13	154
Jul	7.09	220	5.31	165
Aug	5.98	185	4.46	138
Sep	4.29	129	3.12	93.5
Oct	2.61	80.9	1.84	57.0
Nov	1.41	42.2	0.97	29.0
Dec	0.73	22.6	0.50	15.5
Year	4.08	124	2.96	90.0
Total for year		1490		1080

Ed: Average daily electricity production from the given system (kWh)
Em: Average monthly electricity production from the given system (kWh)
Hd: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m2)
Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m2)

6.4.3 PVSYST

On the next 3 pages the results from a simulation in the software system PVSYST is presented. PVSYST is a professional tool and as so it is not free of charge but must be purchased from the University of Geneva.

By contrast to PVGIS, in which the calculation is based on standard values for main categories of module, PVSYST use explicit values for the specific modules and inverters, which are utilized in the system in question. Therefore detailed information regarding obtainable yield and losses is part of the outcome from a simulation.

According to the calculation made based on the data in the example, an annual yield of 1,432 kWh can be expected. This value must be considered as the most qualified estimation of the 3 methods in question, giving that it takes into consideration exact module and inverter specifications as well as long term climatic data.

In the table below, the results from the 3 methods are compared.

Comparison of methods		
Method	Expected yield	Relation to PVSYST value
	kWh/year	%
Manual calculation	1,455	101.6 %
PVGIS	1,490	104.1 %
PVSYST	1,432	100.0 %

Giving that PVSYST is expected to be the most precise estimations, this value is set as baseline and the results from the manual calculation as well as PVGIS has been related to this value.

It can be seen, that the differences between the methods is less than 5 %, which must be considered to be very low. In this context, however, it has to be taking into account that the conditions in the example have been rather uncomplicated. Under more complex circumstances the variations between the methods would probably be more significant, giving that only PVSYST will be able to handle a higher degree of design complexity.

Grid-Connected System: Simulation parameters

Project : **PV-OPT eksempel**

Geographical Site		**Kobenhavn**	**Country**	**Denmark**
Situation	Latitude	55.4°N	Longitude	12.4°E
Time defined as	Legal Time	Time zone UT+1	Altitude	5 m
	Albedo	0.20		

Meteo data : Kobenhavn , synthetic hourly data

Simulation variant : **Basic**

Simulation date 10/04/09 11h00

Simulation parameters

Collector Plane Orientation	Tilt	30°	Azimuth	-45°
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Array Characteristics

PV module Si-mono	Model	**BP275F**		
	Manufacturer	BP Solar		
Number of PV modules	In series	12 modules	In parallel	2 strings
Total number of PV modules	Nb. modules	24	Unit Nom. Power	75 Wp
Array global power	Nominal (STC)	**1.80 kWp**	At operating cond.	1.62 kWp (50°C)
Array operating characteristics (50°C)	U mpp	185 V	I mpp	9 A
Total area	Module area	**15.1 m²**	Cell area	13.5 m²

PV Array loss factors

Heat Loss Factor	ko (const)	29.0 W/m²K	kv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (800 W/m², Tamb=20°C, wind 1 m/s)			NOCT	45 °C
Wiring Ohmic Loss	Global array res.	674.5 mOhm	Loss Fraction	2.9 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.3 % at STC
Module Quality Loss			Loss Fraction	3.0 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1-bo (1/cos i - 1)	bo Parameter	0.05

System Parameter	System type	**Grid-Connected System**		
Inverter	Model	**IG 15 EI**		
	Manufacturer	Fronius		
Inverter Characteristics	Operating Voltage	150-400 V	Unit Nom. Power	1.3 kW AC

User's needs : Unlimited load (grid)

Grid-Connected System: Main results

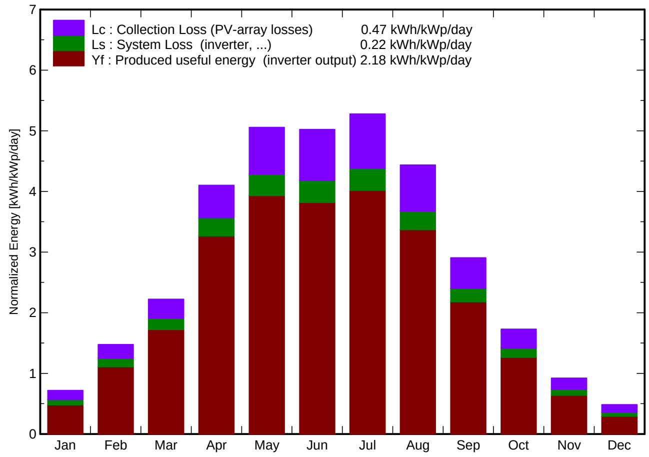
Project : **PV-OPT eksempel**

Simulation variant : **Basic**

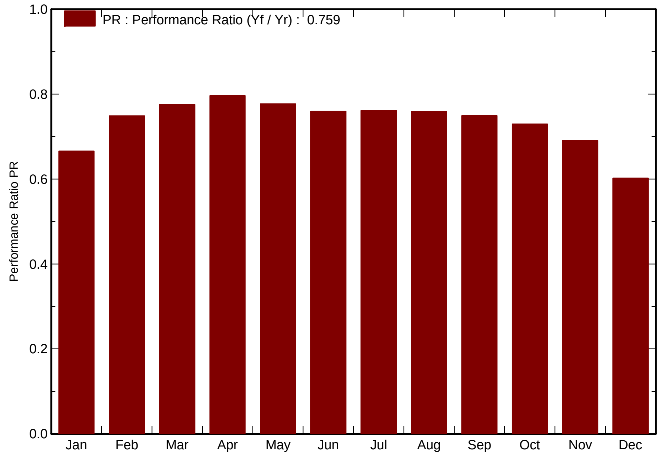
Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	30°	azimuth	-45°
PV modules	Model	BP275F	Pnom	75 Wp
PV Array	Nb. of modules	24	Pnom total	**1.80 kWp**
Inverter	Model	IG 15 El	Pnom	1.30 kW ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**1432 kWh/year**	Specific	795 kWh/kWp/year
	Performance Ratio PR	75.9 %		

Normalized productions (per installed kWp): Nominal power 1.80 kWp



Performance Ratio PR



Basic

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	EOutInv kWh	EffArrR %	EffSysR %
January	16.0	2.30	22.3	21.3	31.7	26.8	9.39	7.93
February	32.0	1.00	41.4	39.7	63.0	55.8	10.06	8.92
March	63.0	2.50	68.9	66.2	106.7	96.2	10.25	9.24
April	115.0	5.10	123.1	118.8	192.6	176.4	10.35	9.48
May	156.0	10.40	156.7	151.7	239.2	219.3	10.10	9.26
June	154.0	13.30	150.7	145.8	225.8	206.2	9.91	9.05
July	165.0	15.20	163.6	158.4	244.7	224.2	9.90	9.07
August	132.0	15.90	137.6	133.0	205.2	188.0	9.87	9.04
September	80.0	13.80	87.2	84.0	129.7	117.6	9.84	8.93
October	44.0	10.50	53.7	51.5	79.2	70.5	9.77	8.69
November	20.0	6.50	27.7	26.4	39.7	34.4	9.49	8.23
December	11.0	4.00	15.0	14.3	20.0	16.3	8.80	7.17
Year	988.0	8.42	1048.0	1011.1	1577.6	1431.7	9.96	9.04

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	EOutInv	Available Energy at Inverter Output
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

Grid-Connected System: Loss diagram

Project : **PV-OPT eksempel**

Simulation variant : **Basic**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	30°	azimuth	-45°
PV modules	Model	BP275F	Pnom	75 Wp
PV Array	Nb. of modules	24	Pnom total	**1.80 kWp**
Inverter	Model	IG 15 El	Pnom	1.30 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year