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Analysis of Photovoltaic Systems

PVPS

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

Report IEA-PVPS T2-01: 2000

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Task 2
Operational Performance of PV Systems and Subsystems

Report IEA-PVPS T2-01: 2000

ANALYSIS OF PHOTOVOLTAIC SYSTEMS

Prepared by:

Ulrike Jahn
Institut für Solarenergieforschung GmbH
Hameln / Emmerthal
Am Ohrberg 1
D-31860 Emmerthal
Germany

Bodo Grimmig, Wolfgang Nasse
Solar Engineering
Decker & Mack GmbH
Vahrenwalder Straße 7
D-30165 Hannover
Germany

Additional copies may be obtained at the following address: Forschungszentrum Juelich GmbH, Mr. R. Dahl, PT BEO 21, D-52425 Juelich, Germany, Phone: +49 (0) 2461 61 3254, Fax: +49 (0) 2461 61 2880, e-mail: r.dahl@fz-juelich.de

IEA-PVPS Task 2
Operational Performance of PV Systems and Subsystems

OPERATING AGENT:

Germany	Reinhard Dahl, Forschungszentrum Juelich

EXPERTS:

Austria	Michael Heidenreich, Arsenal Research Michael Zoglauer, Tiroler Wasserkraftwerke
European Union	Gerd Blaesser, JRC, Ispra Juergen Sachau, JRC, Ispra
France	Didier Mayer, Ecole Des Mines de Paris
Germany	Reinhard Dahl, Forschungszentrum Juelich Ulrike Jahn, ISFH Martina Niemann, ISFH Bodo Grimmig, Solar Engineering GmbH Wolfgang Nasse, Solar Engineering GmbH
Israel	David Faiman, Ben Gurion National Solar Energy Centre
Italy	Salvatore Castello, ENEA
Japan	Koichi Sakuta, MITI Tadatoshi Sugiura, JQA Masafumi Yamaguchi, Toyota Technological Institute
The Netherlands	Karel van Otterdijk, ECN Nico van der Borg, ECN
Switzerland	Luzi Clavadetscher, TNC Consulting AG Andreas Frölich, TNC Consulting AG

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FOREWORD

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD) which carries out a comprehensive programme of energy co-operation among its 23 member countries. The European Commission also participates in the work of the Agency.

The IEA Photovoltaic Power Systems Programme (PVPS) is one of the collaborative R & D agreements established within the IEA. Since 1993, the 20 countries participating in the programme and the European Commission have been conducting a variety of joint projects in the applications of photovoltaic conversion of solar energy into electricity.

The overall programme is headed by an Executive Committee composed of one representative from each participating country, while the management of individual research projects (Tasks) is the responsibility of Operating Agents. The programme is divided into nine Tasks.

The member countries participating in Task 2 are Austria (AUT), France (FRA), Germany (DEU), Israel (ISR), Italy (ITA), Japan (JPN), The Netherlands (NLD), Switzerland (CHE) and the European Commission.

The objective of Task 2 is to provide the other Tasks of PVPS and PV experts with information on the operational performance, reliability and costs of PV systems and subsystems, to present data on the operational reliability of PV systems to research laboratories, utilities and manufacturers, to provide information on PV system design to installers, system designers and vocational schools, and to provide information on the state-of-the-art monitoring and normalized presentation of results of grid-connected and stand-alone PV systems.

This report contains a summary of the work on the analysis of PV systems which was executed within Task 2, Subtask 1 (International Database and Analysis of PV Systems).

This international technical report has been prepared under the supervision of PVPS Task 2 by:

Ulrike Jahn, Institut für Solarenergieforschung GmbH, Germany (DEU) and
Bodo Grimmig, Solar Engineering Decker & Mack GmbH, Germany (DEU)

in co-operation with the experts of the following countries: Austria, European Union, France, Israel, Japan, the Netherlands and Switzerland.

The report expresses, as nearly as possible, the international consensus of opinion of the Task 2 experts on the subjects dealt with.

ABSTRACT AND KEYWORDS

In recent years, national and international demonstration programmes in the field of photovoltaics have been initiated to develop typical market segments and to enhance technology progress. Gathering direct experiences of the feasibility, reliability and operating costs of PV systems is an important aspect of various implementation programmes. Evaluation programmes create a great deal of collected information on technical and non-technical issues, but only a portion is published and available. The International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS) represents an attempt to highlight common achievements and problems, and to promote recommended practices.

As part of the IEA-PVPS programme, Task 2 is collecting and analysing operational data of PV plants in various types of systems (grid-connected, stand-alone systems, hybrid systems) spread all over the world. The objective of this Task is to provide PV experts and other target groups as well as other Tasks with suitable information on the operational performance, reliability and costs of PV system and subsystems. The IEA-PVPS Task 2 database is designed for the normalized analysis and representation of the operational data from different PV applications.

This report summarizes the analysis of more than 260 PV systems integrated in the IEA-PVPS database, illustrates the operational behaviour of the systems by suitable graphs and presents the detailed results in a normalized form. The analysis allows comparisons between typical PV systems in different countries under different climatic conditions and systems of different load pattern.

Keywords: database, evaluation, grid-connected systems, indices of performance, maintenance, monitoring, mounting, national programmes, normalized presentation, power stations, PV components, sizing, stand-alone PV systems

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1 EXECUTIVE SUMMARY

1.1 IEA-PVPS Task 2 database

This work has been carried out by the participants of Task 2 of the International Energy Agency (IEA), Photovoltaic Power Systems Programme (PVPS). Task 2 addresses the operational performance of photovoltaic power systems and subsystems, and is divided into three subtasks. This report deals with Subtask 1 “International Database and Analysis of PV Systems” with emphasis on the evaluation of PV systems (activity 13). The main objective is to provide information on the operational performance, reliability and costs of PV systems and subsystems. In addition reported experiences and results of technical and economical performance are considered as being essential and of great value for the promotion of PV systems and components. The target groups are other Tasks of PVPS and PV experts, research laboratories, utilities, manufacturers, system designers, installers, standardization organizations and vocational schools.

For the IEA-PVPS Task 2 database, monitoring data of 266 PV systems from the IEA member countries (AUT, EU, FRA, DEU, ISR, ITA, JPN, NLD and CHE) were collected. The database contains complete datasets of 266 PV systems with an installed capacity of 11 MWp ranging from 0.1 kWp up to 3 MWp. Grid-connected PV systems including grid-connected hybrid systems are in majority with 80 %, while stand-alone systems and SAS hybrid systems total 20 %.

Most of the monitoring data have been gathered under various national demonstration programmes in the IEA member countries: e. g. Austrian Rooftop Programme, French Rural Electrification Programme, EU Thermie Programme, German 1 000-Roofs-Photovoltaic-Programme, Japanese Sunshine and Japanese Field Test Programme. There has been an increasing trend for demonstration programmes to focus on, or include, grid-connected PV systems. For the purpose of analysing the operational performance three primary applications of on-grid PV systems were identified: decentralized systems ranging from 1 kWp to 10 kWp (PV roofs), dispersed systems ranging from 10 kWp to 100 kWp (BIPV, sound barrier), and centralized systems greater than 100 kWp (PV power plants).

With respect to the operational performance of stand-alone systems including hybrid systems two main categories were defined: off-grid domestic systems for rural electrification (isolated houses and Alpine huts) and off-grid professional systems (remote communications, control and protection devices).

The IEA-PVPS database is designed to accommodate the technical and operational data of different types of systems. For PV systems with more than one PV array, DC/DC converter or inverter, it is possible to enter multiple sets of technical information for the same type of subsystem. The operational data are monthly values of monitored data and can be entered for multiple years of operation. All or parts of the technical or monitored data can be entered manually using the PVbase database programme or imported from an ASCII file. It is also possible to export data to an ASCII file. The database comprises 182 fields for each plant or project. All the fields including type, unit and possible range are listed in annex A – 1. To carry out a normalized evaluation and presentation of all the systems in the database using the PVreport programme, 91 minimum fields were defined as absolutely necessary.

The database software (PVbase and PVreport programmes) allows the user to process the collected data of the systems and to present the results in tables and graphs. Meteorology and energy production data, for example, may be displayed on a monthly basis for an individual system and on a yearly basis for multiple systems. The same feature applies as well for energy yield, performance ratio, and system and components efficiency figures of selected plants. The database programmes are described in chapter 4.

1.2 Evaluation of data and presentation of results

This report focuses on the detailed analysis of the monitored and collected data. All system and subsystem performance data have been evaluated in terms of operational performance and reliability. To a great extent the evaluation procedures are based on the European Guidelines and the IEC Standard 61724. In addition there are additional recommendations for existing guidelines on national levels. Complementary developments which are relevant for the monitoring data in the IEA-PVPS database are carried out in Austria, France, Germany, Italy, Netherlands and Switzerland.

For the presentation of results in this report, the derived parameters from the IEA-PVPS database were exported into spread sheet programmes to produce a variety of graphical presentations (chapter 6). Table 1.1 shows an overview of the derived performance data and the graphical presentations for grid-connected and for stand-alone PV systems. Due to the available data in the database, the scope of the presented results varies considerably from country to country.

Table 1.1: Overview of performance indicators and their graphical presentation for grid-connected systems (GCS) and for stand-alone systems (SAS)

Derived parameter	Symbol	Graphical presentation	Application
Nominal power	P_0	Distribution of P_0	GCS & SAS
Final yield	Y_f	Distribution of annual Y_f	GCS
Performance ratio	PR	Distribution of monthly and annual PR	GCS & SAS
Reference yield	Y_r	Y_f and PR as a function of Y_r	GCS
Array capture losses	L_C	Bar graph of monthly $Y_f + L_S + L_C$	GCS & SAS
System losses	L_S	Bar graph of monthly $Y_f + L_S + L_C$	GCS & SAS
Array efficiency	$\eta_{A,mean}$	$\eta_{A,mean}$ as a function of η_{A0}	GCS & SAS
Module temperature	T_m	$\eta_{A,mean}$ as a function of T_m	GCS & SAS
Overall plant efficiency	η_{tot}	Distribution of η_{tot}	GCS
Energy consumption	E_{CONS}	Distribution of $E_{CONS} = E_{IO} + E_{FU} + E_{TU}$	GCS
Solar fraction	F_S	Distribution of F_S; F_S versus E_{CONS}	GCS
Direct use fraction	F_d	Distribution of F_d; F_d versus F_S	GCS
Potential energy	E_{pot}	Distribution of monthly E_{pot}	SAS
Useful energy	E_{use}	Comparison of monthly E_{use} to E_{pot}	SAS
Matching factor	MF	Distribution of annual $MF = PR \cdot F_A$	SAS
Usage factor	UF	$UF = E_A/E_{pot}$ as a function of PR	SAS
Outage fraction	O	Distribution of O	GCS & SAS

A summary of the performance results is presented and illustrated in annex D, where 38 representative PV systems (three to seven selected systems from each country) are documented in the form of a standard performance report. This standard report for individual (and multiple) systems and for one or more operational years may be produced by using the PVreport programme. It contains general information on the PV plant and annual results of meteorology, system energies, performance indices and utility grid energies as listed in Table 1.2. One selected graph (e. g. indices of performance) for each of the 40 PV systems is included in the standard PV database report.

Table 1.2: Available parameters in the standard PV database report

General information	Meteorology	System energies	Performance indices	Utility grid
Plant name	Irradiation, horizontal	Inverter energy output	Reference yield	Energy to utility grid
Country	Irradiation, in array plane	Useful energy	Final yield	Energy from utility grid
Nominal power	Ambient air temperature	PV array fraction	Array capture losses	
Type of plant		Energy consumption	System losses	
Mounting structure			Performance ratio	
Array area			Array efficiency	
Availability of data			Inverter efficiency	
Calculated month			Overall plant efficiency	

1.3 Results of performance analysis

From the analysis of grid-connected PV systems in the IEA-PVPS database, it was learnt that the average annual yield (Y_f) only slightly fluctuates from one year to another and has typical annual values of Y_f = 700 h/y for Germany and the Netherlands, Y_f = 830 h/y for Switzerland and up to Y_f = 1 600 h/y for Israel. However, there is considerable scattering around these average values for the individual systems ranging from 400 h/y to 950 h/y (Germany) and from 500 h/y to 1 400 h/y (Switzerland).

The performance ratio (PR) is used to indicate the overall effect of losses on the array's rated output due to array temperature, incomplete utilization of the irradiation, and system component inefficiencies or failures. The performance ratio ($PR = Y_f / Y_r$) is defined as the ratio of the final yield to the reference yield, given by a dimensionless number.

Figure 1.1 shows the distribution of annual performance ratios (PR) calculated from 387 annual datasets of 170 grid-connected PV systems. The annual performance ratio (PR) significantly differs from plant to plant and ranges between 0.25 and 0.9 with an average PR value of 0.66 for 170 PV systems. It was found that well maintained PV systems operating well show an average PR value of typically 0.72 at an availability of 98 % (e. g. Switzerland). A tendency of increasing annual PR values during the past years has been observed.

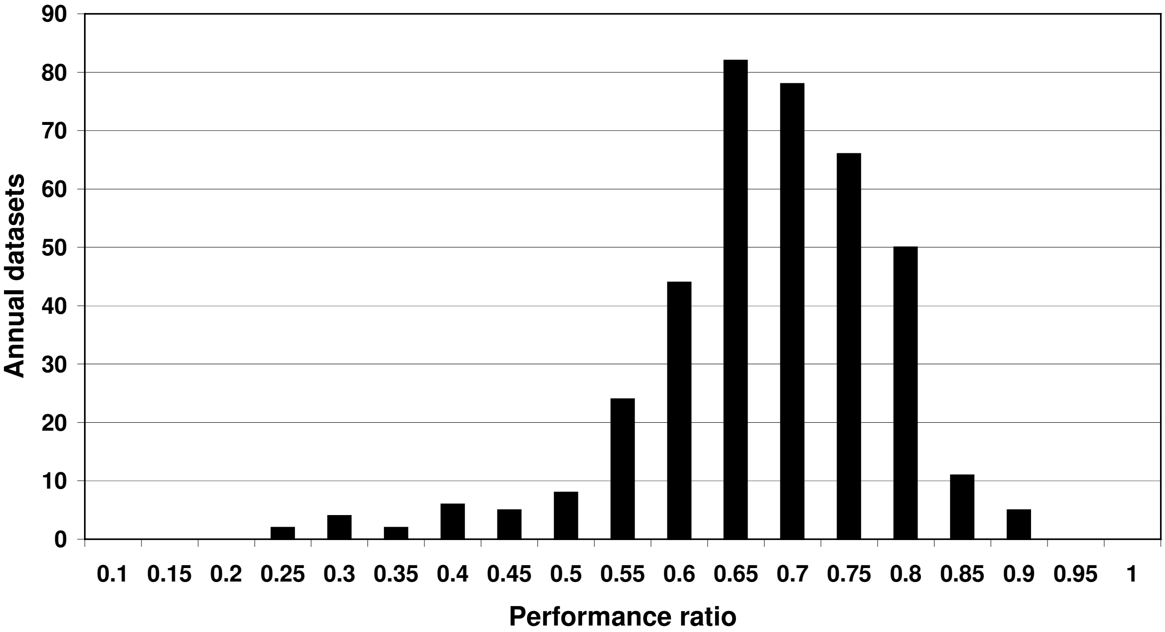


Figure 1.1: Distribution of annual performance ratios (PR) for 170 grid-connected PV systems

One unexpected loss factor is clearly identified among high and very high array capture losses (L_C in the order of 1.5 h/d). There is a systematic deviation of minus 5 points to minus 15 points of the measured PV nominal power from the rated power specified in the data sheets by the manufacturer. As a consequence of these results, the manufacturers of PV modules have improved the accuracy of their module quoting with respect to STC performance during the last years.

Another major loss factor is detected for PV plants having partial shading of the PV array, which leads to a significant reduction of the energy yield of that system. In order to avoid unnecessary energy losses, a position with as little shading as possible should be chosen for the PV array during the planning phase.

The susceptibility of grid-connected PV systems to failures, particularly regarding DC/AC inverters, has clearly decreased. The PV array has continued to be the most reliable component. The inverters of grid-connected systems achieve mean annual efficiency figures of higher than 88 % and a mean availability of better than 97 % (e. g. Germany).

Despite good results, which have been obtained in many of the grid-connected systems, the investigation of the operational behaviour of the reported PV systems has identified further potential for optimization:

- improving efficiencies of components by the selection of high efficiency modules and inverters
- avoiding diode, wiring and mismatch losses
- avoiding MPP inverter losses by optimum components matching
- avoiding high module temperatures by suitable measures of module integration into the building during installation
- avoiding array coverage due to dirt and snow on the PV array surface
- reducing array shading as much as possible during the planning phase

The performance analysis of data from stand-alone and stand-alone hybrid systems has revealed that the operational performance not only depends on the component efficiency, but also on system design and load pattern. Figure 1.2 shows the distribution of annual performance ratios (PR) for 27 domestic stand-alone and stand-alone hybrid systems. Annual performance ratios range from 0.2 to 0.6 for off-grid domestic applications depending whether they have a back-up system and from 0.05 to 0.25 for off-grid professional systems, which are often oversized for reliability reasons. The analysis of stand-alone systems in terms of performance ratio shows that the PR does not reflect the proper technical operation of a system as is the case for grid-connected systems.

Using the matching factor (MF), which is the product of the performance ratio (PR) and the array fraction (F_A), allows a better illustration of the performance of hybrid systems. A high value of the matching factor indicates that the solar component properly matches the electrical load and limits the back-up contribution. For the reported stand-alone systems, annual MF values between 0.2 and 0.6 were achieved highlighting better performance of hybrid systems in general in comparison to SAS without back-up. Nevertheless, the considered hybrid systems have not been designed as such but rather as a juxtaposition of two energy sources (solar PV and conventional). The wide MF range demonstrates that an optimization in the design phase is needed.

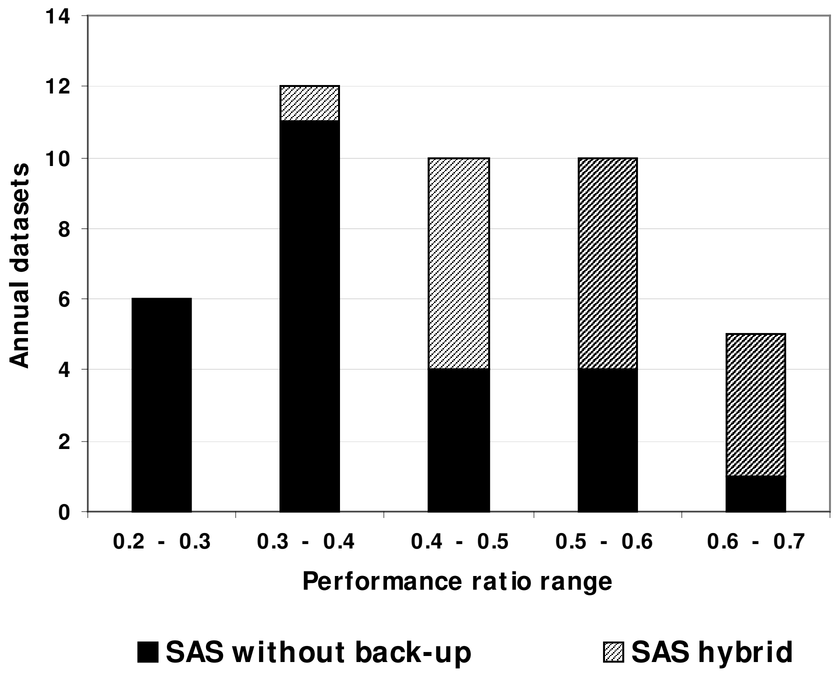


Figure 1.2: Distribution of annual performance ratios (PR) for typical domestic stand-alone PV systems

2 INTRODUCTION

2.1 Motivation

The mission of the Photovoltaic Power Systems Programme is “to enhance the international collaboration efforts through which photovoltaic solar energy becomes a significant renewable energy option in the near future”. The underlying assumption is that deployment of the PV market will increase if technology improvements deliver the cost reductions and performance improvements of PV systems.

This work has been carried out to gather experiences and results of both technical and economical performance, for the promotion of PV. It aims at gaining an increased understanding of the operational performance, energy behaviour, characterization and design of photovoltaic systems, subsystems and components. In addition, performance analysis is a crucial element in the learning cycle of design - installation - monitoring - evaluation - and the improvement of the system design.

2.2 Objectives

The overall objective of Task 2 is to provide technical information on operational performance, long-term reliability, costs and sizing of PV systems to target groups. The target groups are other Tasks of PVPS and PV experts, research laboratories, utilities, manufacturers, system designers, installers, standardization organizations and vocational schools.

The objectives of this work can be summarized as follows:

- to specify the necessary data and criteria for the proposed evaluation
- to define the evaluation procedures
- to evaluate energy balances and indices of performance using normalized representations
- to present the results (tables, graphs) in normalized form
- to learn from the results and experiences in different IEA countries
- to indicate the optimization potentials

2.3 Approaches

This report intends to cover the evaluation of the collected data available in the IEA-PVPS database with respect to the technical performance. The standard tools for the analysis are provided by the database programmes (PVbase and PVreport).

Data collection is described explaining the data sources and import of data into the database. An overview of the IEA-PVPS database contents is given in chapter 3. A general description of the database programmes including the import/export facilities is presented giving an insight into the database tools and how to use them (chapter 4).

An overview of the existing evaluation procedures (chapter 5) is given while explaining the two most important guidelines / standards in more detail. Additional developments carried out in the Task 2 member countries are mentioned, if relevant for the performance evaluation.

The presentation of data and results according to the relevant standards is outlined together with the modifications, and is reflected in the presented results in chapter 6 and annex D. The annual datasets of 266 PV systems in the IEA-PVPS database were analysed for each country and the results are presented in chapter 6.

Standard performance reports are produced for 38 selected PV systems in annex D.

From the analysis of results in chapter 6, the experiences of the reported PV systems are derived, from which the lessons learnt and problems encountered were developed (chapter 7). Tables which are relevant for more than one chapter of this report have been placed in annex A.

3 DATA COLLECTION

3.1 Description of data collection

Data collection was conducted as part of the work defined in Subtask 1 (“International Database and Analysis”), activity 12 (“Data Collection”). This activity included the delivery of processed data from PV systems, data input into the IEA-PVPS database and the checking of new batches of datasets from existing PV systems. Each Task 2 member was responsible for collecting the data of the systems in their country. In most cases data collection for IEA-PVPS Task 2 was correlated with the monitoring initiatives of the national PV promotion programmes existing in various Task 2 countries. These national monitoring programmes are most diverse and monitoring is carried out at different levels: global monitoring (can be manual, yielding monthly meter readings) and analytical monitoring (automatic data acquisition system yielding hourly averages). In the case of analytical monitoring the supplier of the data usually carried out data compression from hourly values to monthly values. The data was then provided to the respective Task 2 member in electronic form (diskette or e-mail).

Depending on the level of monitoring and the framework of the monitoring programme, the scope and quality of the collected data differ significantly from country to country and from plant to plant. In the following, the features of the technical assessment with respect to various monitoring items in various countries are given:

Austria
- analytical monitoring within the Austria PV Rooftop Programme
- specific features of monitoring and analysis of monitoring data of dispersed systems

EU
- analytical monitoring within the THERMIE Programme
- evaluation of energy balances, indices of performance, performance ratio

France
- monitoring of stand-alone systems within Rural Electrification Programme
- datalogger for stand-alone systems

Germany
- high resolution performance data from the 1 000-Roofs-PV-Programme
- statistical analysis of monitoring data from dispersed systems and specific examples

Italy
- real time diagnostic monitoring of PV plants in remote areas
- monitoring of medium and large scale power plants

Israel
- monitoring of grid-connected systems and stand-alone systems
- detailed analysis with respect to tracking and mirror enhancement

Japan
- analytical monitoring within the Field Test Programme
- statistical evaluation of R&D projects with minimum monitoring investments

Netherlands
- analytical monitoring based on national guidelines
- monitoring of grid-connected systems and selected R&D projects

Switzerland
- analytical monitoring of R&D projects
- detailed on-line and off-line analysis of sporadic system malfunctions

A problem encountered in the data collection was the access to the available monitored data by the country representative of Task 2. In the case of direct access due to an involvement of the participant in the national monitoring initiatives or campaigns at that time, transfer and checking of data were easier and faster. In other cases, where the monitored data had to be processed by third parties not directly involved in IEA activities, data collection took considerably more effort and was time consuming. Additionally, any inconsistency detected in the monthly datasets was more difficult to solve without having direct access to the monitored data and to the background information on the system monitoring.

Although the first workplan proposed to finish data collection at an earlier stage of the project, this activity continued until the end of 1998 due to various circumstances and difficulties in gathering the monitored data from third parties.

3.2 Sources of data

Making use of the national monitoring activities was the most common approach for collecting the data of the PV systems for the IEA-PVPS database. Depending on the different emphasis of the various national programmes, the available data come from a broad spectrum of installed PV systems. Most of the systems in the database can be associated with national programmes, under which the data were originally monitored and evaluated. The programmes and their special features with respect to the PV systems in the database are summarized in Table 3.1.

Table 3.1: Overview of the contents of the IEA-PVPS Task 2 database with respect to type of system, number of installations, nominal power range and the corresponding promotion programme

Country	GCS	SAS	Hybrid	Number	Power [kWp]	Promotion Programmes
Austria	X		X	17	1 ... 30	200 kW Rooftop, Eureka
France			X	9	0.5 ... 1	AUDE- Rural Electrification
France (EU)		X	X	2	3 ... 20	THERMIE (EC)
Germany	X			88	1 ... 5	1 000-Roofs-PV-Programme (BMBF)
Germany (EU)	X	X	X	6	4 ... 22	THERMIE (EC)
Israel	X	X		7	0.3 ... 4	
Italy	X	X	X	4	10 ... 3 000	Demonstration Prog. (ENEA, ENEL)
Italy (EU)		X	X	4	4 ... 10	THERMIE (EC)
Japan	X	X	X	70	2 ... 1 428	Sunshine Project; Field Test P. (NEDO)
Netherlands	X	X		14	0.1 ... 10	R&D; National P. (NOVEM)
Switzerland	X			41	1 ... 560	R&D; PV in Schools; National P. (BEW)

In **Austria**, system data are collected from the 200 kW Rooftop Programme and other demonstration projects since 1989.

The **EU** provided selected system data from the THERMIE Programme with operational years from 1987 to 1996.

France focused on data of stand-alone systems in the range of 0.5 kWp to 1 kWp, which were available from the AUDE Rural Electrification Programme in the years 1994 to 1996. Data from overseas islands (off-grid houses, telecommunication relay) and Alpine regions (huts and sheepfold) have also been processed and will be implemented in the database in the next release.

Germany presented all grid-connected system data from the German 1 000-Roofs-Photovoltaic-Programme, monitored from 1993 until 1996.

Israel included monitoring data from grid-connected systems and stand-alone systems of 0.3 kWp to 4 kWp, operating from 1993 to 1996.

Italy concentrated on large power plants between 10 kWp and 3 MWp installed as demonstration projects by ENEA and ENEL and supplied monitoring data from 1990 to 1995.

Japan has a great variety of systems from the Sunshine Programme and Japanese Field Test Programme ranging from 2 kWp to 1 428 kWp. Datasets are from operational years 1985 to 1996.

In the **Netherlands**, grid-connected systems and stand-alone systems were installed within national demonstration programmes ranging from 0.1 kWp to 10 kWp and monitored between 1992 and 1997.

Switzerland provided grid-connected systems with a broad range of installed nominal power from 1 kWp to 560 kWp. The monitoring data are the most complete with one to eight operational years per system from 1990 to 1997.

3.3 Data format and data entry

The IEA-PVPS database was designed to accommodate the technical and operational data of most types of PV systems. The main types are stand-alone, stand-alone hybrid, grid-connected and grid-connected hybrid PV systems. For PV systems with more than one PV array, DC/DC converter or inverter, it is possible to enter multiple sets of *technical information* for the same type of subsystem. The *operational data* are monthly values of monitored data and can be entered for multiple years of operation. It is however not possible to enter separate sets of operational data for each subsystem of the same type (multiple arrays, multiple DC/DC converters or multiple inverters). All or parts of the technical or monitored data can be entered manually using the *PVbase* database programme or imported from an ASCII file. It is also possible to export data to an ASCII file.

The kernel of each dataset is the *unique data* (75 fields) for each PV system in the database and consists of the following information:

- General information (name of plant, location, type of plant, typical use and mounting)
- Subsystems present (DC/DC converter, inverter, storage, load and grid connection)
- DC Storage (technical information)
- Auxiliary power sources (type and power output)
- Investment costs for each subsystem, planing and installation in local currency

All other information in the database can be *reoccurring data* to allow the entry of technical information for PV systems with multiple arrays, DC/DC converters or inverters and also monthly design and operational data. The following six sections of information can be entered or imported as single or multiple sets. A set of 24 fields is defined for the PV array information. This set can be repeated for each array of different characteristics (different modules, orientation, mounting or electrical connection). Eight fields are defined for DC/DC converter information. In case of multiple converters (one for each array) this set can be repeated for each plant or project. A set of 20 fields is defined for the inverter data. If more than one inverter and of a different type is used, multiple sets of technical data for each inverter are possible.

The design data for a PV system is the prediction of the operation and performance of the plant for given parameters (irradiation and load pattern) in monthly steps. A set of twelve fields is entered for each month. 26 fields are defined for the reoccurring annual maintenance costs.

The recorded or *monitored data* are entered as monthly sets of 26 fields and corresponds closely to the data format of the EU Guidelines. The data fields to be entered are all the energies to and from each subsystem, the mean ambient air temperature and the mean module temperature and information such as monitoring fraction (M), outage fraction (O) and PV array fraction (FA).

The data of each of the above sections can be imported or exported as an ASCII file with the *PVimport* programme. In addition it is possible to export the calculated annual values of the monitored data for each plant and year.

Counting only one repetitive set for each section the database comprises 182 fields for each plant or project. All the fields including type, unit and possible range are listed in annex A, Table A – 1. To carry out a normalized evaluation and presentation of all the systems in the database using the *PVreport* programme 91 minimum fields were defined as absolutely necessary.

3.4 Contents of database

To date, the IEA-PVPS Task 2 database contains data from 266 PV systems with an installed PV power of 11 MWp. Table 3.2 shows the distribution of the 266 systems in six different classes of nominal power ranges. Most PV systems can be found in the range between 1 kWp and 5 kWp belonging to the group of decentralized PV roofs. Grid-connected PV systems including grid-connected hybrid systems are in majority with 80 %, while stand-alone systems and SAS hybrid systems total 20 %. The percentages with respect to the installed nominal power of each system type are also given in Table 3.2.

Table 3.2: Overview of the system nominal power ranges and types of systems in the IEA-PVPS Task 2 database

Distribution of Nominal Power of 266 PV Systems							
Power [kWp]	0 ... 1	1 ... 5	5 ... 10	10 ... 50	50 ... 100	> 100	Sum
No of Systems	17	150	26	52	11	10	266
Sum [kWp]	9.2	417.5	211.1	1 236.1	953.2	8 097.4	10 924
Distribution of 266 PV Systems							
	Type of System		No Systems	No [%]	ΣP0 [kWp]	Σ P0 [%]	
	Grid connected		189	71	8 708	79.7	
	Stand-alone		36	13.5	815	7.5	
	Stand-alone hybrid		18	6.8	844	7.7	
	Grid connected hybrid		23	8.7	557	5.1	

Due to the different demonstration programmes mentioned previously, the IEA-PVPS database includes PV systems for a variety of applications. Table 3.3 gives an overview of the type of projects realized in each country and of the different applications. Power stations are most common among grid-connected PV systems (all countries, except Germany). The term “domestic use” refers to electrification of off-grid houses and small dwellings (France), dispersed PV roofs for family houses (Austria, Germany) and to building integrated PV and facades in large office buildings (Netherlands). “Rural application” is represented by PV pumping systems (Japan, Italy) and by PV lighthouse and PV tunnel lighting (EU projects). Professional applications are realized in PV telecommunication relays and are monitored in France, Japan and in EU projects. The electrification of sheepfolds (France) has also been considered as a professional application.

As to the completeness of datasets for the 266 systems, the following is noted: Operational data (see annex A, Table A – 1) are more or less complete for most of the systems in order to perform a representative system analysis. However, design data are only available for some of the 266 PV systems (namely systems from Italy, Netherlands, Japan and EU projects). Regarding new data, French system data are expected to include design data. The data input for cost parameter (investment and maintenance cost) is not satisfactory for all systems; only Italian and Swiss PV plants have partly specified their costs. Although some effort was put into getting further cost data for the integrated systems, the figures are not available.

Table 3.3: Overview of data in the IEA-PVPS Task 2 database regarding different types of projects (R & D; production) and different PV applications installed in nine IEA countries

Country	R & D	Production	Power Station	Domestic Use	Rural Application	Professional Application
Austria	X		X	X		
European Union	X		X	X	X	X
France		X		X		X
Germany		X		X		
Israel	X		X			
Italy	X	X	X		X	
Japan	X	X	X	X	X	X
Netherlands	X		X	X		
Switzerland	X	X	X			

4 DATABASE AND DATABASE PROGRAMMES

4.1 Overview of database programmes

The IEA-PVPS Task 2 database was designed to accommodate and standardize technical and operational data from most types of PV systems in order to achieve a common base for the performance assessment of PV systems. The IEA-PVPS database is a relational client-server database using the “structured query language” (SQL). It consists of the actual database with PV system data and of two database programmes PVbase and PVreport.

The PVbase programme is used to handle the database and allows the user to read, implement and check the data of the database. PVbase includes a facility for electronic import of data from spread sheet programmes and for export of data to spread sheet programmes. Using these import/export tools, data exchange with other available databases can be realized.

The PVreport programme enables the user to analyse and display performance and other data in graphs and tables. The user may select from thirteen main types of data display for various derived performance parameters and can obtain the presented data on screen, hard copy or in files.

4.2 PVbase programme

4.2.1 Data entry

The IEA-PVPS database contains technical data (general information about the PV plant, system data, design data, investment cost) and operational data (monthly sets of all energies to and from each subsystem, etc). All or parts of the technical and monitored data can be entered manually using the PVbase programme or imported from an ASCII file. Using the data import facility implemented in PVbase, the data fields are divided into seven parts:

- general information
- PV array data
- DC/DC converter
- DC/AC inverter
- design data
- costs
- recorded data

It is possible to import parts of the data only. For example, newly recorded data from additional operational years can be imported separately for an existing PV plant. The import programme will define an identification number for each new plant, whenever data of general information (part 001) is to be imported. This identification number is necessary for linking the data to the PV plant and will be used for all other data imports for this plant. There is a given import format concerning the number of data fields for each import file (part 001 contains 77 fields), the separation of the data fields and the type (character or numerical values) and length of the data fields.

4.2.2 Data checks

Using the tool “system data check” within the PVbase programme allows the user to check the data and to find any inconsistency in the processed data of the IEA-PVPS database. This facility provides the annual mean values of derived parameters and energies to and from each subsystem for a selected PV plant as indicated in Figure 4.1. This figure shows an example of “system data check” for a Swiss grid-connected PV system and seven operational years.

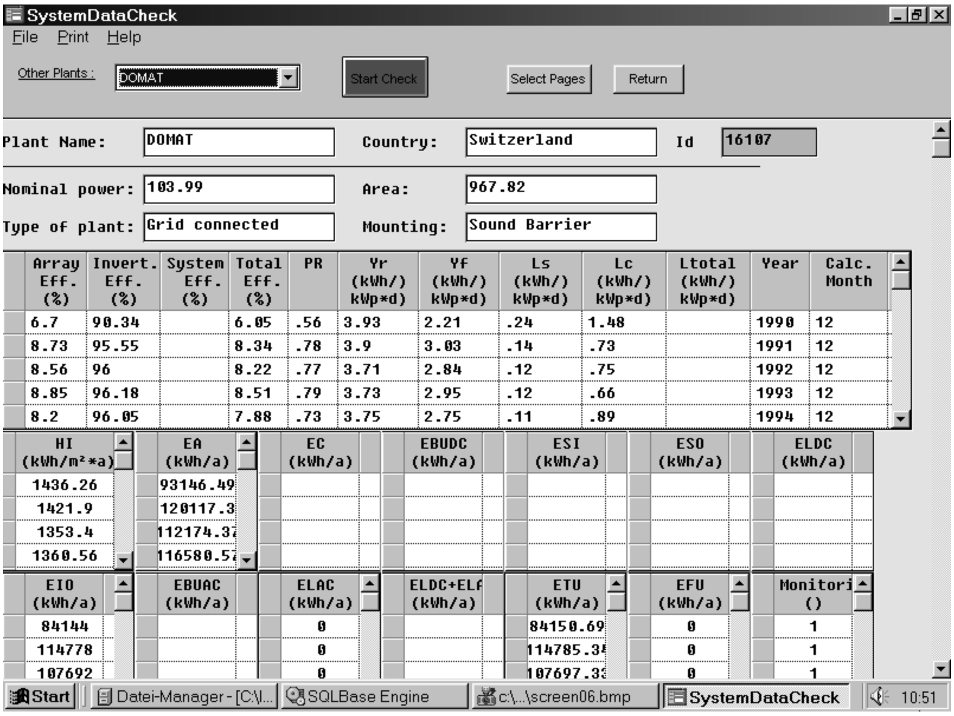


Figure 4.1: Display of “system data check” tool for a selected PV plant

Key figures such as plant name, country, identification number, nominal power and PV array area, type of system and mounting structure are given in the heading. The data table contains the calculated annual sums and averages of the following parameters:

- mean array efficiency
- efficiency of the inverter
- system efficiency (for stand-alone systems only)
- overall plant efficiency
- performance ratio
- daily reference yield
- daily final yield
- daily system losses
- daily array capture losses
- sum of daily system and array capture losses
- year of operation
- recording interval for calculating annual means expressed in months
- annual irradiation, in plane of array
- annual array energy
- annual energy output from DC/DC converter

- annual energy from DC back-up generator
- annual energy supplied to storage
- annual energy drawn from storage
- annual energy to DC loads
- annual AC energy output from inverter
- annual energy from AC back-up generator
- annual energy to AC loads
- sum of annual energy to DC and AC loads
- annual energy supplied to utility grid
- annual energy drawn from utility grid
- monitoring fraction

These figures can be employed to detect inconsistent data or incorrect data entry when comparing the calculated values in the table “system data check” to the defined range of values for each parameter. Any data which fall outside a defined or reasonable range are inconsistent and have to be checked in a subsequent analysis of the recorded data. As an example, the defined range of the performance ratio (PR) is between 0 and 1, the reasonable range for grid-connected PV systems may be between 0.5 and 0.9. Using the tool “system data check” and looking at the annual performance parameter, it may become apparent that there are errors in the recorded data which were not so obvious. Efforts were made to identify the reasons for any error noted and steps taken to avoid similar errors in the future.

4.2.3 Data export

Within the PVbase programme it is possible to export data from the database to an ASCII file and use the data for spread sheet programmes. For exporting data, the data in the database are divided into the same parts as for importing data. Additionally, the user can export the calculated annual performance data (part 008) as indicated in Figure 4.2. This figure shows the menu of the import/export programme and the eight files for the export of data from the IEA-PVPS database for selected PV plants.

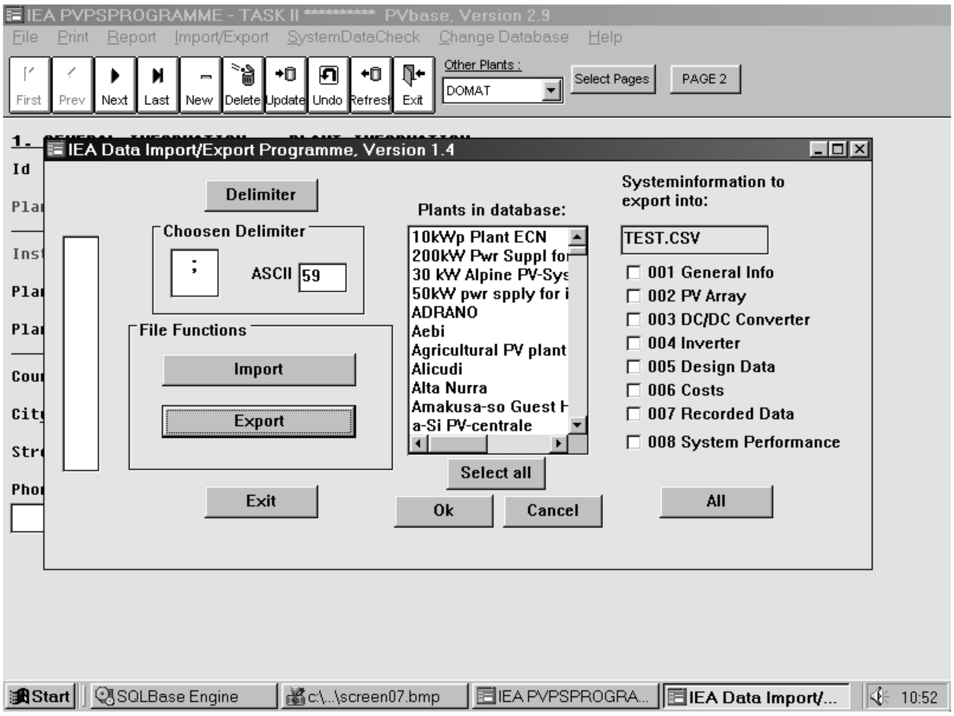


Figure 4.2: Display of import/export programme

4.3 PVreport programme

The PVreport programme allows the user to evaluate and present selected data and results in standard graphs and tables. The criteria for data selection, and the normalized and other presentations of data, are described in the following sections.

4.3.1 Data selection

Using the programme PVreport the user can select database information according to the following criteria:

- PV nominal power
- country
- type of plant
- site data
- auxiliary supply
- module manufacturer
- subsystem
- expected AC energy output from inverter
- expected irradiation in plane of array

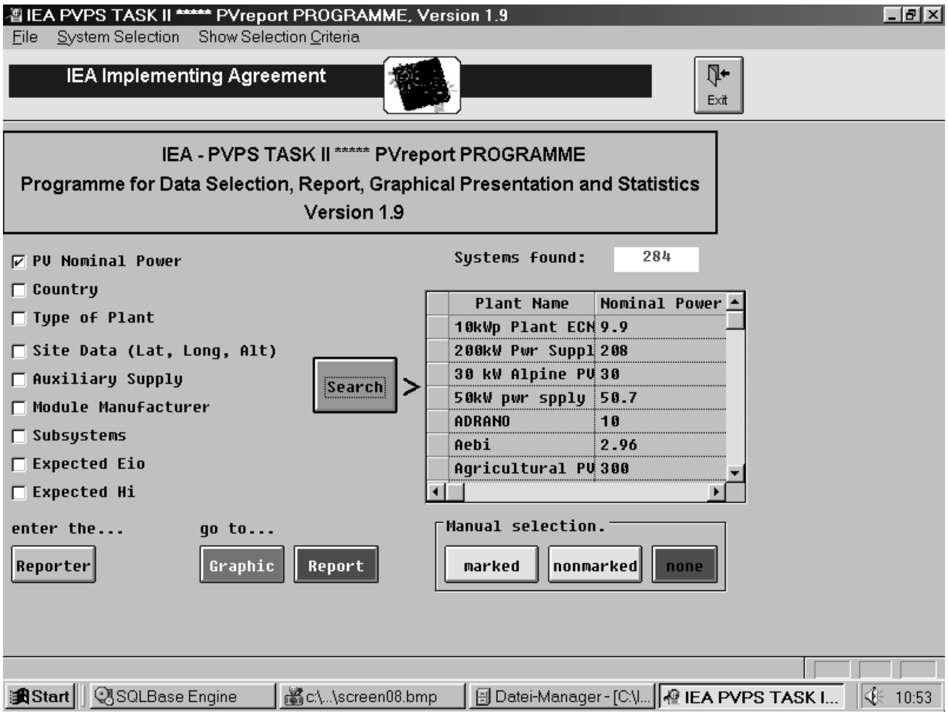


Figure 4.3: PVreport - display of data selection

Figure 4.3 shows the menu for data selection within the PVreport programme. Combinations of two and more criteria are possible. For the selection of data by nominal power, a range of P_0 values has to be given in units of kWp. If the same numerical value is entered in both fields (e. g. 5), the programme will select all systems having P_0 = 5 kWp.

Selecting information by country, multiple selections are possible. The third criterion is type of plant and the different types are grid-connected systems, stand-alone systems (PV only), grid-connected hybrid (e. g. PV and wind), and stand-alone hybrid systems (e. g. PV and diesel). Multiple selection is possible. Selecting information by site data involves specifying the range for latitude, longitude and altitude.

Another criterion enables the user to select PV plants according to auxiliary power supply. There is the option to choose between diesel, grid, wind and others, and multiple selection is possible. Selecting information by PV module manufacturer gives a list of module producers, whose modules are employed in the 260 operating PV systems delivering recorded data for the IEA-PVPS database. The user can choose from this list and select one or more module manufacturers.

Selection by subsystem enables the user to choose between PV array, DC/DC converter, DC back-up generator, DC storage, DC load, DC/AC inverter, AC back-up generator, AC load, PV grid connection and monitoring system, and multiple selection is possible.

The selection criterion “expected AC energy output from inverter” requires the user to enter a range of annual E_{IO} values expressed in kWh/y. For the selection by “expected irradiation in plane of array”, a range of annual H_I values has to be entered expressed in kWh/(m^2·y).

After the selection by one or multiple criteria, the programme searches for available data in the database. The PV systems which fulfil the given selection conditions are listed, counted and displayed together with their nominal power (Figure 4.3). The selection criteria can be stored into a file for later use. Individual PV systems may be deleted from the list, if not appropriate. The selected system data are ready for presentation in graphs and tables using the PVreport programme.

4.3.2 Evaluation and presentation of data

In the presentation of data using the PVreport programme, mainly performance data of components and systems are evaluated in terms of operational performance and reliability. The evaluation procedures of the database programmes are based on the European Guidelines, Document B, while small modifications are carried out. Additional parameters are introduced particularly for stand-alone systems.

From the recorded data, various derived parameters related to the system's energy balance and performance are calculated using sums, averages and ratios over reporting periods such as months or years. The evaluation of performance data, which is relevant for the database programmes, is described in chapter 5.2. The definitions, symbols and units of the derived parameters with respect to operational performance of PV systems can be found in Table 5.1.

PV systems of different configurations and at different locations can be readily compared by evaluating their normalized system performance indices such as yields, losses and efficiencies. Yields are energy quantities normalized to nominal array power. Component and overall PV plant efficiencies are normalized to array area. Losses are the differences between yields.

In the database programmes normalized yields, losses and efficiencies are calculated. Daily mean yields and losses have units of h/d and annual yields, which are determined by using the appropriate energy and the annual summation period, have units of h/y. In the PVreport programme these units of normalized yields and losses are described by (kWh/(kWp·d)) for daily mean yields and by (kWh/(kWp·a)) for annual yields and losses.

For the presentation of results within the PVreport programme a variety of standard graphs and reports can be produced. Depending on the type of system (grid-connected system, stand-alone system) and the available monitoring data, different presentations are applicable. The PVreport programme gives the option to produce thirteen types of graphs and two types of summary reports. The graphs for both normalized presentation and other presentation of results are listed in Table 4.1.

Table 4.1: Types of graphs for the presentation of results within PVreport programme

Normalized performance indicators	Other presentation
• efficiency (inverter, array, overall plant)	• recorded irradiation in plane of array (H_I)
• performance ratio (PR)	• recorded energy output from inverter (E_{IO})
• indices of performance (Y_f, L_S, L_C)	• recorded array output energy (E_A)
• performance ratio vs. nominal power	• recorded energy to loads (E_L, $E_{L,DC}$, $E_{L,AC}$)
	• design vs. operational consumption
	• contribution to and from utility grid (E_{TU}, E_{FU})
	• total input energy (E_{IN})
	• useful energy supplied by system (E_{use})
	• specific energy cost

These graphs are available for an individual PV system (monthly values, one or multiple years) and for multiple PV systems (annual values, one year). Using the graphic tool of the PVreport programme it is possible to change the type, colour, headline, legend and axis label of the displayed graphs. All graphs can be printed, stored in a file or copied into the clipboard for later use within other programmes.

4.3.3 Normalized presentation

In order to be able to compare PV systems, it is important to produce normalized performance indicators. Array and final yields can be obtained by dividing the relevant energy by the nominal array power P_0. Component and overall PV plant efficiencies can be obtained by dividing the relevant energy by the total array area A_A.

As an example for normalized performance indicators, Figure 4.4 shows annual component and overall PV plant efficiencies for different types of PV systems in 1996. The annual values of these efficiencies for selected plants can be displayed in a data table as shown in Figure 4.5. The mean array efficiency represents the mean energy conversion of the PV array. The system efficiency is defined as the ratio of overall PV plant efficiency to mean array efficiency and is used for performance assessment of stand-alone systems such as PV plant “Bigou” in Figure 4.4.

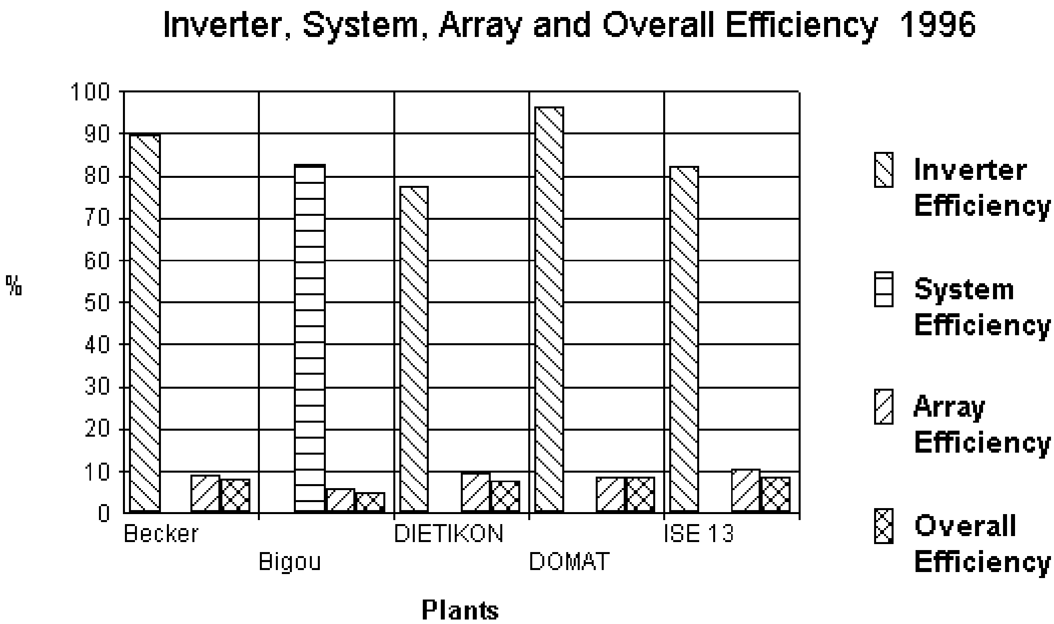
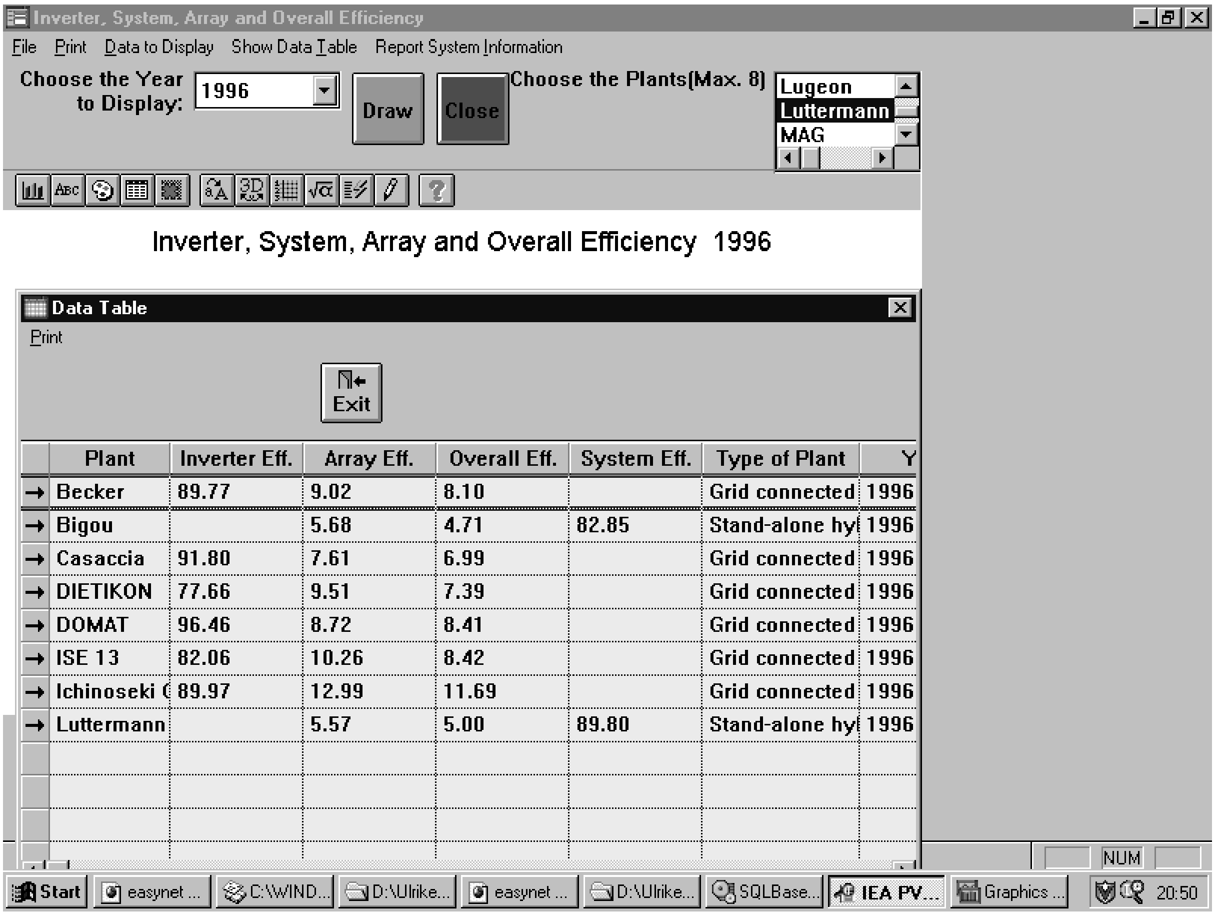


Figure 4.4: Component and overall PV plant efficiency for different types of PV systems in 1996



Plant	Inverter Eff.	Array Eff.	Overall Eff.	System Eff.	Type of Plant	Y
Becker	89.77	9.02	8.10		Grid connected	1996
Bigou		5.68	4.71	82.85	Stand-alone hy	1996
Casaccia	91.80	7.61	6.99		Grid connected	1996
DIETIKON	77.66	9.51	7.39		Grid connected	1996
DOMAT	96.46	8.72	8.41		Grid connected	1996
ISE 13	82.06	10.26	8.42		Grid connected	1996
Ichinoseki (	89.97	12.99	11.69		Grid connected	1996
Luttermann		5.57	5.00	89.80	Stand-alone hy	1996

Figure 4.5: Table of annual efficiency values for different types of systems in 1996

Another example of normalized presentation of performance results is given in Figure 4.6. The bar graph shows monthly final yields (Y_f), system (L_S) and array capture losses (L_C) stacked for each month and expressed in kWh/(kWp·d) or h/d. The annual yields and losses are calculated and displayed at the right hand side expressed in kWh/(kWp·a) or h/y. Figure 4.6 clearly shows the array and reference yields because, by definition, $Y_A = Y_f + L_S$ and $Y_r = Y_f + L_S + L_C$ (see Table 5.1).

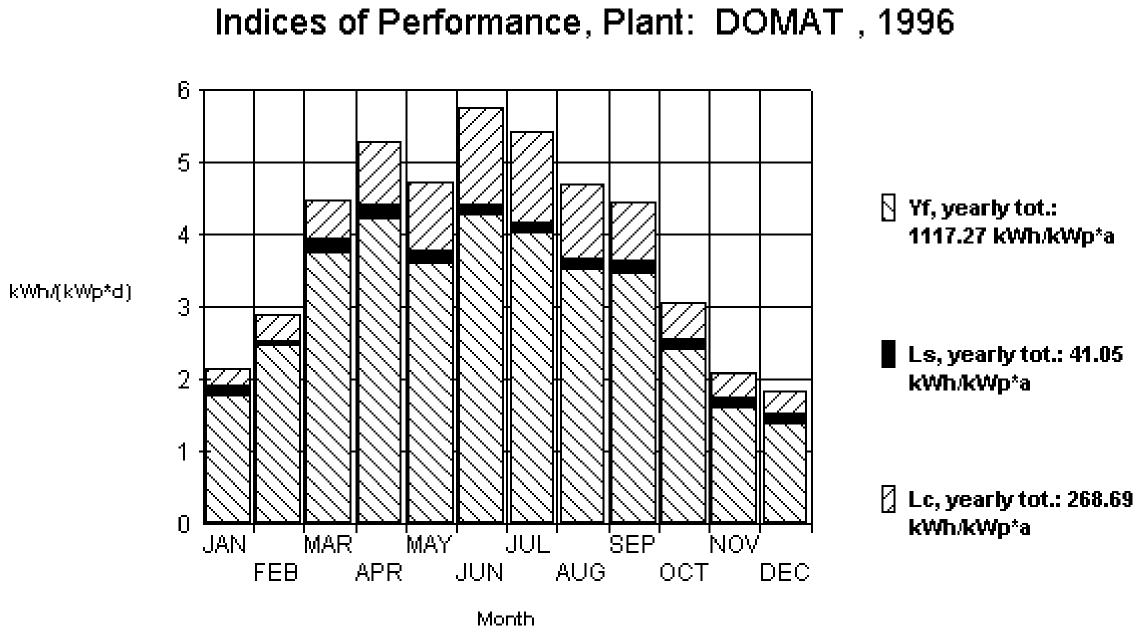


Figure 4.6: Indices of performance for a selected Swiss PV system in 1996

The performance ratio, being the ratio of the final yield to the reference yield, is the most useful normalized performance indicator. It indicates the overall effect of losses on the array's nominal energy output due to array temperature, incomplete utilization of irradiation, and system component inefficiencies or failures. For the comparison of different PV plants, particularly grid-connected PV systems, the performance ratio is widely used because it is independent of the system size and location of the plant.

A bar graph in Figure 4.7 shows the monthly performance ratio for a selected grid-connected PV system in Germany and three operational years. The monthly mean values of performance ratio (PR) can directly be compared for each month and for the three subsequent years. The annual mean values of PR are given numerically at the right hand side of the graph.

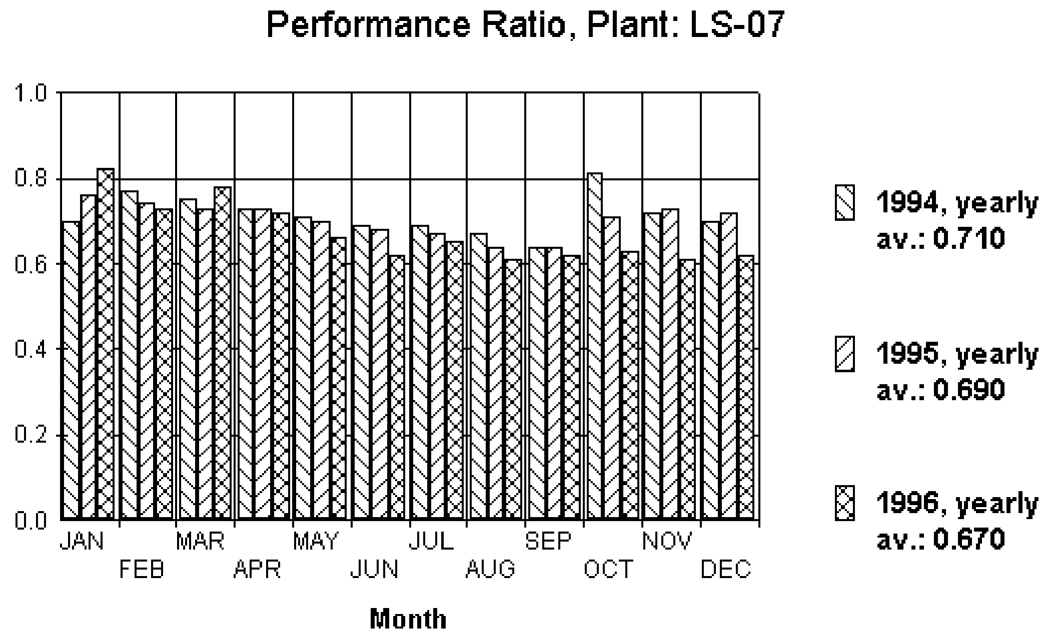


Figure 4.7: Monthly performance ratios for a selected German PV system in 1994-1996

4.3.4 Other presentations

For the presentation of recorded data, graphs of irradiation in the plane of array (H_I), PV array output energy (E_A), energy output from inverter (E_{IO}) for grid-connected plants and energy to loads (E_L, $E_{L,DC}$, $E_{L,AC}$) for stand-alone systems are available in the PVreport programme (Table 4.1). The monthly or annual values of the energy quantities are presented in bar graphs and can be compared for different selected PV systems.

Figure 4.8 shows the monthly AC energy output from the inverter for three grid-connected PV systems in Germany having the same nominal power of P_0 = 1.3 kWp. The annual final yields for the three plants are given at the right hand side of the bar graph. From these figures one may conclude that ISE 1 is a well operating system (Y_f = 827 h/y), ISE 13 an average performing plant (Y_f = 702 h/y) and ISE 49 is showing poor performance figures (Y_f = 566 h/y) under the consumption of the same insolation for all of the three plants.

On the contrary, a closer look at the bar graph reveals that the “poor performing system” ISE 49 shows very often the best monthly productions (January, March, April, May, September) and reasonably high E_{IO} values (February, June, October, November and December), but fails in the yearly sum due to a complete system failure in July and a partial failure in August. The missing energy production in two significant summer months results in a rather low AC output for ISE 49, although it is a well performing system except for the severe inverter failure.

This monthly presentation of energy figures enables to better understand and assess the performance of different PV systems.

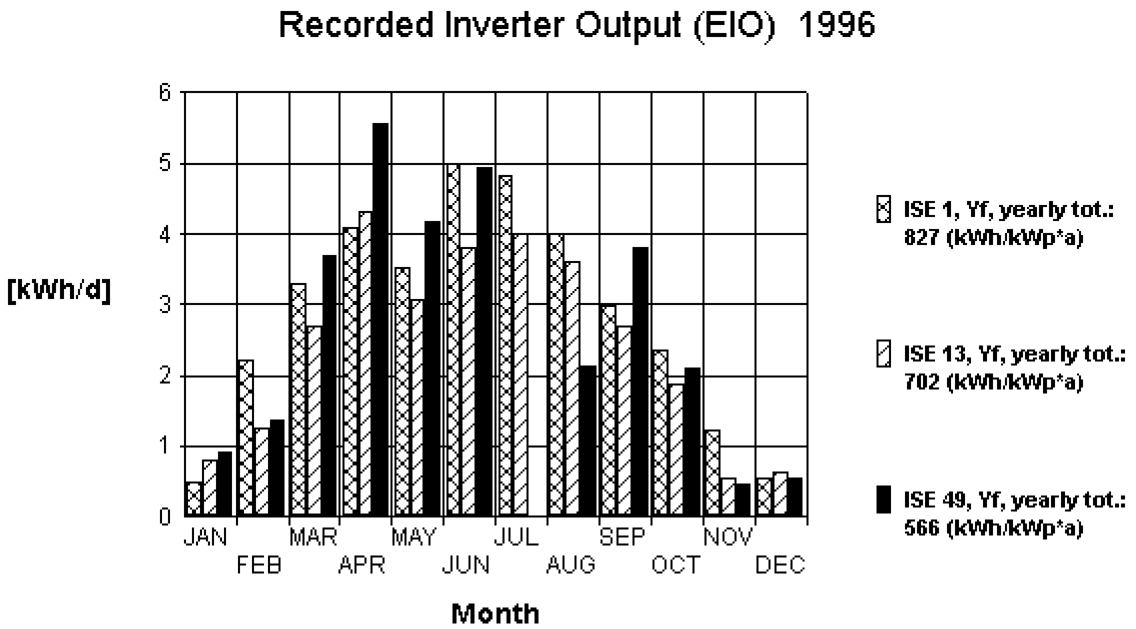


Figure 4.8: Monthly AC energy output from inverter for three grid-connected PV systems in 1996

The overall energy balance of a grid-connected PV system is presented in Figure 4.9. The energy balance includes monthly energies imported from (E_{FU}) and exported to the utility grid (E_{TU}) and indicates the contribution which the PV array has made to the overall operation of the system. This contribution, which differs considerably from winter months to summer months, is given by the PV array fraction of the total input energy F_A. The F_A values range from 0.002 in winter (December) to 0.58 in summer (July) having an annual value of F_A = 0.27 for the selected system in Figure 4.9.

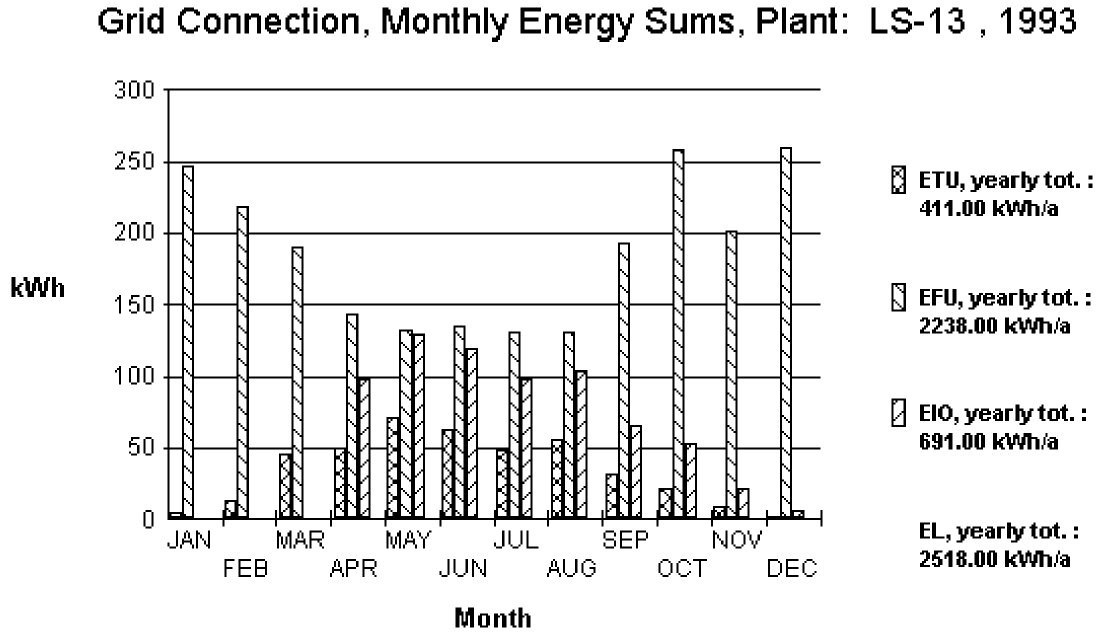


Figure 4.9: Monthly values of AC energy output from inverter, energies to and from the utility grid and energy to loads for a selected German system in 1993

Presentation of economical data is included in the PVreport programme. Specific investment cost, module cost and maintenance cost can be displayed for selected PV plants. The costs are expressed in units of U.S. dollars per kilowatt peak. Figure 4.10 shows the distribution of specific investment cost for different PV systems of installed nominal power between 1 kWp and 8 kWp.

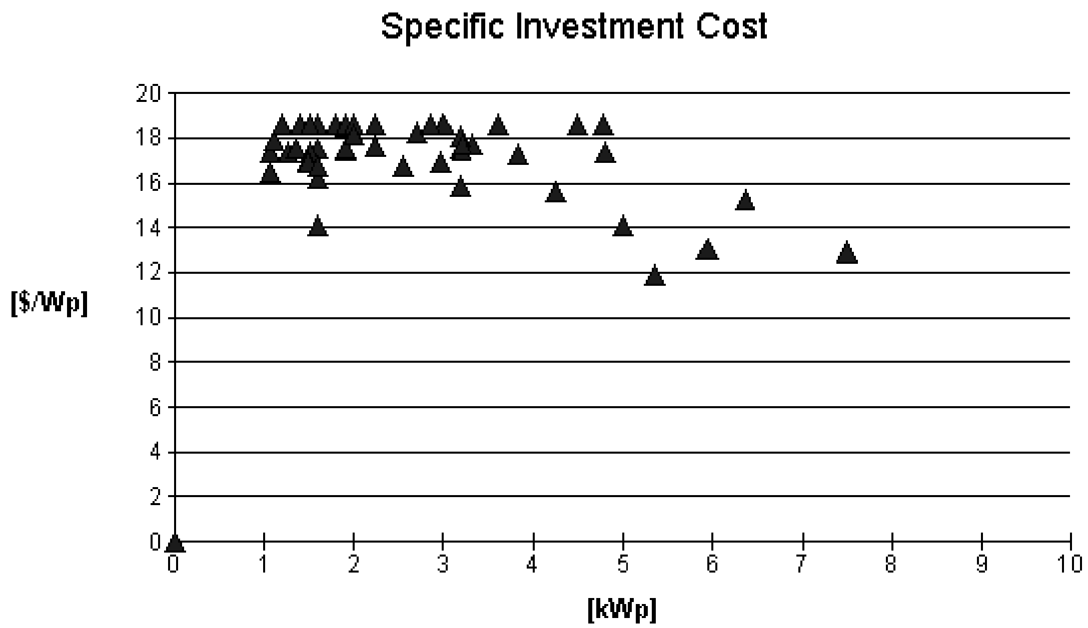


Figure 4.10: Specific investment cost for selected PV systems

Two types of summary reports, one for individual and one for multiple systems, may be produced using the PVreport programme. These tables contain calculated annual data of energy balances and indices of performances, which are listed in chapter 5, Table 5.3. In the case of an individual system, the summary report includes a selected graph from the 13 different types of presentations.

A variety of examples is given in annex D, where individual summary reports of 38 representative systems from nine IEA-PVPS countries are used to document the performance results of PV plants in the Task 2 database. The summary reports can be printed or stored in a file.

5 EVALUATION AND PRESENTATION

This report mainly focuses on the evaluation of the technical performance of the selected types of PV systems. To a great extent existing evaluation procedures are based on the European Guidelines and the IEC Standard 61724. In addition there are additional recommendations on existing guidelines at the national level, aiming to harmonize procedures on data collecting, data processing and presentation in order to facilitate the exchange and comparison of data. The increasing awareness of the importance of the PV technology and its potential has resulted in a world wide acceptance of impressive research and investment programmes.

As a result, there exists a great diversity of monitoring and evaluation reports, addressing:

- overall system balance
- performance ratio and figures
- BOS component balances and efficiencies
- normalized annual, monthly, daily representations
- graphs
- energy flow diagrams
- presentation of results

The type of evaluation strongly depends on motivations, targets, goals and intentions of monitoring. With respect to the monitoring data of the IEA-PVPS Task 2 database and the underlying monitoring programmes, an overview of the relevant and applied evaluation procedures follows.

5.1 Overview of evaluation procedures

Within the PV Demonstration Programme, managed by the European Community, Directorate General for Energy (DG XII), methods and guidelines have been developed, taking into account recommendations of the IEC and are summarized in the next section 5.1.1 „European Guidelines“. These guidelines have played an important role in the preparation and realization of the IEC Standard 61724, addressed in section 5.1.2. A short impression of additional and complementary developments is given in section 5.1.3.

5.1.1 European Guidelines

The European Guidelines for the Assessment of Photovoltaic Plants have been prepared by the European Solar Test Installation within the Institute for Systems Engineering and Informatics of the Joint Research Centre (JRC) in Ispra, which belongs to the European Commission, and with technical support from the European Working Group on PV Plant Monitoring. Also recent recommendations of IEC technical committee 82, working group 3 were taken into account. The recommendations given in the documents A, B and C have been developed to support the PV Demonstration Programme and the THERMIE Programme of the Commission of the European Community (DG XVII), while their use by others is encouraged.

The objectives of PV plant monitoring given in these documents are:

- to judge whether the design goals have been met
- to determine the performance, reliability and durability of the plant and its components
- to present the results clearly in a form that can be easily understood by the user and that is suitable for comparing PV installations of different sizes and different applications, operating in different climatic conditions
- to provide data for a general assessment of the potential of PV technology and the improvement of system design and operation

The European Guidelines imply a PV system structure, which includes PV array, DC/DC converter, DC loads, DC back-up generator, DC storage, DC/AC converter (inverter), AC loads, AC back-up generator and AC utility grid connection. Most conventionally structured PV systems can be mapped within this scheme. The European Guidelines consist of three items:

Document A: "Photovoltaic System Monitoring"
The document A addresses requirements for providing data by analytical and global monitoring, a prescribed data format for the submission of data and data processing. By the adoption of a commonly agreed minimum set of quantities, the guidelines enable reliable comparison between different PV plants. Procedures and requirements for analytical monitoring (automatic data acquisition yielding hourly averages) and for global monitoring (can be manual, yielding monthly or more frequent meter readings) are explained, including recording formats and data submission to the JRC.

Document B: "Analysis and Presentation of Data"
Procedures for analysis and presentation of monitoring data (monitored and derived parameters) are explained, including checks for data consistency and gaps, presentation of checking results, evaluation of meteorological data, energy balances (overall system and BOS components), performance indices (yields, losses and efficiencies) and presentation of the results in figures, tables and graphs. The graphs include charts of monitoring activity, irradiance and array output, a list of meteorological, energy and performance figures, a scatter diagram of hourly PV array output power versus irradiance, a bar graph of daily PV array yields and capture losses, a histogram of normalized distribution of in-plane irradiation and a histogram of normalized distribution of "useful energy" [1].

An overview of the recorded and derived parameters, applied symbols and units is available in this report in annex A, Table A – 2, second column.

Document C: "Initial and Periodic Tests on PV Plants"
The document C addresses recommendations for initial and periodic field tests and inspections of the PV array, inverters and batteries.

5.1.2 IEC Standard 61724

The IEC Standard 61724 titled "Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis" was first published in April 1998. The document has been prepared by the IEC technical committee 82, addressing solar photovoltaic energy systems. This IEC document, which is based on the European Guidelines to a great extent, expresses an international consensus on the subject of PV system performance monitoring and analysis. The document has the form of guidelines for international use published in the form of standards and is accepted by the National committees.

The document concentrates on guidelines for evaluating the performance of an array as part of the PV system. The data analysis provides a performance summary for comparing PV systems from different sites operating in different climates and hence the assessment of merits of different designs. It covers analytical monitoring with automatic microprocessor based data acquisition systems, including specifications of the measurements to be taken and of deriving performance assessment parameters.

Topics covered include normative references, measured parameters (in the groups of meteorology, PV array, energy storage, load, utility grid, and back-up sources), measurements (of irradiance, ambient air temperature, wind speed, module temperature, voltage, current and electric power), data acquisition system, sampling interval, data processing operation, recording interval, monitoring period, system maintenance logging and documentation, exchange of recorded data, check of data quality, derived parameters (irradiation, electric energy quantities, BOS component performance, system performance indices including daily mean yields, normalized losses and system efficiencies), and a suggested method of checking the data acquisition system (linear response, stability, integration and zero values) [2].

Recorded and derived parameters, applied symbols and units are presented in annex A, Table A – 2, first column, and compared to the corresponding parameters and definitions in the European Guidelines, Document B (Table A – 2, second column).

When comparing the IEC Standard 61724 to the European Guidelines, Document B, it was noted that the IEC Standard attempts to equally include energies from all sources for the assessment of the system performance.

For stand-alone systems (SAS), there are different definitions of the term E_{use} (useful energy supplied by the system). While charging batteries is neglected in the European Guidelines, the net energy to storage (E_{TS}) is included for the definition of E_{use} in the IEC document. In case of stand-alone systems, which continue charging the batteries without really using the available energy for the given application, the rating in terms of performance ratio (PR) of the SAS will give different results depending on the method used. Applying the IEC standard will give higher performance ratio values for such systems than using the European Guidelines.

For grid-connected PV systems (GCS), it was noted that the inverter efficiency has almost no effect on the performance ratio, if the net energy from the utility (E_{FU}) is large with respect to the PV array output energy (E_A). This is a weakness of the definitions (E_{IN}, F_A, E_{use}) in both documents. However, many parties are applying the European Guideline method to the PV subsystem only and neglect E_L and E_{FU} for the restricted analysis of the subsystem and thus come up with different results in terms of performance ratio (PR). This difference of up to 40 % between both approaches depends on how the system is defined.

5.1.3 Additional developments

The European Guidelines have been developed over the last eight years, are being updated regularly and are widely used. Almost any country active in the field of photovoltaics has gained significant experiences in the field of monitoring and evaluation issues and has applied these guidelines to a large extent as a basis for the development of domestic guidelines to meet specific demands. Additional and complementary developments which are relevant for the monitoring data in the IEA-PVPS database are summarized below:

- Within the **Austrian** PV rooftop programme a paper has been published on the monitoring of 110 dispersed residential roof integrated PV systems. The described monitoring systems meet the demands of specific monitoring targets by a balanced definition of global and analytical monitoring on the one hand and the required information level on the other.
- **France** has published a paper on a rather diverse data acquisition system that can be used for any stand-alone photovoltaic generator, either locally, or through different means of communication. The system provides information on the operating history of the PV system and enables real time management of available energy and the remote monitoring and control of the PV system.
- **Germany** has published a paper on performance data and focuses on additional performance evaluation features based on a statistical approach to the huge amount of data available within a central database. The paper provides detailed information on: performance ratios, efficiency values of different PV generators, and energy losses of single components within the monitored system. Present approaches to performance evaluation of stand-alone systems in terms of performance ratio are considered inadequate. In a second paper [3], a new factor, the matching factor (MF) has been introduced, which is the product of performance ratio (PR) and solar fraction (F_S). The matching factor shows how well a stand-alone system matches the electrical consumption. It features the advantages of performance ratio and solar fraction.
- **Italy** has published a paper on real time diagnostic monitoring of PV power plants in remote areas. The paper focuses on the requirements and the demonstration of capabilities of real time performance monitoring and diagnostic systems, while at the same time minimizing the off line data analysis effort.
- The **Netherlands** have developed a national guideline for grid-connected systems based on the European Guidelines. The national guideline provides complementary specifications and requirements for sensors for the measurement of physical quantities, the monitoring system, data format and data processing, recommended graphical presentation, and performance indicators.
- **Switzerland** has published a paper on "Normalized Representation of Energy and Power for Analysis of Performance and On-line Error Detection in PV systems“. The paper addresses grid-connected systems and more specifically the introduction of new quantities. It features quantities for normalized power and splitting of capture losses into thermal and non-thermal losses, hence allowing detailed on-line and off-line analysis of sporadic system malfunction.

5.2 Evaluation of performance data

All system and subsystem performance data have been evaluated in terms of operational performance and reliability. To a great extent the evaluation procedures are based on the European Guidelines, Document B, taking small modifications into account. Additional parameters are introduced for the evaluation of stand-alone systems.

Various derived parameters related to the system's energy balance and performance can be calculated from the recorded monitoring data using sums, averages and ratios over reporting periods such as months or years, but expressed in units of h/d. Derived parameters are shown in Table 5.1.

Table 5.1: Overview of derived parameters for performance evaluation

Parameter	Symbol	Equation	Unit
Array Yield	Y_A	$E_{A,d} / P_0$	h/d
Final Yield	Y_f	$E_{use,PV,d} / P_0$	h/d
Reference Yield	Y_r	$\int_{day} G_I\, dt / G_{STC}$	h/d
Array capture losses	L_C	$Y_r - Y_A$	h/d
System losses	L_S	$Y_A - Y_f$	h/d
Performance ratio	PR	Y_f / Y_r	—
Mean array efficiency	$\eta_{A,mean}$	$E_A / \int_\tau G_I \cdot A_a\, dt \cdot 100\ \%$	%
Efficiency of the inverter	η_I	$E_{IO} / E_{II} \cdot 100\ \%$	%
Overall PV plant efficiency	η_{tot}	$E_{use,PV,\tau} / \int_\tau G_I \cdot A_a\, dt \cdot 100\ \%$	%
Annual irradiation, in plane of array	$H_{I,y}$	$\int_{year} G_I\, dt$	kWh/(m²·y)
Annual array yield	$Y_{A,y}$	$E_{A,y} / P_0$	h/y
Annual final yield	$Y_{f,y}$	$E_{use,PV,y} / P_0$	h/y
Annual reference yield	$Y_{r,y}$	$\int_{year} G_I\, dt / G_{STC}$	h/y
PV array fraction	F_A	E_A / E_{IN}	—
Matching factor	MF	$PR \cdot F_A$	—
Usage factor	UF	E_A / E_{pot}	—

For the comparison of PV systems, normalized performance indicators are used. These indicators are obtained by dividing the relevant energies by the nominal power of the PV array. This feature simplifies the evaluation of performance data. The daily mean yields have units of h/d and indicate the actual array operation relative to its rated capacity.

The *array yield* Y_A represents the number of hours per day that the array would need to operate at its nominal power P_0 to contribute the same daily array energy to the system as was monitored.

The *final PV system yield Y_f* is the portion of the daily energy of the entire PV plant which is delivered to the load per kilowatt peak of installed PV array.

The *reference yield Y_r* represents the solar energy theoretically available per kilowatt peak of installed PV per day.

The normalized losses are calculated by subtracting yields. Losses also have units of h/d and indicate the amount of time during which the array would be required to operate at its nominal power P_0 to provide for the losses.

The *array capture losses L_C* are caused by operating cell temperatures higher than 25 °C (thermal capture losses) [4] and by miscellaneous causes such as:

- low irradiance
- wiring, string diodes
- partial shading, contamination, snow covering, non-homogenous irradiance
- maximum power point tracking errors
- reduction of array power caused by inverter failures or by fully charged accumulator (stand-alone systems)
- spectral losses, losses caused by glass reflections (use of pyranometers)

System losses L_S are gained from inverter conversion losses in grid-connected systems and from accumulator storage losses in stand-alone systems.

Because of the given definitions of L_C and L_S [1] (see Table 5.1), a malfunction or inverter failure in grid-connected PV plants will result in a remarkable rise of L_C. This quantity is a very good indicator for system problems occurring in grid-connected PV plants. If the grid-connected system fails completely, the values of Y_A, Y_f and PR will drop to zero, while capture losses will rise towards Y_r and system losses become negligible. Examples are described in section 6.6, where unreliable inverters and complete system breakdowns are responsible for high capture losses and relatively low system losses as shown in the performance figures of large grid-connected PV plants.

The *performance ratio PR* indicates the overall effect of losses on the array's nominal power due to array temperature, incomplete utilization of irradiation, and system component inefficiencies or failures.

The *mean array efficiency $\eta_{A,mean}$* represents the mean energy conversion efficiency of the PV array, which is useful for comparison with the array efficiency η_{A0} at its nominal power P_0. The difference in efficiency values represents diode, wiring and mismatch losses as well as energy wasted during plant operation.

The monthly or annual mean yields can be determined by using the appropriate array energy ($E_{A,m}$ for monthly or $E_{A,y}$ for annual) and the appropriate summation period ($\sum_m$ for monthly or $\sum_y$ for annual summations). The final yields Y_f and reference yields Y_r have units of h/m for monthly yield and h/y for annual yield.

The *fraction of the energy from all sources which was contributed by the PV array* is F_A. The definition is given in Table 5.1 and relevant equations are summarized in annex A – 2. For stand-alone systems without back-up energy ($E_{BU} = 0$) and grid connection ($E_{FUN} = 0$), this fraction is equal to one, because the useful energy to the loads is totally supplied by the solar irradiation and the energy flows from and to the battery are not considered ($E_{FSN} = 0$).

For all PV power stations, which take no energy from the grid ($E_{FUN} = 0$), F_A is also equal to one.

The *matching factor MF* is the product of the performance ratio (PR) and the array fraction F_A. This MF indicator was introduced with respect to stand-alone hybrid systems for a better illustration of the performance (see section 6.3.1.2). The matching factor is valuable for all hybrid systems (F_A less than one) and for grid-connected systems with a considerable contribution from the grid (F_A less than one). The matching factor indicates how the PV generated energy matches the electrical load while using a back-up contribution (SAS) or energy from the grid (GCS).

The *usage factor UF*, being the ratio of the energy supplied by the PV array (E_A) and the potential PV production (E_{pot}), has been introduced to demonstrate how the system is using the potential energy. E_{pot} is a measured energy quantity, which is equal to E_A (UF = 1) for all grid-connected systems and differs from E_A for all SAS presenting PV array disconnection due to a fully charged battery. UF values are used to highlight the different operation of SAS having the same PR and allow the detection of system problems (see section 6.3.1.3).

5.3 Presentation of results

The European Guidelines, Document B, are used as the basis for the presentation of results arising from the data in the IEA-PVPS Task 2 database. Due to the variety of the recorded data available within various demonstration programmes, the standard presentation of results had to be modified and adapted to the integrated data. An overview of the standard reports and graphs, which can be produced using the database programme (PVreport) is given in chapter 4. Depending on the different types of monitoring, data evaluation and presentation is as follows.

For global monitoring, presentation of performance data includes:

- energy quantities
- energy balances
- overall system balance
- BOS component balances and efficiencies
- indices of performance
- performance ratio and figures

For analytical monitoring, performance data may be presented in the form of:

- monthly or annual summary reports, addressing site data, monitoring period, monitoring fraction, PV array data, inverter data, nominal power, PV array area
- normalized presentation on a monthly base of energy quantities, energy balances, overall system balances, BOS components balances, indices of performance, performance ratio
- graphical presentation of meteorological data, irradiation (horizontal and in the plane of the array), irradiance distribution, array efficiency, inverter efficiency, overall plant efficiency, performance ratio figures, indices of performance (bar graph of monthly final yields, system and array capture losses)

For the presentation of performance results in this report, derived monthly and annual figures were exported from the IEA-PVPS database into spread sheet programmes to produce a variety of graphical presentations (chapter 6). Table 5.2 shows an overview of the derived performance data and the graphical presentations for grid-connected and for stand-alone PV systems. Due to the available data in the database, the scope of the presented results varies considerably from country to country.

Table 5.2: Overview of performance indicators and their graphical presentation for grid-connected systems (GCS) and for stand-alone systems (SAS)

Derived parameter	Symbol	Graphical presentation	Application
Nominal power	P_0	Distribution of P_0	GCS & SAS
Final yield	Y_f	Distribution of annual Y_f	GCS
Performance ratio	PR	Distribution of monthly and annual PR	GCS & SAS
Reference yield	Y_r	Y_f and PR as a function of Y_r	GCS
Array capture losses	L_C	Bar graph of monthly $Y_f + L_S + L_C$	GCS & SAS
System losses	L_S	Bar graph of monthly $Y_f + L_S + L_C$	GCS & SAS
Array efficiency	$\eta_{A,mean}$	$\eta_{A,mean}$ as a function of η_{A0}	GCS & SAS
Module temperature	T_m	$\eta_{A,mean}$ as a function of T_m	GCS & SAS
Overall plant efficiency	η_{tot}	Distribution of η_{tot}	GCS
Energy consumption	E_{CONS}	Distribution of $E_{CONS} = E_{IO} + E_{FU} + E_{TU}$	GCS
Solar fraction	F_S	Distribution of F_S; F_S versus E_{CONS}	GCS
Direct use fraction	F_d	Distribution of F_d; F_d versus F_S	GCS
Potential energy	E_{pot}	Distribution of monthly E_{pot}	SAS
Useful energy	E_{use}	Comparison of monthly E_{use} to E_{pot}	SAS
Matching factor	MF	Distribution of annual $MF = PR \cdot F_A$	SAS
Usage factor	UF	$UF = E_A/E_{pot}$ as a function of PR	SAS
Outage fraction	O	Distribution of O	GCS & SAS

A good summary of performance results is presented and illustrated in annex D, where 38 representative PV systems from nine IEA member countries are documented in the form of annual summary reports. This standard report for individual (and multiple) systems and for one or more operational years may be produced by using the PVreport programme. It contains general information on the PV plant and annual results of meteorology, system energies, performance indices and utility grid energies as listed in Table 5.3. One selected graph (e. g. indices of performance) for each of the 38 PV systems is included in the standard PV database report.

Table 5.3: Available parameters in the standard PV database report

General information	Meteorology	System energies	Performance indices	Utility grid
Plant name	Irradiation, horizontal	Inverter energy output	Reference yield	Energy to utility grid
Country	Irradiation, in array plane	Useful energy	Final Yield	Energy from utility grid
Nominal power	Ambient air temperature	PV array fraction	Array capture losses	
Type of plant		Energy consumption	System losses	
Mounting structure			Performance ratio	
Array area			Array efficiency	
Availability of data			Inverter efficiency	
Calculated month			Overall plant efficiency	

5.4 References

[1] Guidelines for the Assessment of Photovoltaic Plants, Document B, “Analysis and Presentation of Monitoring Data”, Commission of the European Union, Joint Research Centre, ESTI, Ispra, Italy, Version 4.3, March 1997

[2] International Standard IEC 61724 “Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis”, International Electrotechnical Commission, Geneva, Switzerland, First Edition, April 1998

[3] A. Sobirey, H. Riess, P. Sprau: “Matching factor - A New Tool for the Assessment of Stand-Alone Systems”, Proceedings 2nd World Conference and Exhibition (PVSEC´98), Vienna, Austria, 6-10 July 1998

[4] H. Haeberlin, C. Beutler: “Normalized representation of energy and power for analysis of performance and on-line error detection in PV systems“, Proceedings 13th European Photovoltaic Solar Energy Conference, Nice, France, 23-27 October 1995

6 ANALYSES AND RESULTS

6.1 Austria

6.1.1 Introduction

Since the early 1990s in Austria the installed PV capacity grew to 2.2 MWp by the end of 1997. Various research and promotion programmes are relevant here. The most important one was the 200 kW Rooftop Programme which took place between 1992 and 1994. Moreover, in recent years various other promotion models were implemented e. g. local rebate programmes, rate-based incentives, and green pricing. Furthermore, it is important to note that since 1990 total system costs of PV in Austria dropped by about 50 %.

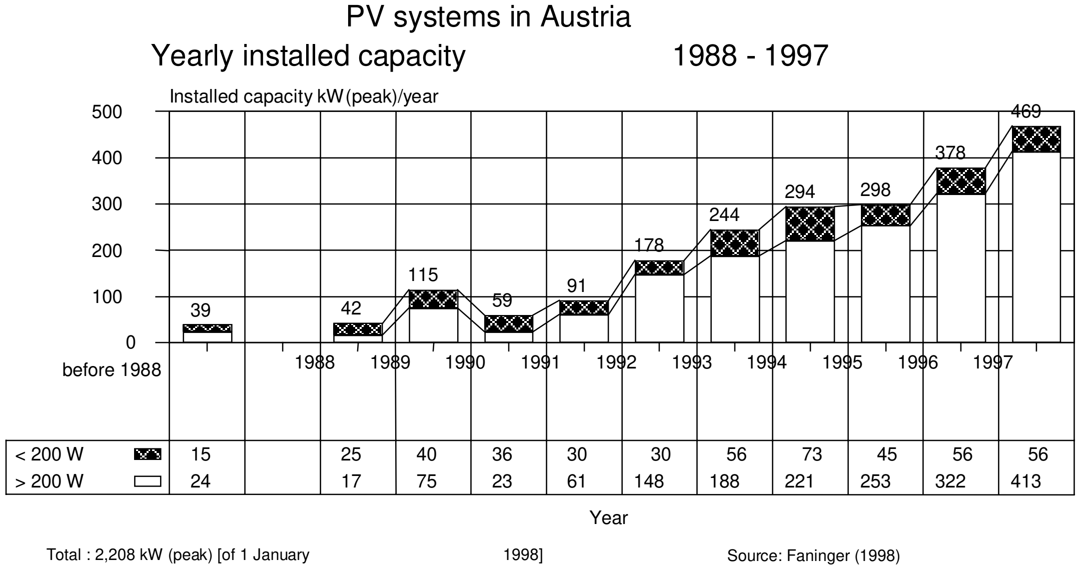
The most important research and development activities on PV in Austria were:

- Research on stand-alone systems (~1983-1988)
- Documentation of existing projects (1991)
- Pre-study for the 200 kW Rooftop Programme (1991)
- Participation in the IEA Solar Heating and Cooling Programme: Task 16 "Photovoltaics in Buildings": Three demonstration buildings were constructed in Austria (1990 -1997)
- Participation in the IEA Photovoltaic Power Systems Programme Task 1, 2, 5 and 7 since 1993
- Research project on "Technical monitoring programme within the 200 kW Rooftop Programme" (1996 -1998)
- Research project on "Socio-economic aspects of the 200 kW Rooftop Programme" (1997)
- Testing inverters for utility interactive operation (1997)
- EU Project BIMODE: Development of bifunctional photovoltaic modules for building integration (1997 -1999)
- EU Project ESDEPS: EMC and safety design for photovoltaic systems (1998 - 2001).

6.1.2 PV plants in Austria

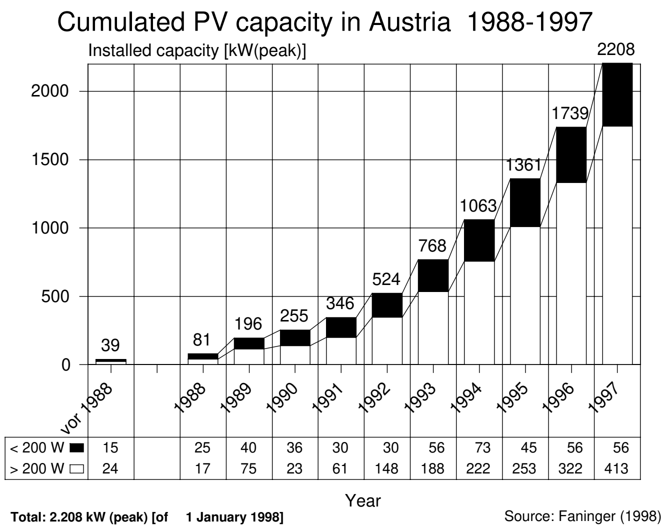
The historical development of PV in Austria can be roughly summarized as following: 1985 - 1987 - First stand-alone systems Baumgartlalm and Hochleckenhaus, 1987 - First grid-connected system Gmunden (OKA) 1.3 kWp, 1989 - First PV power plant Loser (30 kWp), 1992 - Largest PV system in Austria Seewalchen (sound barrier, 40 kWp) and 1992 - 1994 - Austrian 200 kW Rooftop Programme.

Since 1988 the installed capacity increased to an historical maximum of 469 kWp in 1997, see Figure 6.1.1. Up to the end of 1997 the total installed PV capacity run up to 2 208 kWp, see Figure 6.1.2.



	before 1988		1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
< 200 W	15		25	40	36	30	30	56	73	45	56	56
> 200 W	24		17	75	23	61	148	188	221	253	322	413

Figure 6.1.1: Yearly installed PV capacity in Austria 1988 - 1997



	vor 1988		1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
< 200 W	15		25	40	36	30	30	56	73	45	56	56
> 200 W	24		17	75	23	61	148	188	222	253	322	413

Figure 6.1.2: Cumulative installed PV power in Austria 1988 - 1997

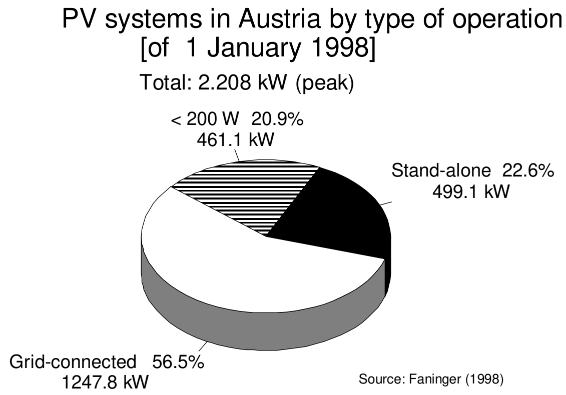


Figure 6.1.3: In 1997 in Austria installed PV systems by type of application

The most common installed type of PV system is grid-connected. Stand-alone systems are mainly installed where the electric grid is not available e. g. in huts of the Alps. Also private small huts and houses in gardens are a good market for PV.

For promoting the development and distribution of PV plants in the Austrian market a scientific monitoring programme was implemented to collect detailed PV system data. The monitoring programme enables analysis of performance data from individual systems and comparison between different data. The technical reliability of PV systems is one of the most important criteria for a broader acceptance and promotion of this technology. Only if PV systems work without problems and maintenance, can they highlight the maturity of this technology. The technical reliability of systems can be seen from the ratio between the annual generated electricity (in kWh) per kWp installed divided by the amount solar irradiation per m² (kWh/m²) of array area.

By publishing the analysed results of data and comparisons, valuable information is provided to the national manufacturers, installation companies and to IEA-PVPS members on the international level. It proves that monitoring is an effective tool to improve the performance and reliability of PV systems and components.

6.1.2.1 Grid-connected plants

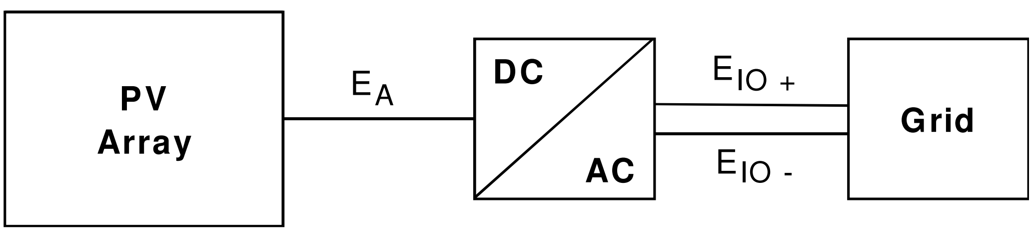


Table 6.1.1: Specifications of the selected PV systems

Plant	Array	Inverter	Annual final yield [h/y]
1. Grazer Stadtwerke	• 2 kWp = 40 modules of Siemens M55 • Flat roof mounting • Tilt: 45°, • azimuth: 13° south east	• Siemens • P_0 = 2.5 kWp • η_I = 86 %	• 1993: 830 • 1994: 853
2. House of the Future (Energie AG) • 1 plant is installed on the roof of the house	• 1.073 kWp = 4 modules of Pilkington • Roof integrated, part of an hybrid collector	• Fronius	• 1997/8: 845
• 1 plant is installed on the roof of the garage	• 2.4 kWp Kyocera • Flat roof mounting	• Fronius	• 1997/8: 898
3. House Weiß (Arbeitsgemeinschaft Erneuerbare Energie, Gleisdorf)	• 2 kWp = 40 modules of Siemens M50L • Laminate • Tilt: 35°, • azimuth: 30° west		• 1993: 810 • 1994: 806 • 1995: 802 • 1996: 597 • 1997: 795

Some remarks about the specifications of the selected PV systems:

Grazer Stadtwerke – an utility of the capital of “Bundesland” Steiermark – has installed a demonstration PV plant with monitoring system as part of the “Graz Roof Programme”. The solar generator is mounted on the flat roof of the central utility garage and has been working since 1993.

“House of the Future” of Energie AG was designed by the Norwegian/Austrian architect Sture Larsen. It was built in the period between 1996 and April 1997. The idea was to use prefabricated wooden building elements with very good insulation to drastically reduce the heating load. The house contains several renewable energy technologies like the two PV plants in Table 6.1.1, air collectors and thermal storage as well as a ground coupled heat pump. The house was one of the main attractions of the “1997 Garden Exhibition” in Schmiding (Upper Austria). Since 1st of October 1997 the operational behaviour of the building and the final yield of the PV plants have been monitored.

A 2 kWp PV plant is installed on the roof of “House Weiß”, which is supplying nearly the complete requirement for electricity of the one family household. The PV system was promoted within the Austrian 200 kW Rooftop Programme and was one of the demonstration objects in the successfully completed IEA Programme of Solar Heating and Cooling, Task 16, Photovoltaics in Buildings. Therefore and because of the interest of the owner the plant of “House Weiß” is one of the best long-term monitored PV systems in Austria.

6.1.2.2 Stand-alone systems

The largest number of installations is represented by stand-alone systems. In many cases, they are combined with another source of generation such as diesel or wind. Some particular initiatives of measurements were started, but a generalised public monitoring programme or data collection effort does not exist in Austria.

6.1.3 Monitoring and measurements

The greatest national public initiative of measuring and monitoring in the field of PV was carried out by the ministry of science and research accompanying the Austrian 200 kW Rooftop Programme.

6.1.3.1 Standard measuring programme

One of the conditions for participating in the PV Rooftop Programme was the operator’s willingness to take part in a measuring programme, which is performed under standard conditions by an architects/ engineers consultant company in St. Pölten (KWI). Every owner of a PV system is obliged to read and transmit three parameters on a monthly cycle over a period of five years. The relevant parameters are:

- PV energy output,
- energy delivered from the utility grid and
- energy supplied to the utility grid.

The operator transmits the data to the consultant KWI, who then determines the monthly values of the solar power fraction that is directly used in the specific household, the share of the household’s energy consumption covered by solar energy (solar coverage) and the surplus solar energy that is fed into the grid. Furthermore, the consultant KWI reports to the supporters and operators of the PV systems.

6.1.3.2 Intensive measuring programme

In order to carry out monitoring, a measuring device is installed at the PV plant. This measuring device locally registers the daily characteristics and derived values. The interesting values are the efficiencies of PV solar generators and inverters, the reliability of the system and components as well as the solar coverage. The measured values in detail are:

- horizontal and inclined irradiation,
- voltage, current and electrical power of the PV array,
- ambient air temperature and module temperature of the PV array,
- inverter power output and
- energy consumed from the grid and fed into the grid.

The values are collected from plants of different configurations and from installations of different locations with varying climatic conditions like plains, mountains or valleys. The measuring equipment consists of pyranometers (horizontal and built in the plane of the module), transducers behind the PV generators and the inverters as well as consumption supply meters. The values are registered by the data logger every minute. Data of 15-minutes averages are then produced, stored in a memory and finally transmitted by modem to the central computer at Arsenal Research, a centre for research and testing in the fields of renewable energy and energy efficiency, constructing and environmental matters in Vienna. Here the data are processed and transformed into an international readable standard. To avoid measurement failures because of sudden changed voltages and currents the plausibility of transmitted data is automatically checked. Finally the results are sent to a mailbox for external users to be integrated into national and international evaluation programmes.

6.1.4 Results

The Austrian monitoring and measuring initiatives (public as well as private) delivered a useful collection of information for developing solar strategies and new programmes for the installation of PV applications.

Grid-connected installations are able to reach yearly performance ratio (PR) values higher than 0.7, especially in Alpine regions, while facade projects have shown that the monthly PR can be in a range from 0.35 - 0.4 in summer and 0.55 - 0.7 in winter. In Figure 6.1.4 and Figure 6.1.5 you can find some typical performance values of selected Austrian plants.

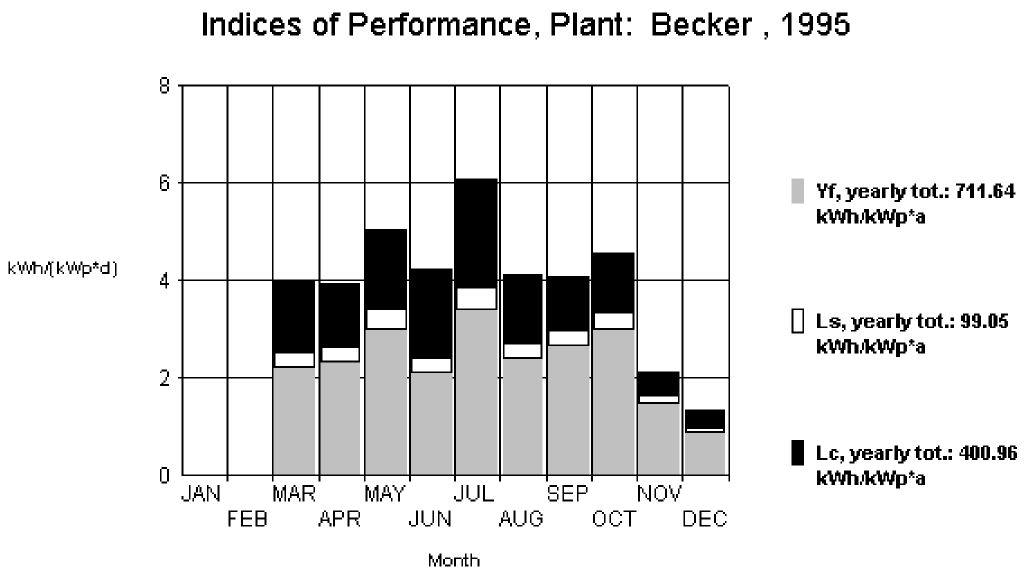


Figure 6.1.4: Indices of performance (Becker, Austria)

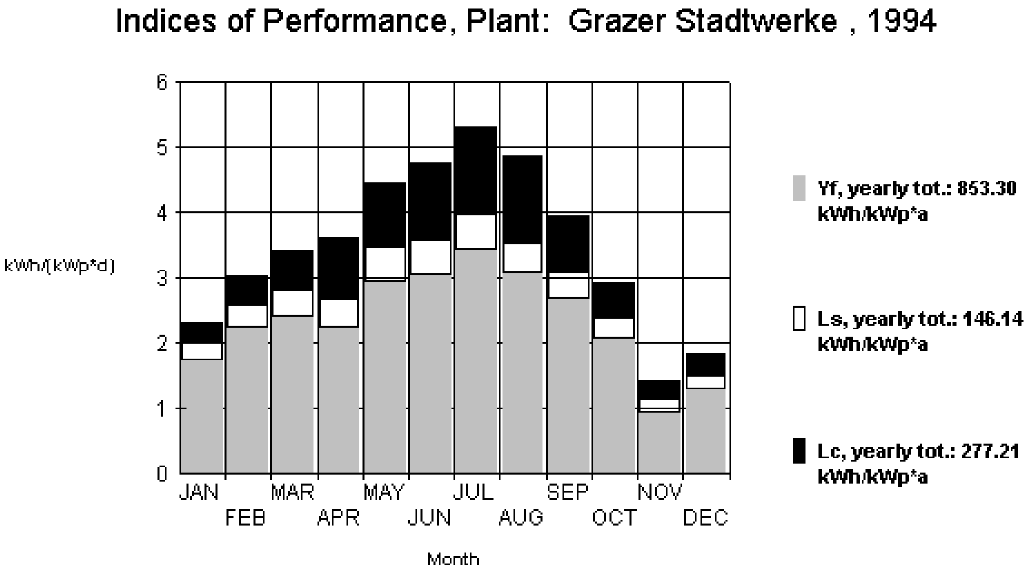


Figure 6.1.5: Indices of performance (Grazer Stadtwerke, Austria)

One result of the PV system monitoring is that the annual final yield is in the range of 400 h/y to 800 h/y for six selected plants in 1995. The annual yield is depending on location, azimuth and tilt of the PV systems as well as on local climate. Corresponding to the large deficits of final yield for plant No 3 and 4 (Figure 6.1.6), the annual performance ratio (PR) deviates from typically PR = 0.55 to PR = 0.4. 1997 was a year with low irradiation figures. The range of annual final yield for five selected plants of that year is corresponding to the variation in irradiation for the different locations (Figure 6.1.7).

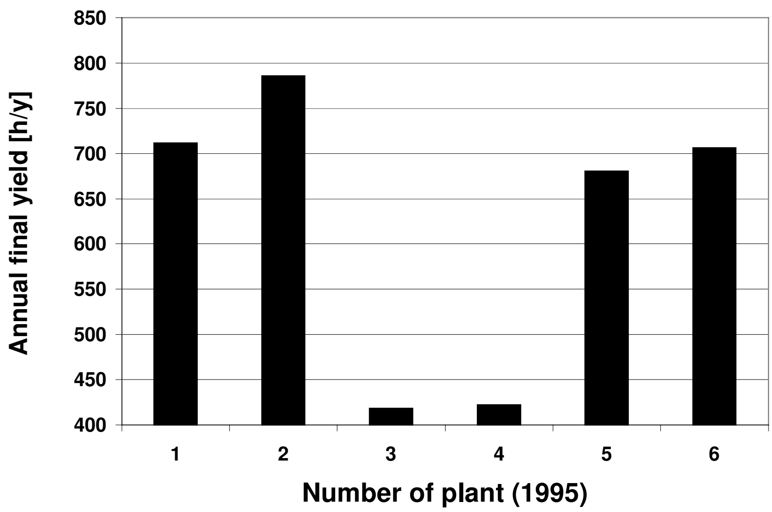


Figure 6.1.6: Annual final yield for six grid-connected PV systems in 1995

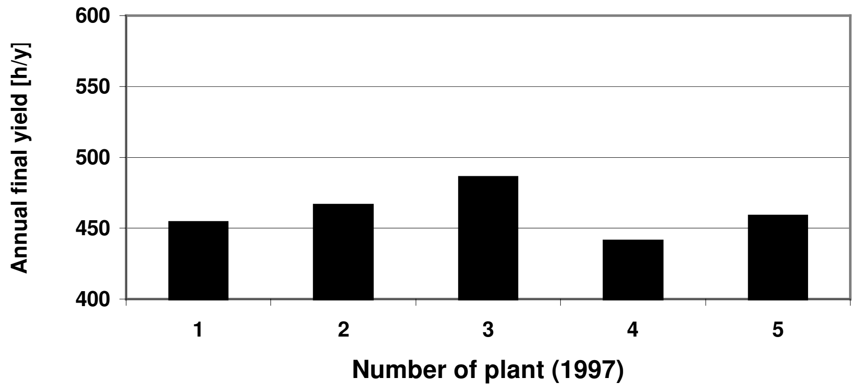


Figure 6.1.7: Annual final yield for five grid-connected PV systems in 1997

6.1.5 Conclusion

The analysed results of the monitoring data and comparisons were published and provided to the national manufacturers, installation companies and to IEA-PVPS members. This has led to a continuously increasing energy yield of new PV installations in the last few years. The overall performance could be improved by optimizing several factors as well as avoiding failures. One reason for the progress is the continuous monitoring and evaluation of PV systems under various circumstances and environmental conditions. People in the field of photovoltaics can benefit from the experiences of an international expert group, who analyse the monitoring data and publish the results and recommendations for the PV system designer. Manufacturers of PV components such as modules or inverters are looking for reliable data and performance results from an independent source in order to prove the reliability of their products.

6.2 European Union

Within the European Photovoltaic Demonstration, vast experience can be gained from analytical monitoring of more than 80 systems in a wide application range with an installed capacity of over 2.4 MWp. Since 1984, monitoring has provided feedback to system operators and thus developed into a key element for good maintenance, which is crucial for supply quality, economy and user satisfaction.

Following the first MW of photovoltaic power installed in the PV pilot plant programme of DG XII between 1982 and 1984 with 15 PV plants in sizes between 30 kWp and 300 kWp, the PV Demonstration Programme of DG XVII has established more than 150 projects extending installed power to over 7 MWp. The monitoring database has been continuously influenced by the European Working Group on PV Plant Monitoring which resulted in improvements of the file format and finally in a stable new unified file format. In combination with extended guidelines, this will also allow inclusion of more recent system structures with module and string related inverters and AC parallel power conditioning.

In the beginning there was much concern about the impact of mismatch losses on the output of larger PV systems and emphasis was on the on-site measurements of the PV array current versus voltage characteristics. By means of a portable switched capacitor load sub-arrays and even single modules could as well be measured.Using extrapolation to the standard test conditions of 1 000 W/m^2, 25 °C and a global spectrum corresponding to air mass 1.5, characteristics could be obtained within 5 % tolerances compared to the standard in-door module measurements. Normalized monitoring data is allowing direct comparison of systems of most different sizes.

With the high reliability and quality of modules, system aspects and the aquisition of operational data became more important and at the same time, the initially high prices for the monitoring equipment decreased considerably.

In the typical course of commissioning a PV project with the final phase is an acceptance test, that verifies the installed PV power and proper plant functioning. From then on, on the basis of hourly data, performance monitoring allows continuous analysis of performance and control of supply quality. If no on-site diagnostic tests become necessary as for malfunction or further checks, the obligatory monitoring period can be finished after two years with a final test which is identical to the acceptance test and allows quantification of the influence of ageing.

In addition to the direct use of the monitoring data for analysis and management of plant performance and supply quality - including the recording of information for trouble shooting - there are further aspects:

- evaluation of economics,
- optimization of the steering methods and
- improvement of design and sizing,

which are of interest not only for the single plants, but also for groups of plants under common organization in order to derive more general insights into system behaviour and properties.

The monitoring coupled to the PV system delivers data as defined in the monitoring guidelines which are then converted into the new unified file format (NUFF) by a specific data conversion. Accessing the NUFF Database, performance analysis and reporting follow a unified method for all projects. They are providing feedback to the system operators in order to assist them in maintenance, improvement in plant operation and possibly in re-design, e. g. following increases in load demand.

Rapid progress in signal processing and in power conditioning with new power semiconductors and microcomputer control together with trends to higher switching frequencies and miniaturization, are continuously increasing performance and decreasing prices. For photovoltaic power supplies, the basic trends in systems technology:

- parallel power conditioning with splitted PV rail,
- advanced internal and external communication and
- grouping of systems into supply structures

are changing monitoring. As a consequence of parallel power conditioning with module and string related inverters, the independent monitoring obviously has to be limited. It must however remain in line with the minimal monitoring that is required for the guarantee of results. This needs at least measurement of in-plane irradiation together with metering of supplied kWh and counting of supply availability time over longer periods.

With increasing use of cabled and wireless fieldbuses within the PV systems there is no additional hardware required to access data as measured internally in the components. Defining an acceptable dataset for monitoring makes it necessary to adjust it to the independently acquired data. Common line voltage and frequency can thus be accomplished by active and reactive power currents of each component, supplemented by DC-side values in order to determine losses in power conversion.

The trend to group systems once more emphasises the need to integrate remote monitoring by using general communication structures. With respect to short term updates of monitoring data this especially opens the way to common operation/maintenance/repair infrastructures.

In order to follow the main identifiable trends in systems technology, monitoring will be developing towards decrease of independent monitoring, increase in use of system-internal data via fieldbus coupling and communication over longer distances for remote monitoring.

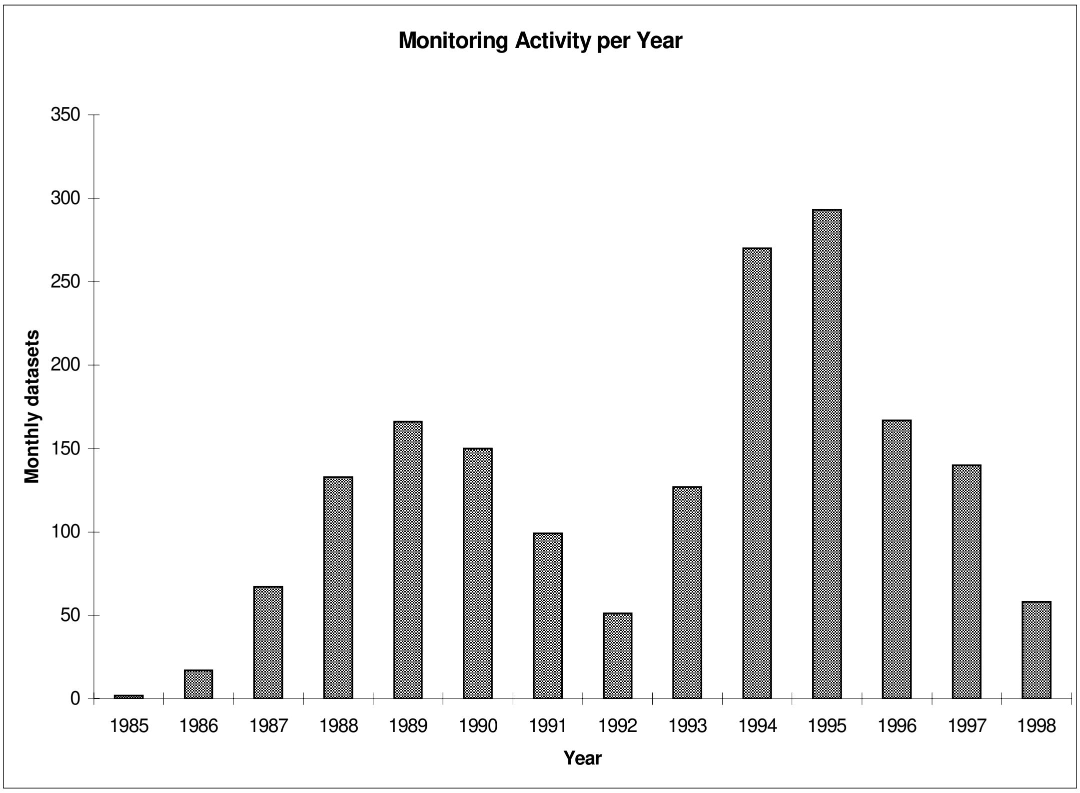


Figure 6.2.1: Monitoring activity per year (EC)

6.2.1 References

[1] Guidelines for the Assessment of Photovoltaic Plants, Document A - Photovoltaic System Monitoring, June 1993

[2] Guidelines for the Assessment of Photovoltaic Plants, Document B - Analysis and Presentation of Monitoring Data, June 1993

[3] Blaesser, G., Jantsch, M.: "Converting the European PV Monitoring Database into the New Unified File Format", 13th European PVSEC, Nice 1995

[4] The Future for Renewable Energy - Prospects and Directions, EUREC-Agency, James & James, London 1996

6.3 France

Within the frame of the IEA-PVPS programme Task 2 has been devoted to the analysis of the operational performance of PV systems.

The objectives of such work are to give PV experts or target groups information on:

- data on operational performance (energy balances, yields, efficiencies)
- the comparison between systems performance
- data on failures (weak components, origin of the failures)
- costs (cost distribution between components)

Most of the effort dedicated to this work has been devoted to the selection of systems to be put in the database and to the analysis of their performance in order to extract from them relevant information on systems operation for future improvements.

France has focused its efforts on stand-alone systems (SAS) extracted from Ademe / EdF rural electrification programmes and Thermie ones. Nearly 40 PV systems from the metropolitan France and the overseas islands were collected representing about 55 datasets which have been split into two categories:

- domestic systems for rural electrification
- professional systems

For each category the performance analysis has been conducted leading to specific results giving a short overview about what results can be expected in terms of performance. A conclusion will highlight the points which have to be dealt with in greater depth to lead to recommendations namely on system sizing.

6.3.1 Domestic PV systems for rural electrification

The analysis presented here under has been carried out on 27 PV systems representing 43 annual datasets. The peak power of the considered installations varies between 450 Wp and 1 500 Wp as shown in Figure 6.3.1.

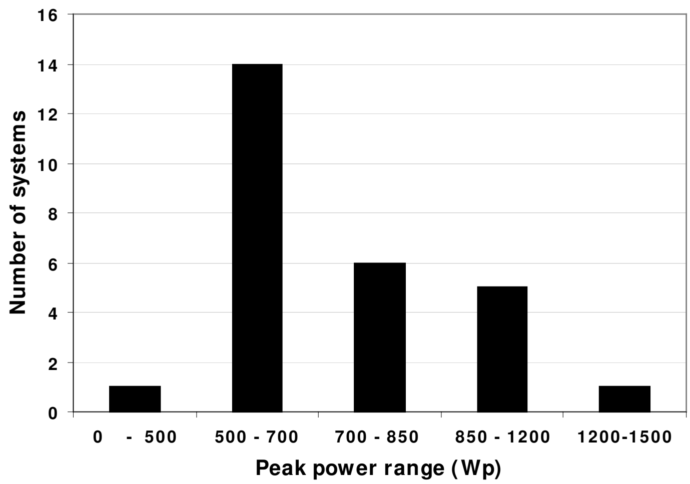


Figure 6.3.1: Range of nominal power for the selected systems

6.3.1.1 Performance ratio (PR)

The performance ratio (PR) was introduced to characterize the system operation whatever application is considered. It figures out how the potential energy of a PV system is used. This potential energy is defined in Standard Tests Conditions.

The higher the PR is, the better the system uses its potential. A low PR value means production losses due to technical or design problems.

In stand-alone systems (PV only), a high PR value does not always mean that the system is operating in the best conditions. If the system is under designed for the considered application, the PV system will show a very high value of PR, but at the same time the user will not be supplied with electricity.

An oversized system will have to face frequent array (partial or total) disconnection affecting directly the PR value.

All the 27 PV systems considered in this section have a back-up generator which in most cases was already on-site before the PV electrification. However, these stand-alone systems have never been sized as hybrid systems. The reference to hybrid systems only means in this section that during solar energy deficit, the user has to use the back-up. The reference to PV only means that no back-up generator has been used.

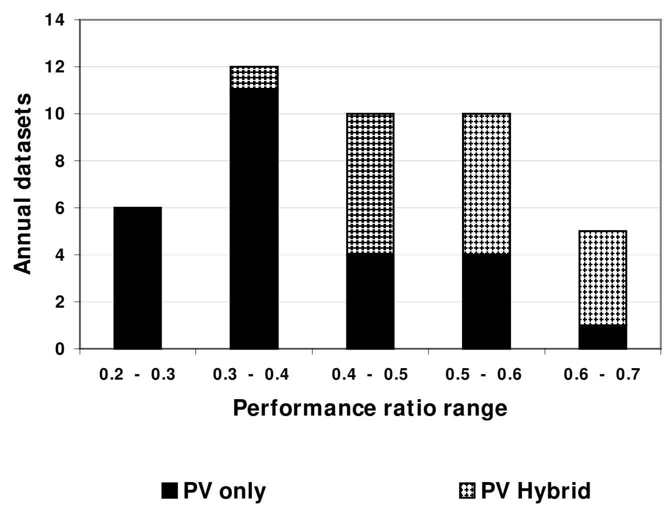


Figure 6.3.2: Range of yearly performance ratio for typical domestic SAS

The analysis of the systems performance in terms of PR (Figure 6.3.2) shows that SAS present a wide range of PR which does not reflect the proper operation of a system from a technical point of view (component degradation, low efficiency components) as is the case for grid-connected systems.

The value of the PR is user consumption dependent. If the consumption level is not correlated to the potential of the PV generator, the PR will reach values which can be less than 0.2 on a monthly basis. Such a low PR value is due to high array capture losses. Detailed presentation of results for selected PV systems in annex D (section D – 3) clearly illustrates this point.

Hybrid systems characterized by the use of the back-up generator, as stated earlier, can show good performance if the consumption level matches quite well with the potentiality of the PV generator (Figure 6.3.3).

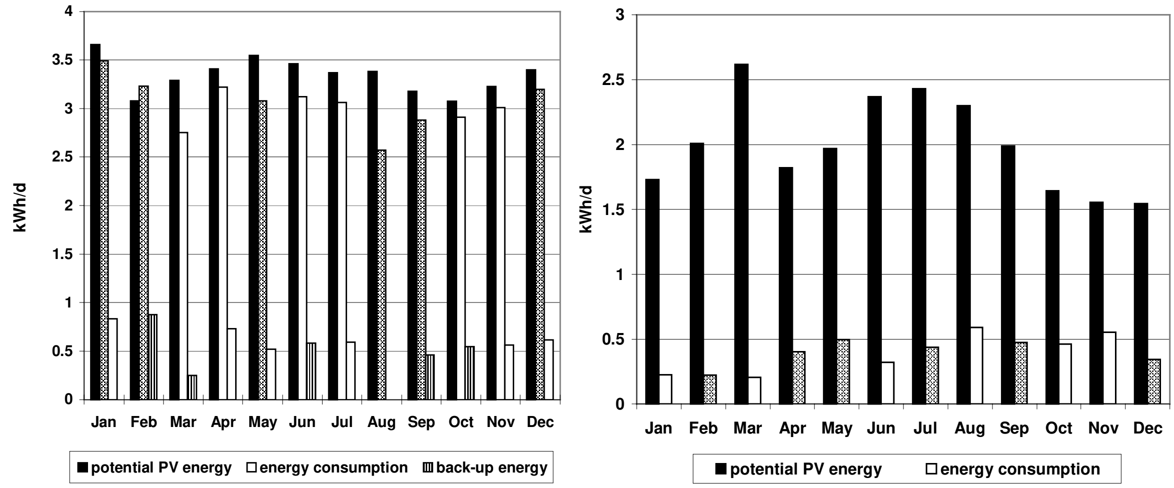


Figure 6.3.3: Consumption level measured in two different systems (PR = 0.65 and PR = 0.2)

However, it has to be pointed out from Figure 6.3.2 that a well designed PV only system can present yearly PR values up to 0.6 overcoming 0.7 on a monthly basis.

6.3.1.2 Matching factor (MF)

The matching factor (MF) is calculated by multiplying the PR with the array fraction (FA). This array fraction equals 1 for PV only SAS and decreases as the use of the back-up system increases.

The introduction of the matching factor allows a better illustration of the performance of hybrid systems. A high value of the MF indicates that the solar part properly matches the electrical load while limiting the back-up contribution.

Annual MF in the range 0.2 to 0.6 were achieved highlighting better performance of hybrid systems in general in comparison to PV only SAS (Figure 6.3.4). Nevertheless the considered hybrid systems have not been designed as such, but as a juxtaposition of two sources (PV solar and conventional). The wide MF range demonstrates that an optimization in the design phase is always needed. The maximization of MF provides a basis for more work regarding sizing rules of hybrid systems.

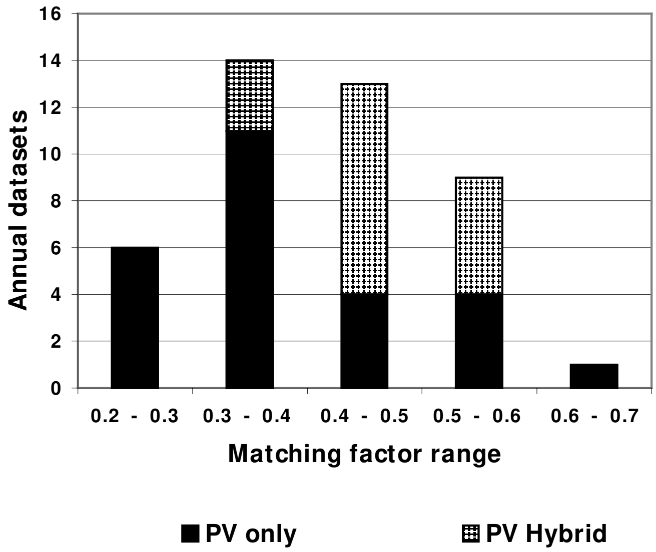


Figure 6.3.4: Range of yearly matching factor for typical domestic SAS

6.3.1.3 Usage factor (UF)

A SAS which is not operating properly will show a low PR. But as has been demonstrated this is not reciprocal. In order to have an idea on how the system is using the potential solar energy, a new factor has been introduced, defined as follows:

Usage factor = Energy supplied by the generator/ potential PV production

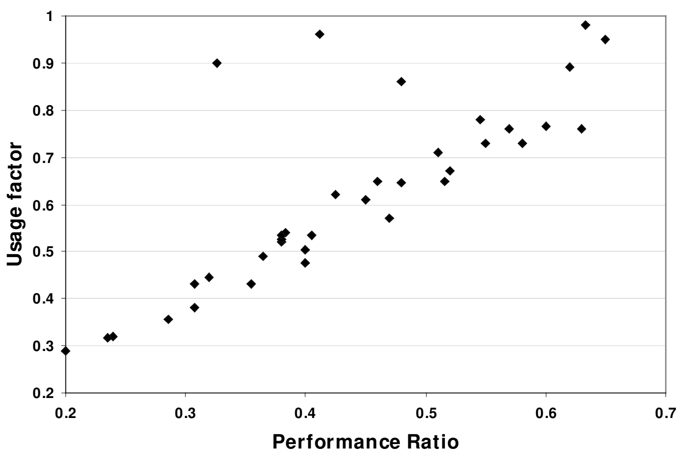


Figure 6.3.5: Yearly usage factor and performance ratio for typical domestic SAS

Figure 6.3.5 shows the variation of the usage factor as a function of the PR. This figure indicates that for most systems the usage factor is more or less a linear function of the PR. The better the system uses its solar potential, the higher the PR is.

However there are three systems which are outside this linear tendency. When analysing their operation characteristics, it can be seen that for these peculiar systems, the system losses are abnormally high.

Indices of performance for two systems presenting the same PR value (PR = 0.3) but very different UF (UF = 0.45 and UF = 0.9) are illustrated in Figure 6.3.6. This figure highlights the difference of operation of these systems and demonstrates that using such a representation allows easy detection of the systems which present technical problems.

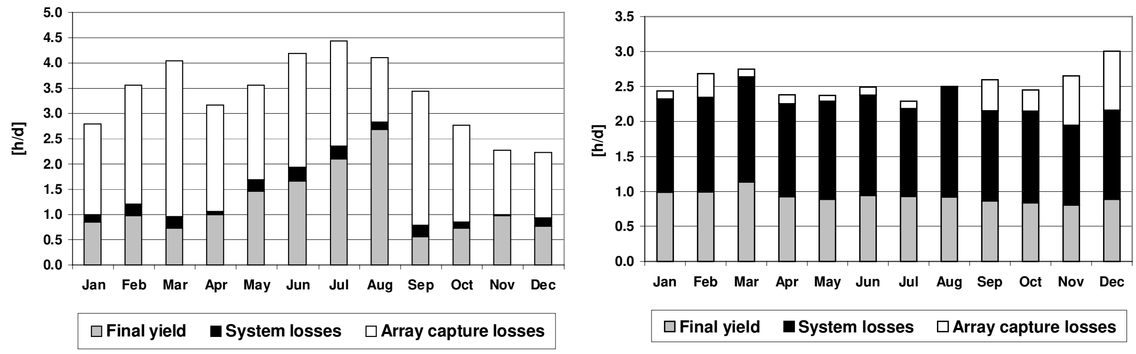


Figure 6.3.6: Indices of performance for two systems with PR = 0.3 (UF = 0.45 and UF = 0.9)

6.3.2 Professional PV systems

The analysis presented below has been carried out for ten PV systems corresponding to 19 annual datasets in this section. The peak power of the considered installations varies between 300 Wp, 1 600 Wp for sheepfolds and Alpine huts and 2 200 Wp for telecommunication relays.

The analysis of the systems' performance in terms of PR (Figure 6.3.7) shows that SAS designed for professional applications present very low values of PR which does not reflect the operation of a system from a technical point of view (component degradation, low efficiency components) but which is the consequence of a conscious oversizing for reliability reasons.

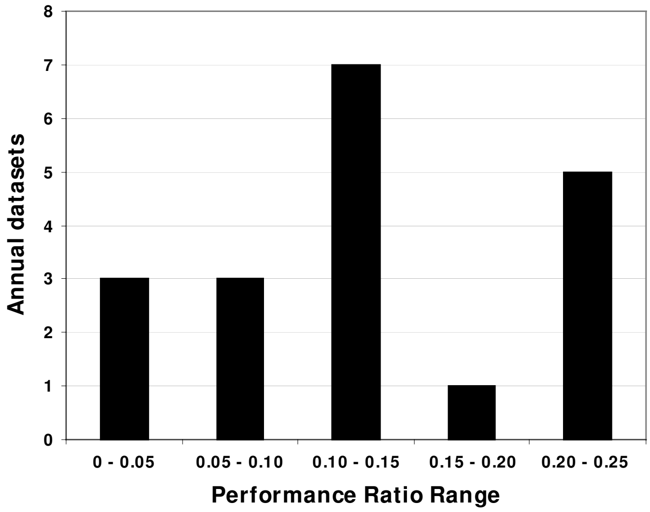


Figure 6.3.7: Range of yearly performance ratio for professional SAS

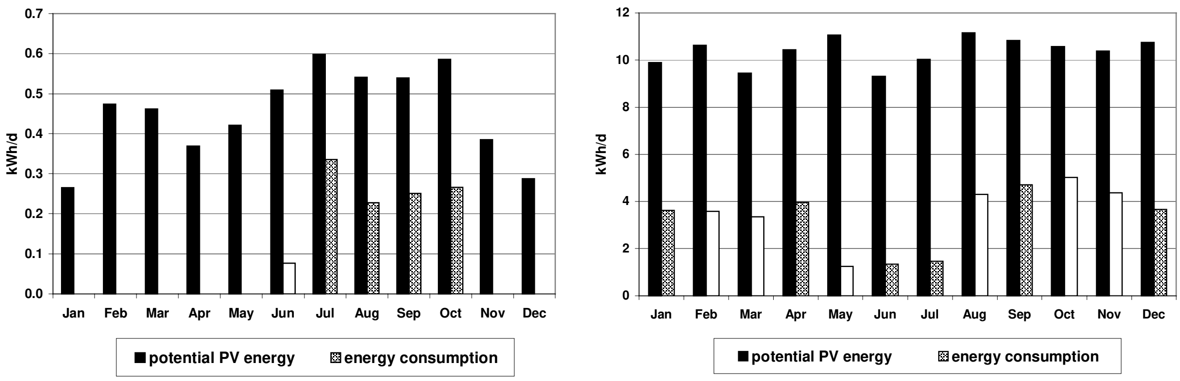


Figure 6.3.8: Consumption level and load profile in two different applications (Sheepfold (left) – Telecommunication relay (right))

Figure 6.3.8 illustrates how low PR values can be obtained in the case of two very different applications. On the left, the PV system is sized for only several months of utilization per year showing a PR of about 0.35 to 0.4 during these months. On the right, the system is oversized for reliability reasons (PR = 0.2).

For professional applications, the specifications are different from one application to another so the comparison between system performance is not very relevant especially in front of so few examples.

6.3.3 Conclusion

The analysis of data coming from on-site installations has shown interesting results concerning the operation of SAS.

It shows that contrary to grid-connected systems, the PR alone cannot be used to describe the operation of SAS from the technical point of view.

Achieving greater detail will necessitate:

- More detailed and more reliable monitoring campaigns, which are at present feasible even for small remote systems with the development of integrated data loggers.
- Several years of measurement to better appreciate the evolution of user behaviour over time.
- The use of simulation tools to evaluate the influence of new component sizes or new regulation strategies to increase the system performance.

The objectives are:

- to identify the relevant factors for a quick performance evaluation and if needed SAS systems ranking procedure
- to come up with recommendations or guidelines on sizing either PV only or PV hybrid systems to improve SAS performance

6.4 Germany

6.4.1 Introduction

In recent years, Germany has executed important programmes in the field of photovoltaics, for example the Monitoring and Documentation Programme and the 1 000-Roofs-Photovoltaic-Programme, which have triggered remarkable results in market development and technology progress. The 1 000-Roofs-Photovoltaic-Programme was initiated to build up considerable practical experiences in electrotechnical and architectural requirements for utilization of grid-connected roof PV systems. This programme was supported by the Federal Ministry of Education, Science, Research and Technology (BMBF) and the governments of the Federal States.

In the 1 000-Roofs-Programme, about 2 000 PV systems with a total installed power of 5.3 MWp were put into operation between 1991 and 1995 (average system size 2.64 kWp). The PV systems are mounted onto the roofs of one- and two-family houses with peak power between 1 kWp and 5 kWp. A broad spectrum of system configuration is covered. Systems are integrated into inclined roofs, installed on the roofing and mounted free-standing on flat roofs. The PV arrays are installed at different tilt angles (0° up to 65°) and orientations (facing east to facing west) and are located all across the country at different latitudes (48° up to 52°). All systems are grid-connected and have no energy storage such as batteries. The PV systems feed the electric energy into the house distribution system using DC/AC inverter, or, in case of excess, into the utility grid. In case of energy demand which cannot be covered by the PV production, the energy for the household appliances is drawn from the utility grid.

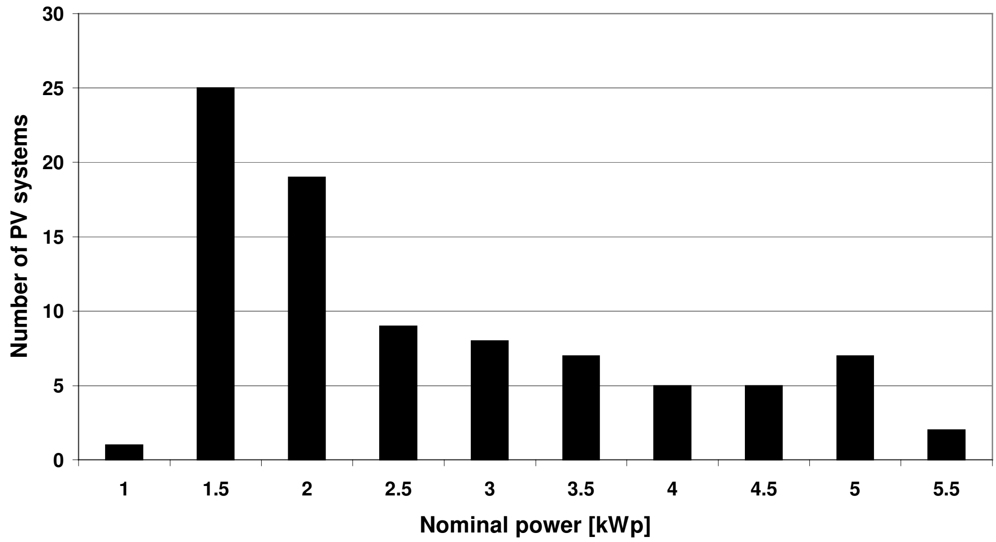


Figure 6.4.1: Frequency distribution of installed nominal power for 88 German PV systems in the IEA-PVPS database

From this programme, 88 grid-connected PV systems and corresponding datasets from the years 1993 to 1996 were collected and imported into the IEA-PVPS database. Figure 6.4.1 shows the distribution of the nominal power of these 88 grid-connected systems ranging from 1 kWp to 5.5 kWp with an average system size of 2.56 kWp.

To analyse the system performance and to evaluate the PV contribution to the electricity supply, all PV systems within the 1 000-Roofs-Programme were subject to a monitoring and evaluation programme. This was the first analysis programme with such a large number of similar PV systems being monitored and analysed with identical monitoring systems according to uniform criteria. In an intensive monitoring programme, data at five-minute-averages have been acquired from 100 PV systems spread over the entire country. 40 of these 100 PV systems have been included in the IEA-PVPS database. The other 48 PV plants chosen for the IEA-PVPS database are selected systems from the standard monitoring programme, which was conducted for all of the 2 000 PV plants. The criteria for the selection were an even distribution of plant locations, a large variety of system components and types of mounting as well as a high availability of the PV system data. The annual datasets of the 88 PV systems in the IEA-PVPS database range from one to four years of operational data resulting in 207 years of operation. This section focuses on the analysis of the operational performance of the systems in the database (6.4.2), the interpretation of selected results (6.4.3) and on the PV energy contribution to the energy supply (6.4.4).

6.4.2 Selected results

6.4.2.1 Yields and performance

The average annual yield of the German PV systems in the IEA-PVPS database is about 700 kWh/(kWp·y) as shown in Table 6.4.1. In the following the unit of annual mean yields is written in [h/y] in accordance with the IEC Standard 61724. The average yield calculated from a relevant number of systems appears to be rather constant, except for significant differences in the solar irradiation: 1995 was a year of higher irradiation, while 1996 was a year with low irradiation in Germany. However, there is a very large variation of the annual final yields for all the 207 years of operation as shown in Figure 6.4.2. The final yields range from 400 h/y up to 950 h/y, which is significantly higher than the variation in irradiation. Correspondingly, the annual performance ratio (PR) for 207 years of operation varies from 0.4 to 0.82 as shown in Figure 6.4.3. Annual PR values of 0.8 and higher can be achieved by performing PV systems, but this figure is missed by 90 % of the evaluated systems.

Table 6.4.1: Evolution of mean final yields and performance ratios over four years of operation

	Number of evaluated PV systems	Mean of Annual Final Yield [h/y]	Mean of Performance Ratio
1993	48	640	0.67
1994	48	679	0.66
1995	37	717	0.65
1996	74	697	0.68

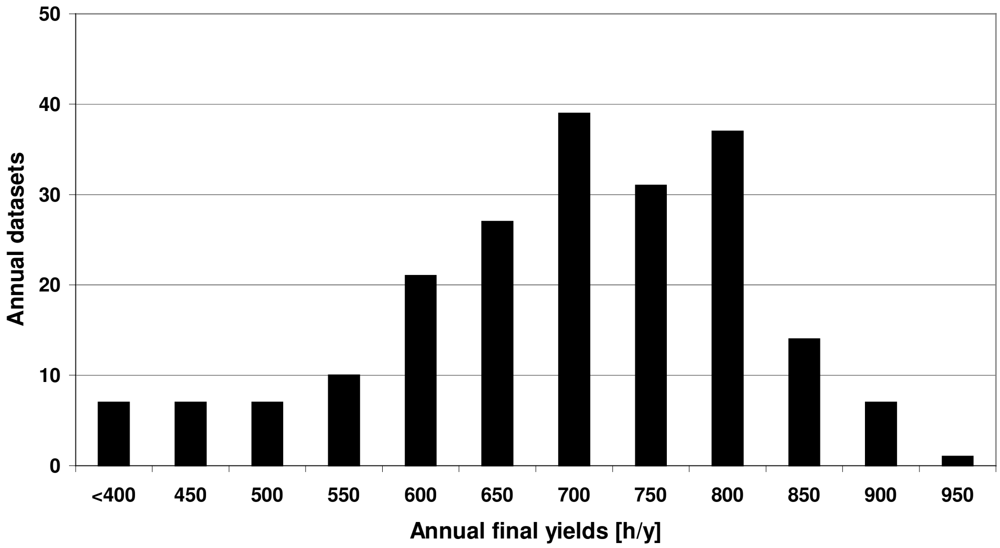


Figure 6.4.2: Frequency distribution of annual final yields for 88 grid-connected PV systems with a total of 207 years of operation (1993 - 1996)

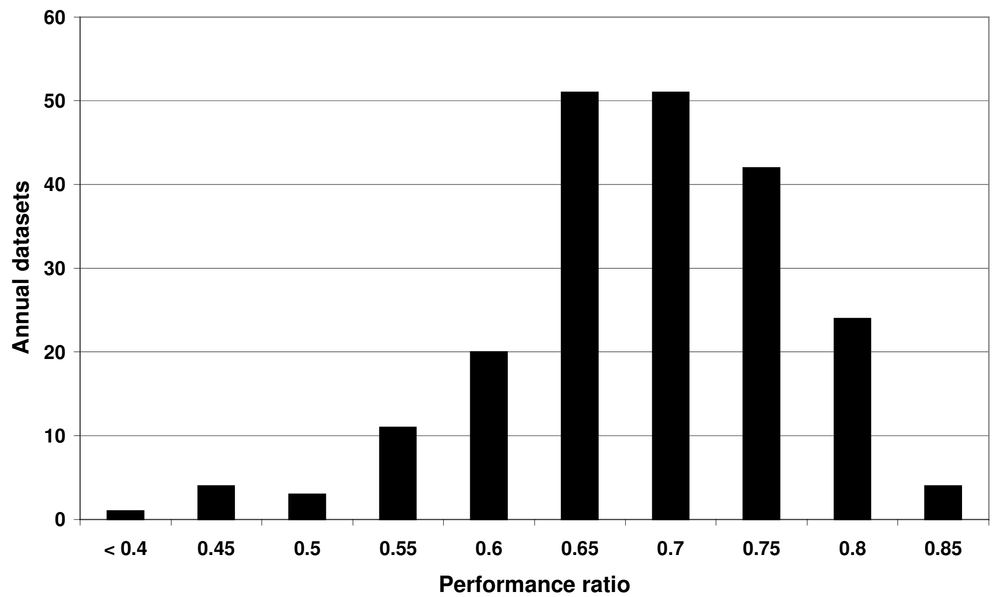


Figure 6.4.3: Frequency distribution of annual performance ratio for 88 grid-connected PV systems with a total of 207 years of operation (1993 - 1996)

The average of the mean annual performance ratios for the years 1993 to 1996 is PR = 0.67 (Table 6.4.1) and thus 16 % lower than achievable PR values of PR = 0.8. The reasons for this large discrepancy between optimum yield and performance ratio, and average final yield and PR values cannot sufficiently be explained by

- different irradiation due to different locations or
- different array orientations (less than optimum).

Figure 6.4.4 shows annual final yields Y_f as a function of irradiation in the plane of the array H_I for 74 systems operating in 1996. The Y_f values depend on the irradiation sum, but the large variation around the mean (linear trend) is obviously determined by other factors (see section 6.4.3). Even for systems receiving very low irradiation due to bad array orientation, some PV systems may achieve performance ratio values higher than PR = 0.7. An example is given in Figure 6.4.4, where one system with non-optimal array orientation (tilt angle = 52° and azimuth = + 63° west) and low annual irradiation sum of H_I = 772 kWh/(m^2·y) reaches an annual final yield of Y_f = 558 h/y and a PR value of 0.72 (Figure 6.4.5).

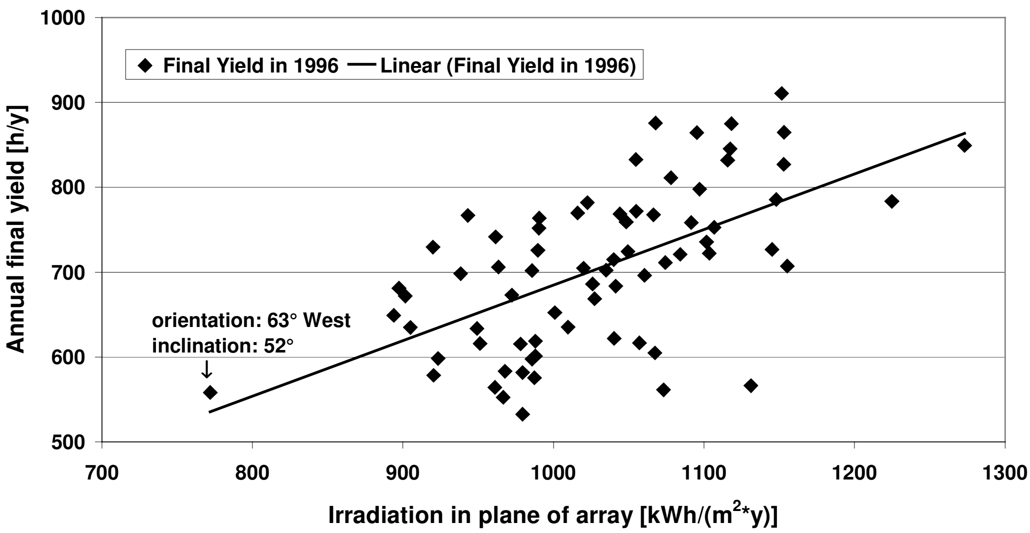


Figure 6.4.4: Large variation of annual final yields for 74 PV systems in 1996. The statistical mean of the final yield is a linear function of the irradiation in the plane of the array.

Figure 6.4.5 shows the corresponding annual performance ratio as a function of the irradiation in plane of array. The variation of the PR values is large; the mean variation is independent of the irradiation in plane of array.

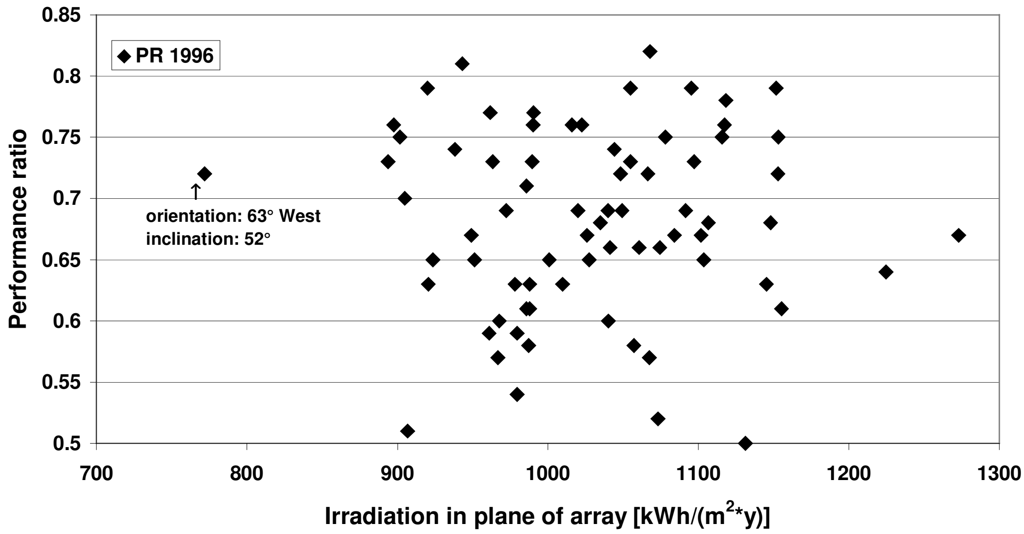


Figure 6.4.5: Annual performance ratios for 74 PV systems in 1996. The mean performance ratio is PR = 0.68.

To distinguish between system losses (mainly due to inverter efficiency) and array capture losses, a normalized presentation is used as shown in Figure 6.4.6. The annual yields Y_f, system losses L_S and array capture losses L_C of 17 grid-connected systems between 1 kWp and 2 kWp are shown in this figure. The final yields Y_f vary between 1.53 h/d and 2.4 h/d, the system losses L_S between 0.18 h/d and 0.42 h/d and the capture losses L_C between 0.34 h/d and 1.25 h/d. The largest variation is found for the array capture losses and thus for the conversion of solar radiation into electricity by the PV array.

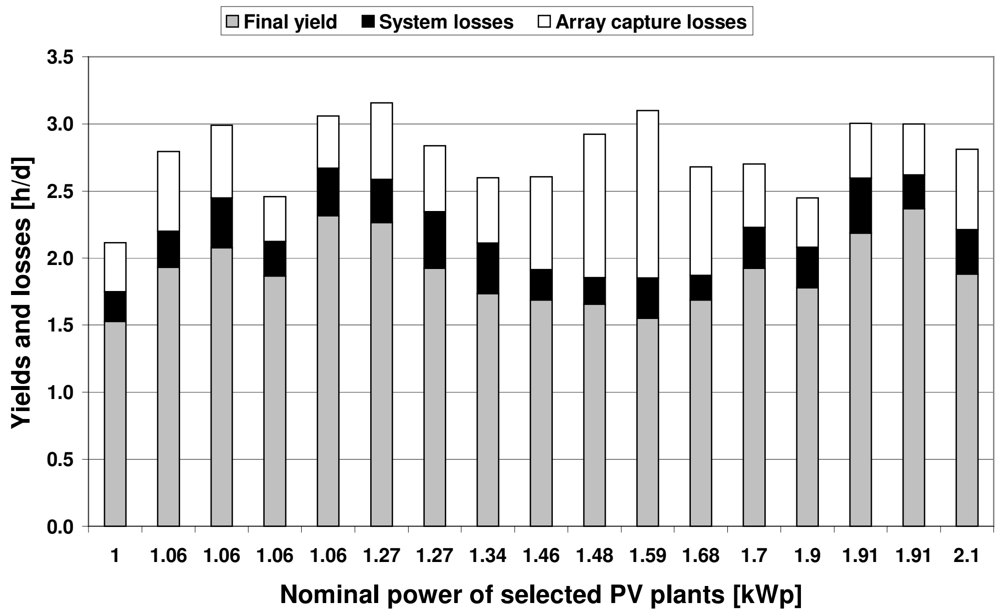


Figure 6.4.6: Annual final yields and losses of 17 grid-connected PV systems with an installed nominal power between 1 kWp and 2 kWp

6.4.2.2 Array efficiency

The mean array efficiency is defined by

$$\eta_{A,mean} = E_A / (A_a \cdot H_I),$$

where E_A is the energy of the PV array and H_I is the irradiation that impinges the overall array area A_a within the reporting period.

This efficiency represents the mean energy conversion efficiency of the PV array, which is useful for the comparison with the array efficiency η_{A0} at its rated power P_0. Per definition [1] the difference in efficiency values represents diode, wiring and mismatch losses as well as energy wasted during plant operation.

In the following Figures 6.4.7, 6.4.8, 6.4.9 and 6.4.10 annual values only of efficiencies are considered. Figure 6.4.7 shows the mean array efficiency $\eta_{A,mean}$ as a function of the nominal array efficiency η_{A0} according to the manufacturer's data sheets for eight different module types. One can see in Figure 6.4.7 that the measured array efficiencies of 34 PV systems lie significantly below the nominal array efficiency. The difference in efficiency values is between - 10 points (best PV arrays) and - 40 points (worst PV arrays). There are only few module types and systems, which reach efficiency values above the 80 %-line in Figure 6.4.7.

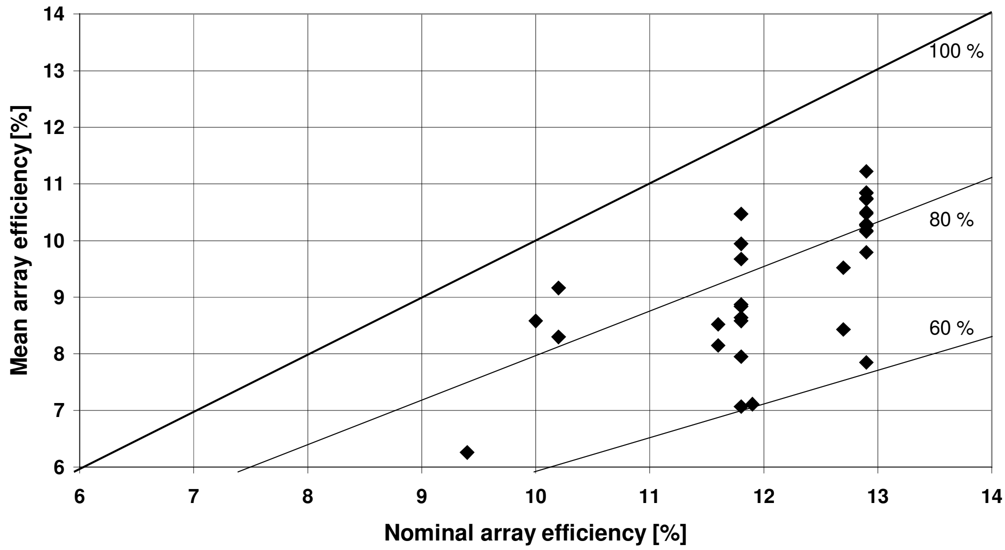


Figure 6.4.7: Mean array efficiencies of eight different module types measured in 1996 at 34 PV plants and compared to nominal array efficiency according to manufacturers' quoting

The module manufacturers of the investigated module types are given in Figure 6.4.8. This figure shows a manufacturer specific average ratio of mean and nominal array efficiency for the 34 PV systems with eight different module types from five manufacturers. It is noted that the average efficiency ratio of only one manufacturer achieves a value above the 80 %-line (Figure 6.4.8).

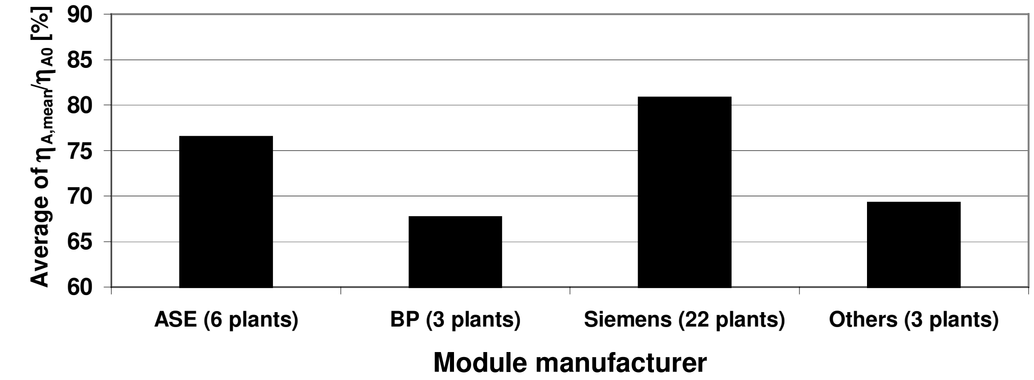


Figure 6.4.8: Manufacturer specific average ratio of mean array efficiency and nominal array efficiency for eight different module types in 34 PV plants

As shown in Figure 6.4.9, the ratio of $\eta_{A,mean}$ and η_{A0} is obviously a linear function of the performance ratio. From Figure 6.4.9 one may conclude that for all PV systems above the 80 %-line of the ratio of mean and nominal array efficiencies (y-axis), the performance ratios are typically higher than PR = 0.7. There are two exceptions of systems with very low annual inverter efficiencies (η_I = 0.83 and η_I = 0.88), which prevent them from reaching good PR values, although their ratios of array efficiency values are above 80 % (Figure 6.4.9).

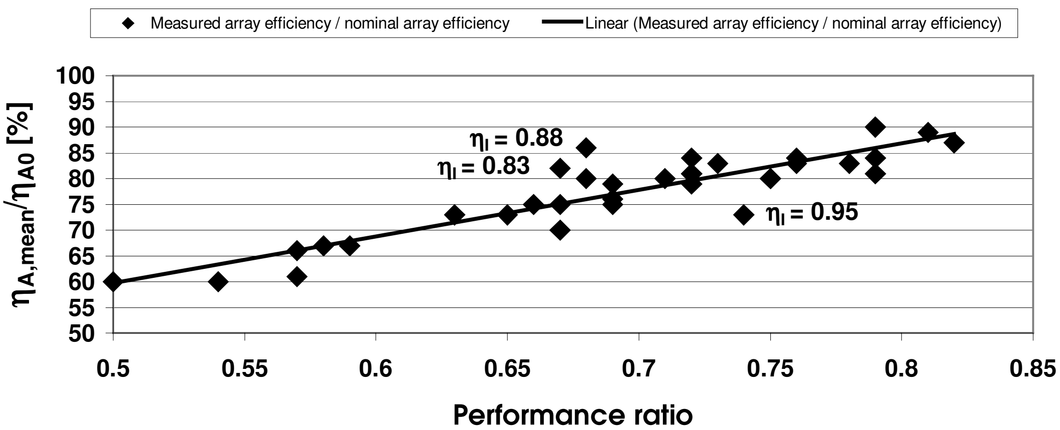


Figure 6.4.9: Ratio of the mean array efficiency and nominal array efficiency ($\eta_{A,mean}/\eta_{A0}$) as a function of performance ratio for 34 grid-connected PV plants

Thus the ratio of mean and nominal array efficiencies of a grid-connected PV system is a good indicator for the evaluation of the system operational performance. Good operation of systems (PR > 0.7) can be expected from systems with a ratio $\eta_{A,mean}/\eta_{A0}$ > 80 %, although other parameters (e. g. inverter efficiency) and effects (e. g. shading) have to be taken into account.

6.4.2.3 Inverter efficiency

The efficiency and availability of the inverter are two important factors for the system performance. Figure 6.4.10 shows the operational efficiency of different inverter types measured at 40 PV systems in 1996. For these 40 plants the mean annual inverter efficiency has a value of 87.9 %. As one can see from Figure 6.4.10, some inverter types are able to reach annual operational efficiencies higher than 90 %. During the course of the 1 000-roofs-monitoring-programme (1991-1997), inverter types with poor operating results were replaced by new types with higher efficiencies. In 1996, the inverters of the above mentioned 40 systems achieved an average availability of 97.1 %. While many inverters reached annual values higher than 99 %, less reliable inverters had values of 85 %. An availability of 40 % was achieved in the worst case due to long term inverter failure. The mean annual inverter availability ranged from 84.6 % (ASP: 5-system-average) to 99.7 % (UfE: 4-system-average) as shown in Table 6.4.2.

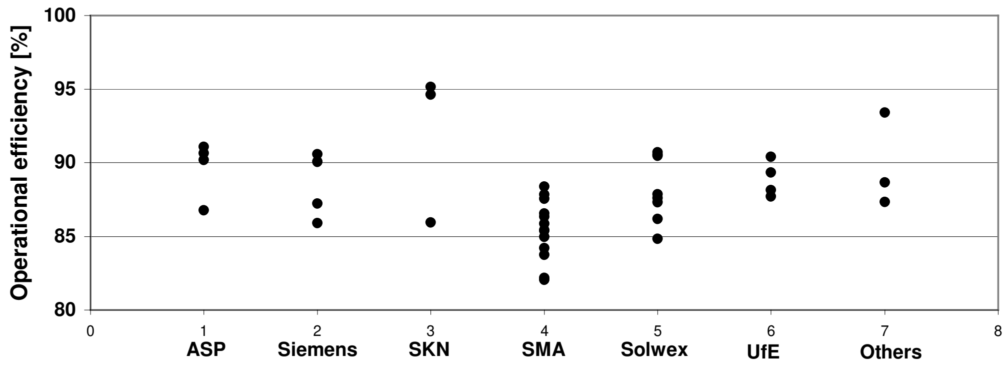


Figure 6.4.10: Operational efficiency of inverters from different manufacturers, measured at 40 grid-connected PV systems in 1996

Table 6.4.2: Mean annual availability of inverters from different manufacturers and overall average availability in 1996

Manufacturer	ASP	Siemens	SKN	SMA	Solwex	UfE	Others	Sum/mean
No of inverters	5	4	3	14	7	4	3	40
Availability [%]	84.6	99.5	99.5	98.5	99.3	99.7	97.7	97.1

6.4.3 Interpretation of the selected results

The annual final yields range from 400 h/y up to 950 h/y (Figure 6.4.2) with a mean value of about 700 h/y (Table 6.4.1).

The annual performance ratio (PR) varies from 0.4 to 0.82 (Figure 6.4.3) with a mean value of 0.67 (Table 6.4.1). The variation of the annual yields (Figure 6.4.4) and performance ratios (Figure 6.4.5) is much larger than the variation in irradiation.

The difference between mean and nominal array efficiency ranges from - 10 points to - 40 points (Figure 6.4.7). Only some module types (manufacturer dependent) achieve ratios $\eta_{A,mean}/\eta_{A0} \geq 80$ % (Figure 6.4.8), which appears to be correlated to systems performing well with performance ratios PR ≥ 0.7 (Figure 6.4.9).

For 40 PV systems the mean annual inverter efficiency is 87.9 % (Figure 6.4.10) with a mean inverter availability of 97.1 % (Table 6.4.2).

For 88 grid-connected PV systems with a total of 207 years of operation, the average annual performance ratio has a value of 0.67, which is about 16 % lower than the possible (realistic) value of PR = 0.8. There are three reasons for this:

- Measurements of individual PV modules [2] and the reduced yield analysis of the 1 000-roofs-programme [3] show that there is a systematic deviation of the measured module nominal power from the rated module power specified in the data sheets. This deviation fluctuates from manufacturer to manufacturer and is generally negative: deviations from - 5 % up to - 15 % were reported [2], [3].

  This also supports the selected results found in section 6.4.2.2: The maximum difference of 40 % between mean and nominal array efficiency can partly be explained by this „quoting deviation“ and the value of $\eta_{A,mean}/\eta_{A0}$ is obviously correlated to specific module types or rather manufacturers. The other technical reasons for $\eta_{A,mean}/\eta_{A0} < 100$ % are:
  - Operation of PV array at low irradiance (G < 1 000 W/m^2) $\Rightarrow L_C = (3 ... 7)$ %.
  - Operation of PV array at high module temperatures ($T_m > 25$ °C) $\Rightarrow L_C = (1 ... 6)$ %.
  - Diode, wiring and mismatch losses $\Rightarrow L_C = (2 ... 5)$ %.
  - Shading of the PV array $\Rightarrow L_C = (0 ... 20)$ % [3].
- Although system (mainly inverter) failures were reported from 30 % of all systems during their first year of operation, the average non-availability of the inverters during the following years of operational (e. g. 1996) was only between 2 % to 3 % (Table 6.4.2). The influence of the component failures on the mean performance ratio was estimated to be between 2 % and 5 % [4].
- The operational behaviour of the inverter at partial load and of the PV array at low irradiance significantly determines the efficiencies of these components. Diode, wiring and mismatch losses, MPP inverter losses, bad module integration causing higher module temperatures as well as array coverage (dirt, snow) and array shading will reduce the final yield and the performance of the system. The latter effects, which might be avoided by optimum components matching, selection of high efficiency components and careful system installation with respect to shading, are assumed to contribute in the order of 5 % to the average losses of the performance ratio [4].

6.4.4 Energy consumption

The energy consumption E_{cons} of a household is calculated from the energy output of the inverter E_{IO}, the energy from the utility grid E_{FU} and the energy to the utility grid E_{TU}. E_{cons} is given by

$$E_{cons} = E_{IO} + E_{FU} - E_{TU}.$$

The solar fraction F_S is the ratio of the photovoltaic energy (inverter output) and the total energy consumption of the household. The solar fraction is given by

$$F_S = E_{IO} / E_{cons}.$$

The "direct consumption“ describes the share of the photovoltaic generated energy, which is directly used within the household at the time of its generation. The direct use fraction F_d is given by

$$F_d = (E_{IO} - E_{TU}) / E_{IO}.$$

Investigations of the consumer behaviour in the 1 000-roofs-programme-households show that users are not always "energy savers“. In 1996, the average annual energy consumption of 69 of those households was 4 595 kWh/y per household as shown in Figure 6.4.11. In the previous years the mean annual consumption was 4 428 kWh/y in 1994 and 4 525 kWh/y in 1995. It is thus comparable to the average annual energy consumption of one-family houses with four and more persons in Germany. Figure 6.4.11 shows the broad range of annual energy consumption of households within the 1 000-roofs-programme, in which only 10 % of the households consume less than 2 000 kWh/y, but for about 20 % of the households the consumption exceeds 6 000 kWh/y.

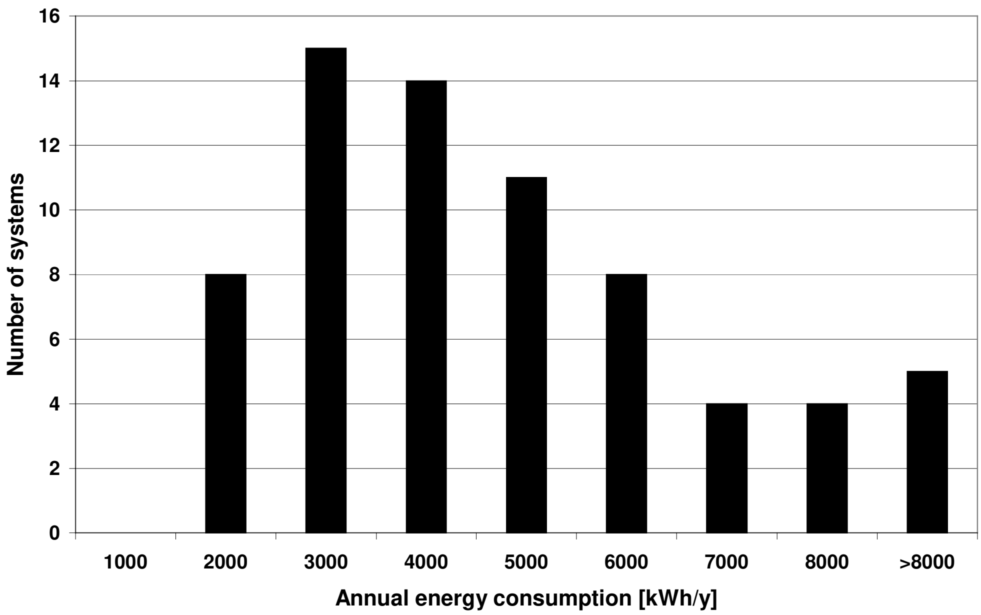


Figure 6.4.11: Frequency distribution of annual energy consumption of 69 households with PV plants in 1996

Figure 6.4.12 shows the frequency distribution of the annual solar fraction calculated for those 69 households in 1996. Due to the consumer behaviour and the system size the values of F_S vary considerably between 0.1 and more than 1.0. The highest F_S value which has been calculated is 2.0, and the mean annual solar fraction is $F_S = 0.5$ for the 69 households under investigation. Consequently, a well operating 2.5 kWp system ($Y_f = 900$ h/y) can provide half of the average annual energy consumption of 4 500 kWh/y in Germany.

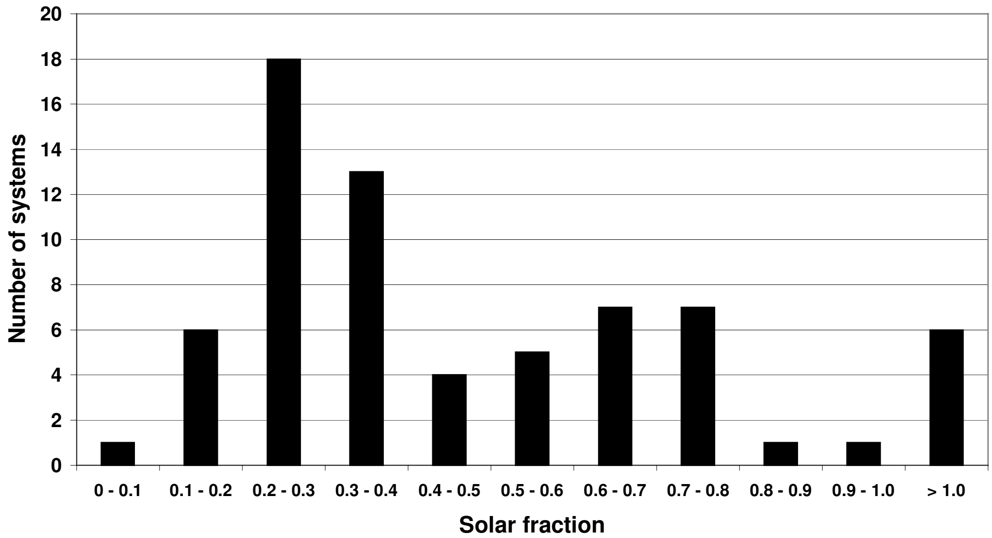


Figure 6.4.12: Frequency distribution of solar fraction calculated for 69 households with PV systems in 1996

Introducing a normalized energy consumption, the solar fraction can be expressed by

$$F_S = E_{IO} / E_{cons} = Y_f / E_{cons,\ normalized},$$

where $E_{cons,\ normalized} = E_{cons} / P_0$ is the normalized energy consumption of a household.

In Figure 6.4.13, the annual solar fraction reaches values between 0.1 and 2.0 for the 69 individual PV system users. Six households obtain F_S values higher than 1.0, while most consumers have annual F_S values between 0.2 and 0.8. The solar fraction is inversely proportional to the normalized consumption. The imagined trend line in Figure 6.4.13 represents the average value of annual yield Y_f = 700 h/y. Most realized F_S values vary around this value due to higher or lower system yields. This diagram shows clearly the dependence of the solar fraction on both parameters, photovoltaic generated energy and energy consumption, at the same time.

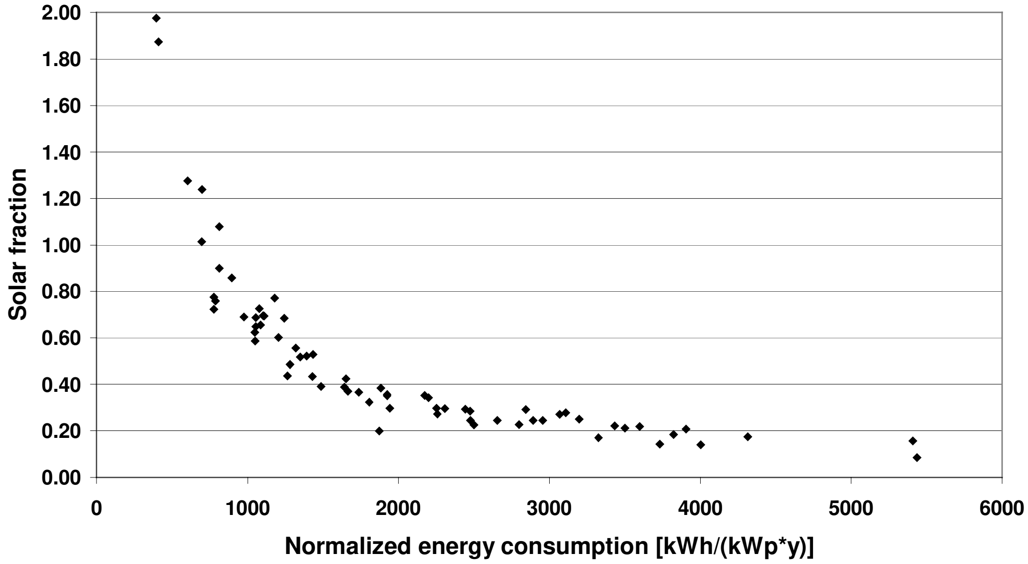


Figure 6.4.13: Matching PV system yield and energy consumption of 69 households with PV plants in 1996

Figure 6.4.14 shows the frequency distribution of the direct use fraction for the same number of households. In 1996, the average direct use fraction amounts to 0.57. This means that more than half of the photovoltaic generated energy is directly used in the households of the 1 000-roofs-system users.

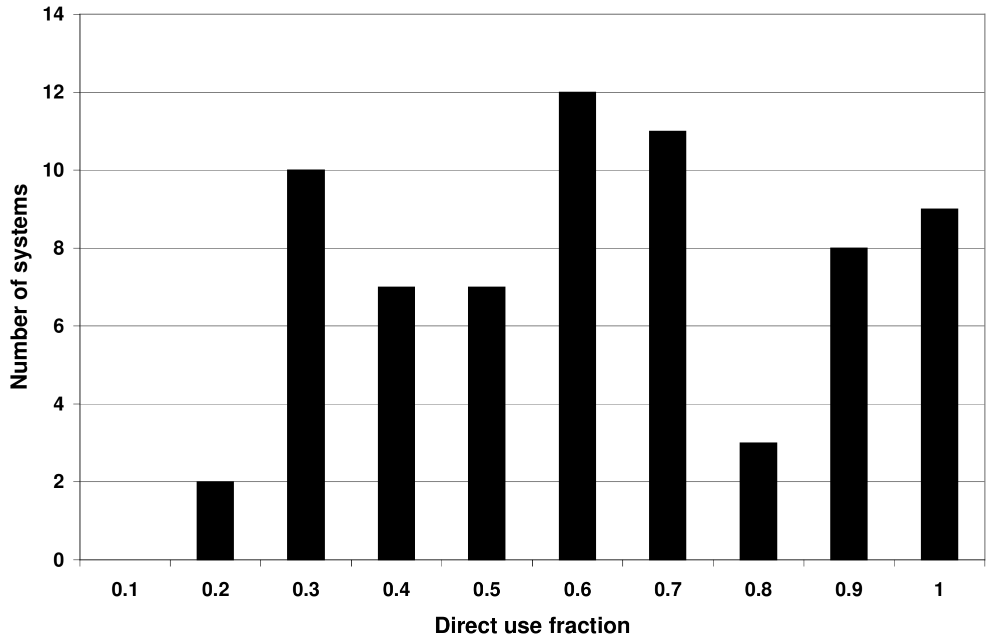


Figure 6.4.14: Frequency distribution of direct use fraction of 69 households with PV plants in 1996

Figure 6.4.15 shows the mean annual values for F_d as a function of the annual solar fraction F_S. The direct use fraction is inversely proportional to the solar fraction. The realized values indicate that the high expectation for a better correlation of both solar fraction and direct use can typically not be achieved.

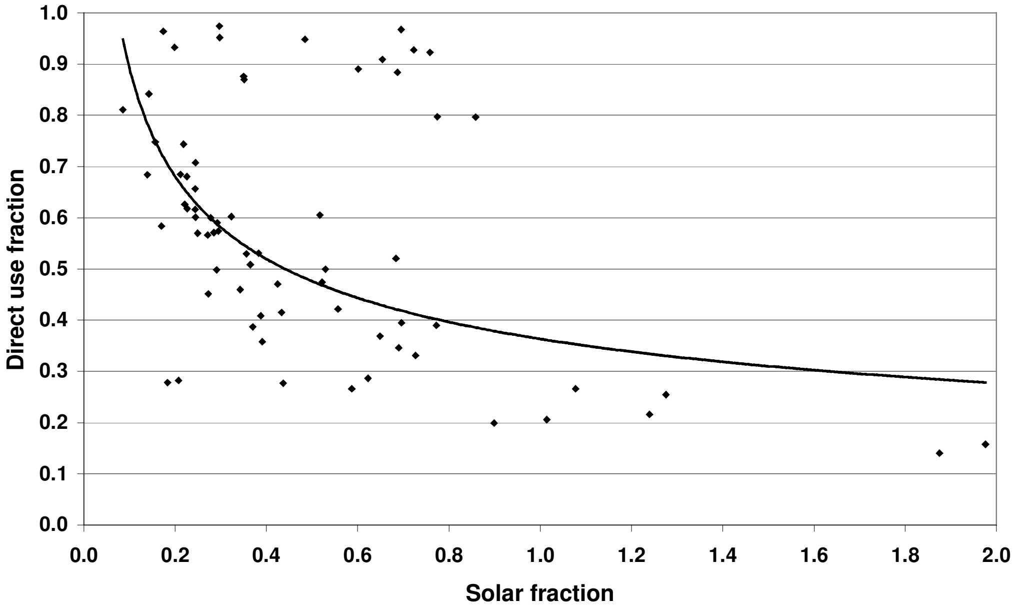


Figure 6.4.15: Mean annual values of direct use fraction as a function of solar fraction for 69 households with PV plants in 1996

6.4.5 Conclusion

The 88 grid-connected PV systems in the IEA-PVPS database cover only 4.4 % of the 2 000 PV systems that were installed within the German 1 000-roofs-programme, but represent 40 % of the selected systems for the intensive monitoring and analysis programme. The results of this analysis fit well to previous evaluations of the 1 000-roofs-programme [3], [4].

Despite the good performance results which have been obtained, the investigation of the operational behaviour identifies further potential for optimization of grid-connected systems. Because photovoltaic generated energy and energy consumption of households are typically not correlated, the size of grid-connected PV systems should be matched to energy consumption in conjunction with energy saving measures in future PV applications.

6.4.6 References

[1] International Standard IEC 61724 "Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis", International Electrotechnical Commission, Geneva, Switzerland, First Edition, April 1998

[2] U. Jahn, D. Tegtmeyer, J. Grochowski: "Analysis of the 1000-Roofs-PV-Programme: Measurements of PV arrays", Proceedings 10th Symposium PV Solar Energy, Staffelstein March 1995, pp 69 – 77 (in German)

[3] B. Decker, J. Grochowski: "Reduced yield analysis of the 1000-Roofs-PV-Programme", Final Report, BMBF, Contract No. 0329588, August 1997 (in German)

[4] Working group for the 1000-Roofs-Monitoring-and-Analysis-Programme: "Annual Journal 1997", editor: Fraunhofer Institute for Solar Energy Systems, 1998

6.5 Israel

6.5.1 Comparison between static and dynamic PV systems at Sede Boqer, Israel

The Israeli systems documented in the IEA-PVPS Task 2 database are all located at a research institute in an arid desert (Latitude 30.8° N; altitude above sea-level 475 m; annual global horizontal irradiation 2 000 kWh/(m^2·y); annual rainfall 90 mm). The environmental conditions are, accordingly highly stressful for system components.

Although the number of PV systems in Israel is rather small, compared to those in other countries, they occupy a unique place in the first version of the IEA-PVPS Task 2 PV systems database because they are the only sun-tracking systems for which data have been reported. This chapter, accordingly, compares the side-by-side performance of conventional "tilt = latitude" static PV systems with a number of different sun-tracking systems.

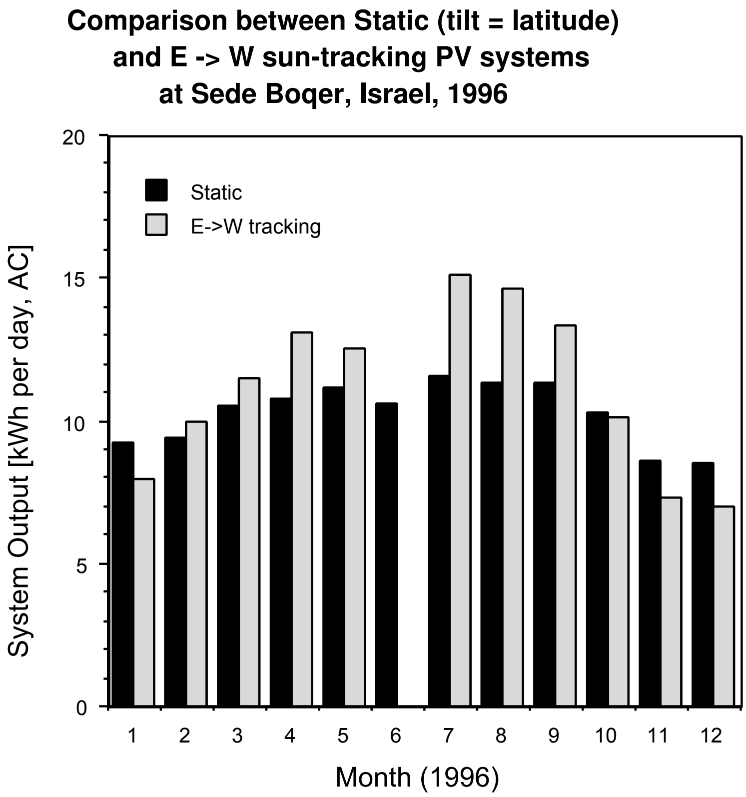


Figure 6.5.1: Comparison between static and E/W sun-tracking PV systems (Israel)

Figure 6.5.1 displays a side by side comparison of the monthly performance, during 1996, of two grid-connected PV systems which differ from one another only in their tracking strategies. The system illustrated by black bars (PAZsta) consists of 60 Solarex MX-146, polycrystalline Si, PV modules mounted on a static stand, facing due south, with tilt angle = Latitude = 30°. The nominal rating of the array is 2.88 kWp and it feeds the grid via a single-phase Omnion Corp. DC/AC inverter. The second system (PAZNS), illustrated by candy-striped bars, is identical except that the modules are mounted on NS horizontal axes which track the sun from E to W. (June output from the latter system is absent owing to its having been shut down for research purposes during that month).

We point out that, from geometrical considerations (i. e. plane of array irradiance), the static system would be expected to out-perform the tracking system during the months November, December and January. In practice the static system was indeed found to out-perform the tracking system during these months but also, during October. However, closer scrutiny of the information in the database reveal that the DC array output did follow these expectations. It is therefore probable that a variation in inverter efficiency was responsible for the observed October anomaly.

In terms of the relative amounts of incident radiation received by the two systems during the eleven months for which comparative data are shown, one would expect the tracking system to produce 17 % more energy than the static system. In practice, the tracking system produced only 8.6 % more AC energy and 14.6 % more DC energy.

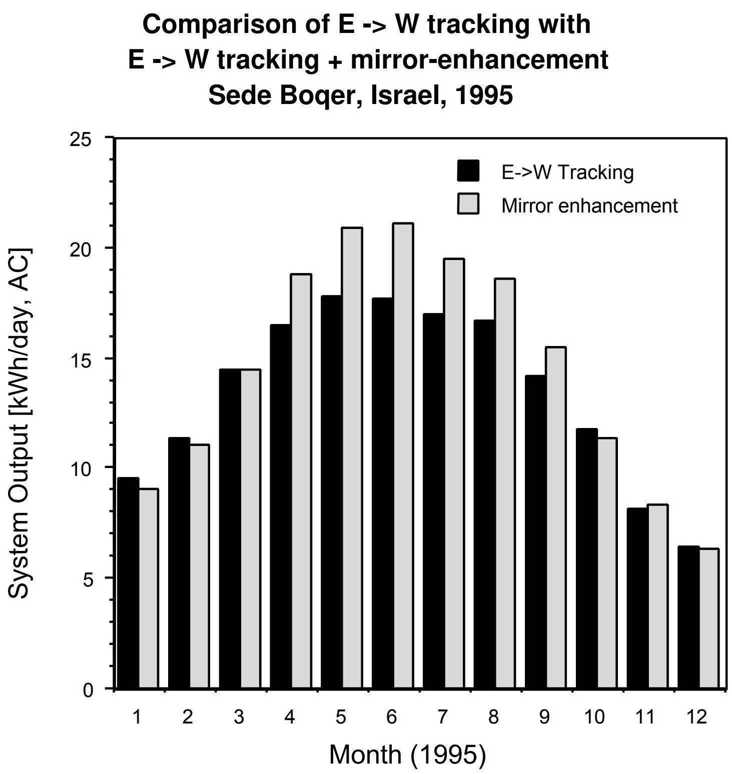


Figure 6.5.2: Comparison of E/W tracking with E/W tracking and mirror enhancement (Israel)

Figure 6.5.2 displays a side-by-side comparison of the monthly performance, during 1995, of the same E to W sun-tracking system discussed above (PAZNS) with a similar system which has V-trough mirror enhancement (PAZNSm).

One sees that mirror-enhancement of the PV modules appears to have produced an enhanced system output only during the months April, May, June, July, August, September and November. Once again, closer scrutiny of the database information reveals that the DC array output of the mirror-enhanced system exceeded that of the system without mirrors during the sequence of months April through September. This pattern is presumably hidden, in the plotted AC data, by variable inverter efficiency.

The theoretical radiation-weighted annual enhancement factor of these mirrors is expected to be 1.57 [1], i.e., one might expect the mirrors to contribute 57 % more energy. In practice, the mirror-enhanced system produced only 8.5 % more AC energy and 4.8 % more DC energy.

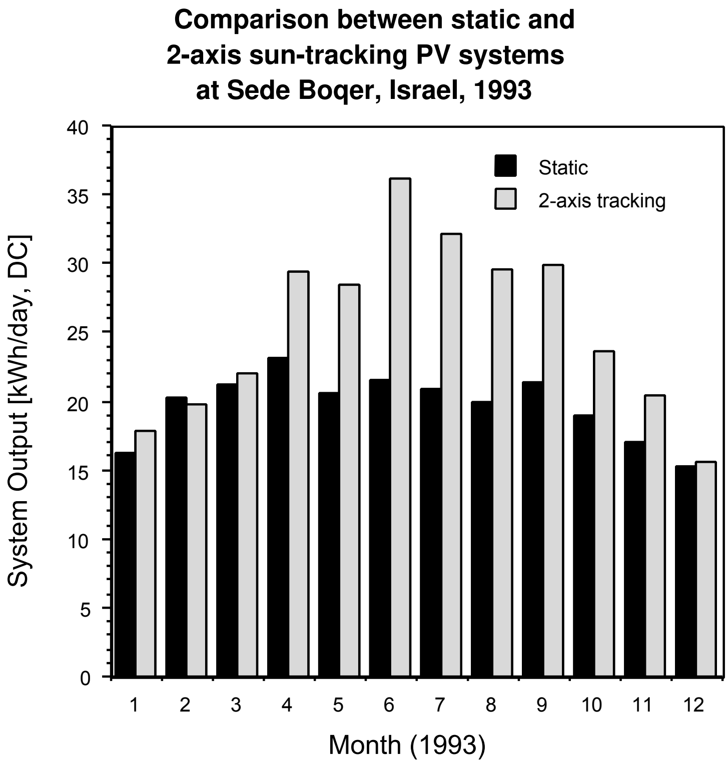


Figure 6.5.3: Comparison between static and 2-axis sun-tracking PV systems (Israel)

Figure 6.5.3 displays a side by side comparison of the monthly performance, during 1993, of another two systems which differ from one another principally by having different tracking strategies. The system indicated by candy-stripe bars (IEC2ax) consists of 75 Siemens SM55, single-crystal Si, PV modules mounted on a dual-axis tracker. The nominal rating of the array is 3.98 kWp and it feeds the grid via a three-phase Sun Power Solartechnik inverter. The second system (BGsing) consists of a single Arco Solar M53, single-crystal Si, PV module mounted on a static stand, facing due south, with tilt angle = Latitude = 30°. This module is not grid-connected but, instead, powers a DC load. In order for the comparison to be meaningful, two adjustments have been made to the data. First, based on side-by-side comparison of module characteristics for the M53 and SM55 modules, performed at Sede Boqer during 1993, the M53 rated power output has been increased by 30 % in order to bring it into line with a typical SM55 module (i. e. we compare the output of 75 SM55 modules with that of 97.5 M53 modules). Secondly, since no AC data exist for the M53 module, Figure 6.5.3 compares monthly DC outputs for the static and sun-tracking systems.

From plane of array irradiance measurements during 1993 one would expect the two-axis tracking system to out-perform the static system by 28 %. In practice, the two-axis system produced effectively 29 % more DC energy.

6.5.2 Conclusions

Experience with single, horizontal axis sun-tracking systems was disappointing. In general the system output was found to be lower than the designers had expected. In the case of simple tracking vs. static (Figure 6.5.1), large winter angles of incidence resulted in poor system performance. In the case of mirror-enhanced tracking versus simple tracking (Figure 6.5.2), two effects combined to reduce system output: Summer performance was reduced due to high mirror-enhanced module *temperatures*; and winter performance was reduced due to non-uniform illumination (an effect that could have been reduced by re-positioning the mirrors). On the other hand, the two-axis tracking system performed more or less according to expectations.

6.5.3 References

[1] J. Freilich, J.M. Gordon: “Case study of a central-station grid-intertie photovoltaic system with V-trough concentration”, Solar Energy, vol 46 (1991) 267

6.6 Italy

6.6.1 Introduction

Since the early eighties, Italy has been engaged in a wide photovoltaic (PV) demonstration programme focused in the field of large grid-connected power plants and aimed at investigating on the identification and validation of satisfactory solutions and on the reliability of subsystems and components. ENEA (Italian Agency for New Technology, Energy and Environment), ENEL (National Electric Utility), ANIT (major Italian PV industry) and some local authorities and private operators have been the most active operators. The total cumulative PV power installed in Italy at the end of 1998 was about 17.6 MWp. Rural electrification (about 5.0 MWp), off-grid non-domestic applications (about 5.2 MWp) and centralized demonstrative systems (about 6.6 MWp) constitute the most important sectors of the Italian applications.

ENEA's study on medium and large power plants has been carried out on Delphos 1 (one unit of 300 kWp), Delphos 2 (group of three standard 100 kWp modules, called PLUG) and Casaccia PLUG grid-connected plant. This module, dubbed PLUG (Photovoltaic Low-cost Utility Generator), was conceived as a basic building block for medium-sized plants connected to the national grid, though single PLUGs can naturally be installed to generate electricity for small local networks. The PLUG unit operating in Sardinia at the ENEL Alta Nurra wind turbines test facility has allowed ENEA to evaluate the combined use of wind and PV, while study to test the high penetration of PV in a small isolated grid are carried out on the PLUG installed on Vulcano island. ENEL, nevertheless the privatization process, has maintained a very important role in development and demonstration of PV systems. ENEL's most important results have been the construction of the 3.3 kWp Serre plant and of some small- and medium-sized systems for distributed generation and the use of cost-effective applications to supply customers remote from the grid.

Besides ENEA, ENEL and ANIT, some local authorities and private operators have promoted several power plants, built in the frame of demonstration programmes supported by the Italian Government and / or European Commission (Valoren Project). The Elio 1 plant (1 MWp) has been the first example of a large modular PV power station installed in Europe. Moreover, Carloforte and Lamezia constitute some examples of hybrid medium-sized systems (300 kWp PV and 340 kW wind generator). The main features of the above mentioned PV plants are reported in Table 6.6.1.

Table 6.6.1: Description of main Italian PV plants

PV Plant	Power [kWp]	Commissioning	Owner / Operator
Delphos 1	300	1986	ENEA
Delphos 2	300	1992	ENEA
Casaccia	100	1991	ENEA
Alta Nurra	100	1996	ENEA
Vulcano 2	100	1998	ENEA
Serre	3 300	1994	ENEL
Vulcano	80	1984	ENEL
Alicudi	28	1992	ENEL
Adrano	70	1998	ENEL
Cittadella	35	1997	ENEL
Carloforte	300	1994	ANIT
Lametia	300	1996	Consortium
Mandatoriccio	216	1996	Municipality
Elio 1	1 000	1993	Consortium
Leonori	86	1995	Consortium
Zambelli	70	1985	Utility

6.6.2 New initiatives

The new emerging world-wide strategy for PV market penetration, privileging the development of small low-voltage grid-connected systems (distributed generation), has been considered of strategically importance in Italy in the last years. In 1998 an ambitious five-year national programme has been launched under commission of both Italian Ministries for Industry and for Environment. The Programme [1], aimed at installing 10 000 roof tops for a final capacity of 50 MWp, will be managed and monitored by ENEA and is funded by a public contribution (decreasing in the time) on plant investment costs. Plant sizes below 5 kWp (to be connected to single-phase low voltage grid) and plants with a rated power in the range of 5 kWp to 50 kWp (to be operated in connection to the three-phase grid) will be eligible for the contribution. Almost 8 900 small plants for a total installed power of 22.5 MWp and about 1 100 systems of 5 kWp to 50 kWp rated power are foreseen in the next five years.

During the first year of the programme, 500 plants are expected to be installed: 400 small systems (1 to 5 kWp) and 100 larger systems (5 to 50 kWp) with a total capacity of 3.5 MWp. The trend of the related costs is expected to be reduced, year by year, with an annual upper limit continuously revised according to the acquired results.

Some preliminary and collateral programme activities have been defined and started. Among them, technical, demonstrative, training and advertising actions have been set up, with a particular attention paid to both the technical guidelines definition and the demonstration programme development. In this framework a close cooperation between ENEA and ENEL has given, as a first result, the draft of programme guidelines, which has been approved by the Italian Industry and the Environment Ministry and is going to be evaluated by the Italian utilities. A specific demonstration and experimental programme has been defined and is started with the construction of 20 small PV systems. Concerning training and advertising activities, the preparation of didactic materials started. In addition, in the framework of specific agreement with the Italian section of ISES, information seminars have been organized in different Italian cities, strongly pursuing the involvement of the local authorities.

6.6.3 Typical examples of operational performances

Because of some systems operational data being not available, only a fraction of the systems listed in Table 6.6.1 is described and analysed. In Table 6.6.2 the main features of selected plants are summarized.

Table 6.6.2: Description of analysed PV systems

PV Plant	Latitude	Layout / tilt angle	Module technology	Years of operation
Delphos 1	41.3° N	Single row / 20°	p-Si & mc-Si	1992 - 97
Delphos 2	41.3° N	Parallel row / 30°	mc-Si double glass	1994 - 97
Casaccia	42.0° N	Flat roof / 7°	mc-Si double glass	1992 - 97
Alta Nurra	40.5° N	Parallel row / 30°	mc-Si double glass	1997

Their typical operational performances in terms of final yield, array capture losses, system losses and performance ratio are shown in Figures 6.6.1 to 6.6.4. A summary of the performance results for the PV plants Delphos 1, Delphos 2, Casaccia and Alta Nurra is given in Table 6.6.3 which can be used to compare the PV plants under investigation.

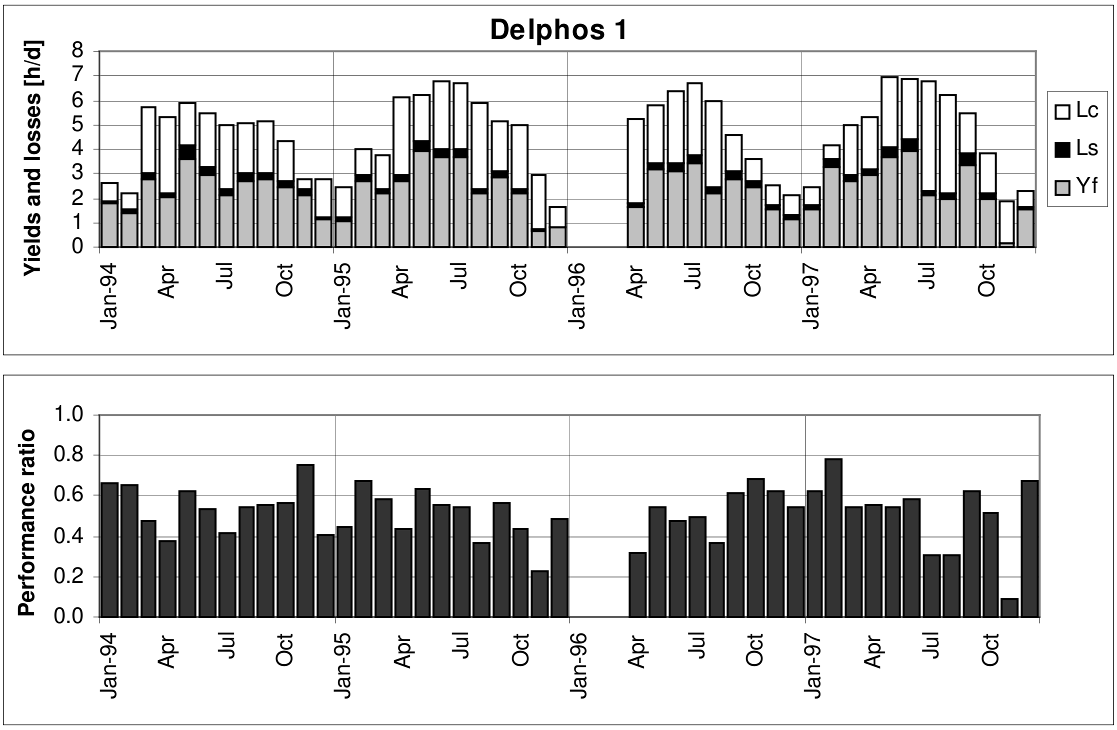


Figure 6.6.1: Daily final yields (Y_f), array capture losses (L_C), system losses (L_S) and monthly performance ratio (PR) for Delphos 1 plant from January 1994 to December 1997

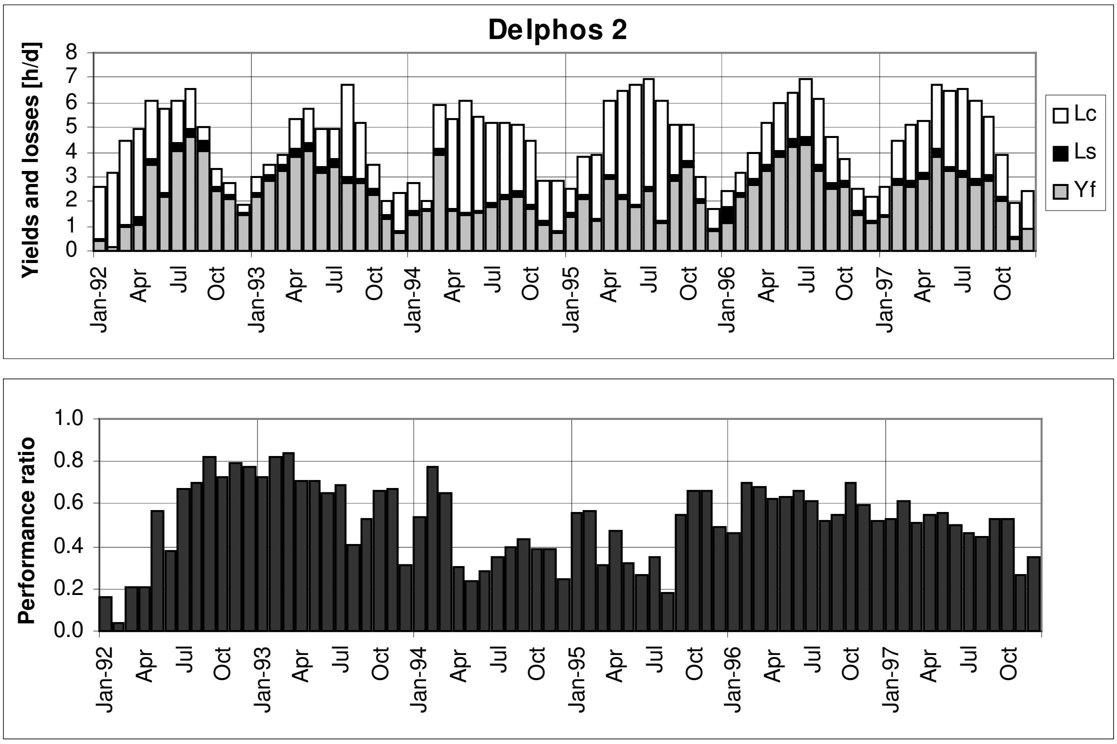


Figure 6.6.2: Daily final yields (Y_f), array capture losses (L_C), system losses (L_S) and monthly performance ratio (PR) for Delphos 2 plant from January 1992 to December 1997

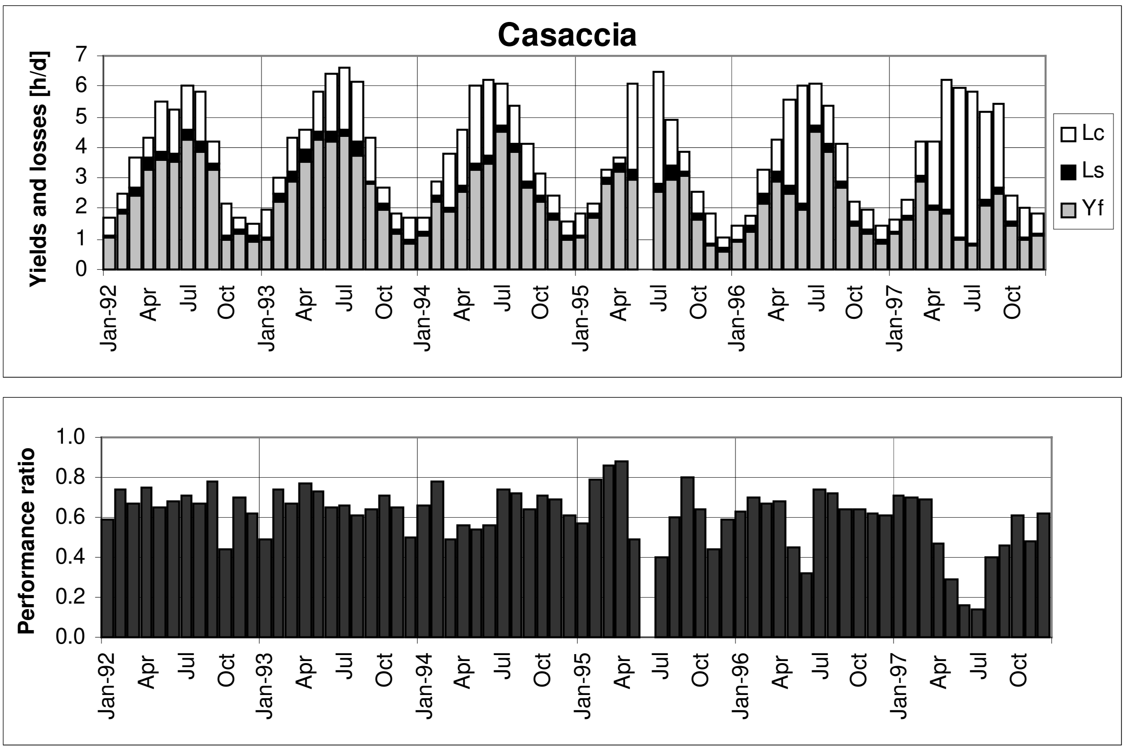


Figure 6.6.3: Daily final yields (Y_f), array capture losses (L_C), system losses (L_S) and monthly performance ratio (PR) for Casaccia plant from January 1992 to December 1997

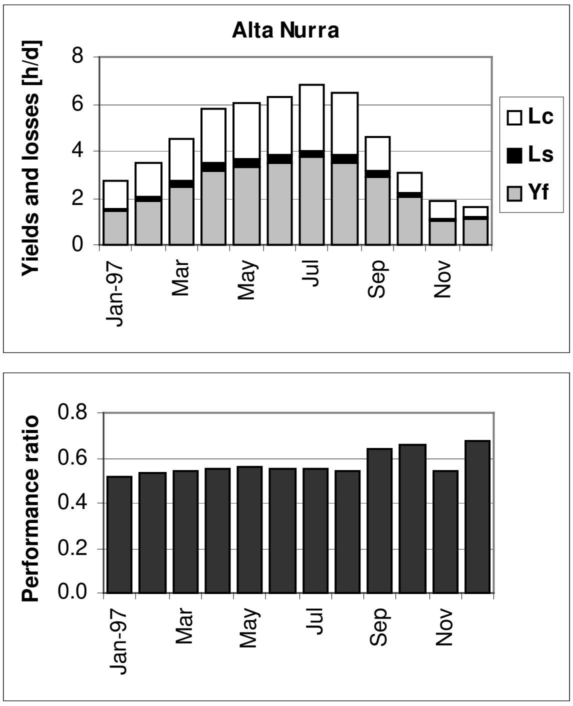


Figure 6.6.4: Daily final yields (Y_f), array capture losses (L_C), system losses (L_S) and monthly performance ratio (PR) for Alta Nurra plant for 1997

Table 6.6.3: Annual mean values of final yield (Y_f) and performance ratio (PR) for selected PV plants in 1992 – 1997

PV Plant	Year	Y_f [h/d]	PR
Delphos 1	1994	2.31	0.55
	1995	2.39	0.50
	1996	2.38	0.52
	1997	2.42	0.51
Delphos 2	1992	2.24	0.50
	1993	2.72	0.64
	1994	1.76	0.42
	1995	2.00	0.45
	1996	2.70	0.60
	1997	2.38	0.49
Casaccia	1992	2.51	0.67
	1993	2.75	0.65
	1994	2.54	0.64
	1995	2.13	0.64
	1996	2.18	0.62
	1997	1.62	0.48
Alta Nurra	1997	2.50	0.57

6.6.4 Discussion

In order to estimate the influence of failures on PV plant performances, maintenance data of the period 1992 – 1996 [2] have been considered, pertaining the Delphos power stations consisting of different kinds of units: Delphos 1, 300 kWp, based on single unit, and Delphos 2 formed by PLUGs 1, 2 and 3, 100 kWp each, in accordance with the multiple units concept and pertaining Casaccia plant.

All forced maintenance events have been recorded and, for single forced downtime, the duration and the man-hours (MH) involved have been analysed. On the basis of the different layout and operating logic, failures have been divided into the two categories according to the kind of plant outage (partial or total) concerned. The experimental data are summarized in Figures 6.6.5 to 6.6.7. Figure 6.6.5 reports the annual cumulative total outages that occurred owing to failures of critical components (inverter, medium voltage equipment and power factor and filtering components).

During the period taken into consideration, the cumulative total outages amounted to 176. The inverter unreliability was the main cause of the total outage: 43 % for Delphos 1 and 54 %, 67 % and 54 % for PLUG 1, 2 and 3 of Delphos 2. That difference was ascribed to the fact that the analysis was performed in the initial debugging period of the PLUG.

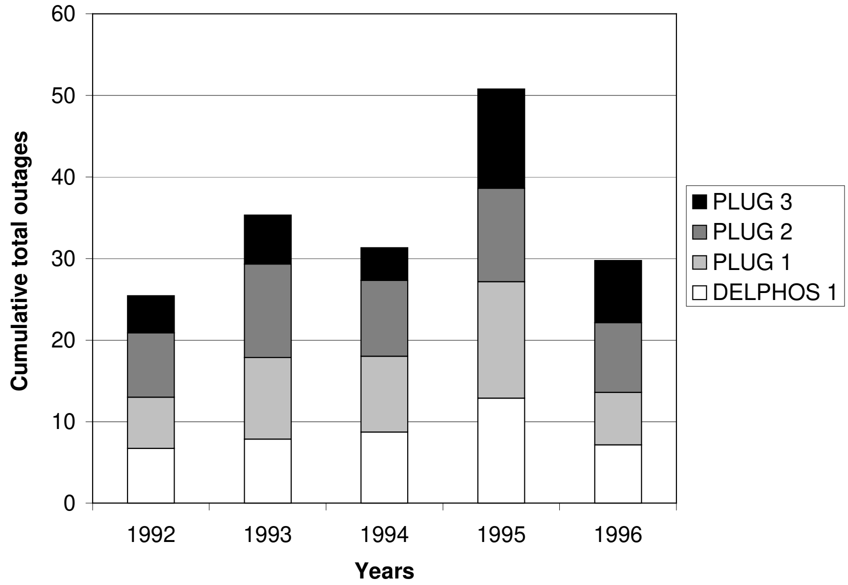


Figure 6.6.5: Total outages of Delphos 1 and Delphos 2 power stations from 1992 to 1996 (total outage events: 176)

In a similar way, Figure 6.6.6 shows the cumulative partial outages due to failures of PV generator components (cabling and switches) which do not prejudice the complete operation of the plant. The PV generator average annual failure rate strongly depends on ageing. It ranges from nine for Delphos 1 to about one for Delphos 2. Delphos 1 failures are nearly always due to low isolation of the PV module junction box. Considering total and partial outages, the Delphos power stations required 264 forced maintenance actions, 43 % for Delphos 1 and 57 % for Delphos 2. The five years forced maintenance work took about 900 man-hours (MH) corresponding to 0.3 MH/kWp/year.

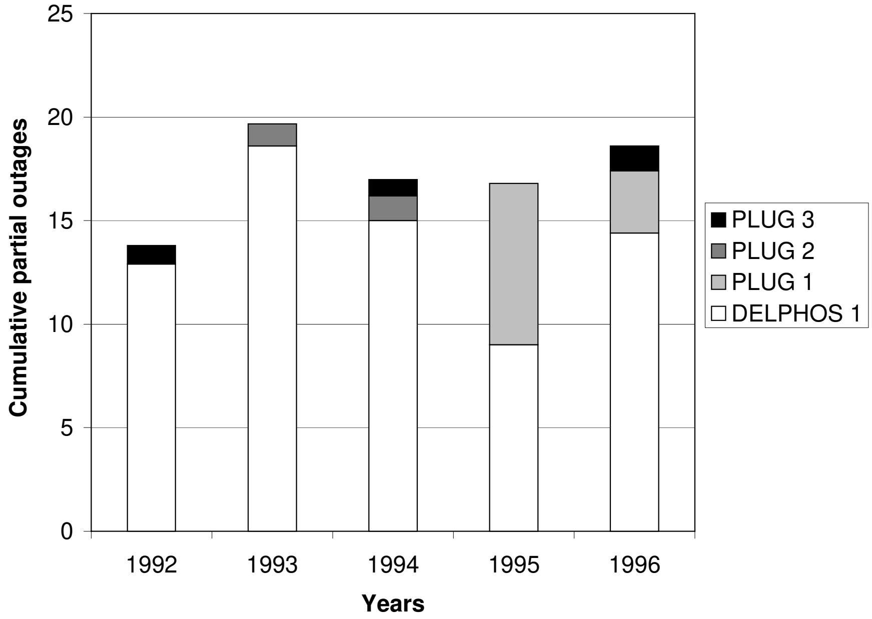


Figure 6.6.6: Partial outages of Delphos 1 and Delphos 2 power stations from 1992 to 1996 (partial outage events: 88)

To estimate the influence of failures on energy production, the annual duration of the single unit downtime corresponding to the repair time has been recorded and is reported in Figure 6.6.7.

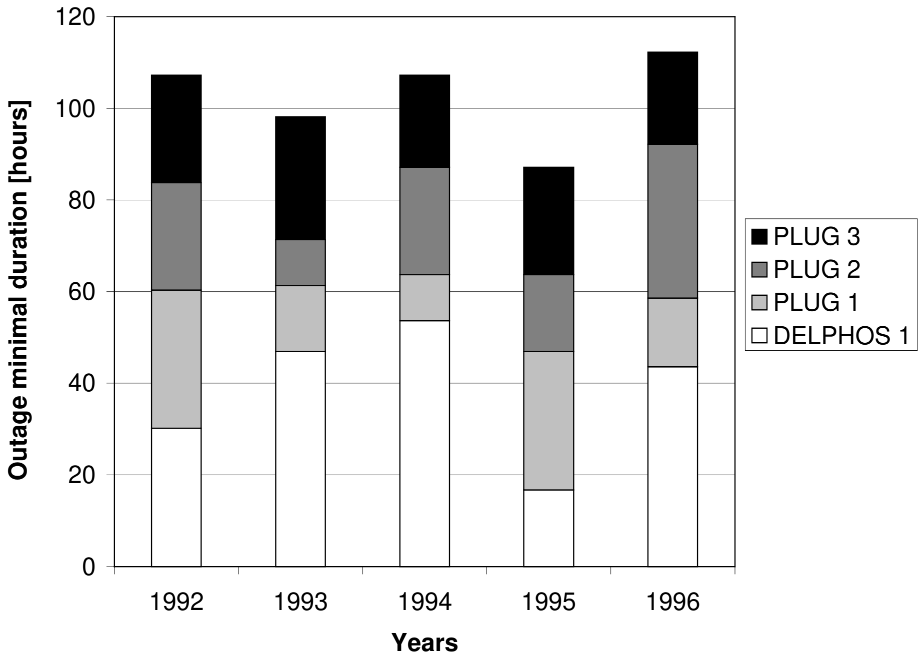


Figure 6.6.7: Minimum duration of non-availability of the Delphos power station units (sum of downtime minimum duration: 516 hours)

The data show that in the case of an immediate maintenance action, a plant non-availability is in the order of 3 % to 6 %. In practice, because of the time spent for detecting and locating the failure, for diagnosis and for supplying in situ the parts to be replaced, it ranges from 15 % to 30 % of the theoretical working hours (3 300 hours).

Concerning Casaccia plant (connected to the low voltage grid) during the same period (1992 to 1996), 25 outages have been recorded, corresponding to an average plant non-availability of 8 % and 0.4 MH/kWp/year. The bad behaviour of Delphos power stations with respect to their availability can be explained by taking into account that most of the failures are mainly due to the medium voltage connection equipment and to the grid disturbance. They have caused a long plant non-availability due to the time spent to supply the components to be replaced. A direct correlation between required man-hours and plant availability has not been registered for the investigated plants as the plant availability is strongly influenced by the kind of failure and by the time spent in situ to obtain some kind of component to be replaced. For all the plants taken into consideration, it results that the cost of the components replaced were nearly always similar to the cost related to manpower.

6.6.5 References

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[2] A. Sarno, S. Castello, S. Cordisco, M. Guerra: "ENEA experience in managing PV plants installed and operating in different locations", Proceedings of the 14th European Photovoltaic Solar Energy Conference, Barcelona, Spain, July 1997

6.7 Japan

6.7.1 Introduction

The total number of PV systems included in the IEA-PVPS database is 70, and they are the systems installed under several different governmental programmes through the New Energy and Industrial Technology Development Organization (NEDO), including:

- R&D programme for PV systems called "Sunshine Project"
- Field test programme for new energy power generation

Due to some incompleteness of the data, it is not possible to analyse all the datasets in the database, and only a fraction of the systems included in the database are described and analysed in this chapter. The outline of the above programs is described and some detailed analysis of the performances of selected systems, as well as a few typical examples of operational performance data, are presented.

6.7.2 National programmes to promote introduction of PV

6.7.2.1 R & D programme (New Sunshine Project)

The Japanese national research and development programme for new energy sources, called “Sunshine Programme”, was initiated in 1974 just after the first oil crisis. The programme consisted of four major research fields; solar energy, geo-thermal energy, clean coal technology and hydrogen energy. After almost 20 years of R&D effort, the programme was re-formulated in 1993 to combine the research fields of renewable energies, energy conservation technologies and environmental technologies under the name of the “New Sunshine Programme”. Concerning the R&D on PV technologies, a long-term plan was formulated in 1993. The final goal of the programme is set for the year 2010, and the current R&D activities are within the first phase (1993-2000) of this long-term plan. The objective of the first phase is to establish the PV technology available to supply electricity at a cost less expensive than the electricity rate in the residential sector.

6.7.2.2 Promotion programmes

With the purpose of promoting the introduction of new energy sources including PV, the Japanese government announced a basic national policy called "Basic Guidelines for Introducing New Energy Sources" in December 1994. According to these guidelines, it is expected that the total installation capacity of the PV systems will grow up to 400 MW by fiscal year (FY) 2000 and to 4 600 MW by FY 2010. To realize this challenging goal, the government initiated the following promotion programmes for PV.

a) Field test programme for new energy power generation
The goal of this programme is to accumulate the operational data of various new energy power generation systems, such as photovoltaic power generation systems, fuel cells and wind power generation systems. Public buildings are the target of this programme, and 1/2 to 2/3 of the total installation cost is subsidized by the government through NEDO. The programme started in FY 1992, and 180 photovoltaic power generation systems with a total output of about 4 960 kW have been installed up to the end of FY 1997 throughout Japan. Table 6.7.1 shows the numbers of the installed PV systems and the total output capacity of

the systems in each year. After this successful programme, the new field test programme for industrial PV application started in FY 1998.

Table 6.7.1: Field test programme for new energy power generation (PV systems)

Year	No. of Systems	Total Capacity (kW)
1992	11	235
1993	19	476
1994	11	370
1995	31	719
1996	40	1 270
1997	68	1 890
Total	180	4 960

b) Monitoring Programme of Residential PV Systems
The high installation cost is the primary barrier for the potential users of PV power generation systems. In order to achieve the target volume of the “Basic guidelines”, the Japanese government started the "Monitoring Programme of Residential PV Systems" in FY 1994. This programme subsidizes the cost for purchasing and installing PV systems on the roof of private houses. The year by year statistics are summarized in Table 6.7.2. About half to one-third of the installation cost of the rooftop PV systems are subsidized in this programme. A monitoring programme to measure detailed operational data of 100 systems installed in this programme started in FY 1997.

Table 6.7.2: Monitoring programme of residential PV systems

Year	No. of Systems	Total Capacity (MW)
1994	539	1.9
1995	1 065	3.9
1996	1 986	7.5
1997	5 654	19.5
1998	8 229	31.8
Total	17 473	64.6

6.7.3 Outline of the performances of PV systems in the database

Grid-connected systems are the dominant PV system in Japan because of the well-developed utility grid system throughout the country, but a variety of different types of systems, including stand-alone and hybrid systems, are included in the database. The total number of the systems is 70, and the numbers of each type are summarized in Table 6.7.3. Figure 6.7.1 shows the distribution of the nominal power of the 70 systems ranging from 2 kWp to 1 428 kWp.

Table 6.7.3: Overview of the different types of Japanese PV systems in the database

Type	No.
Grid-connected	25
Grid-connected hybrid	20
Stand-alone	20
Stand-alone hybrid	5
Total	70

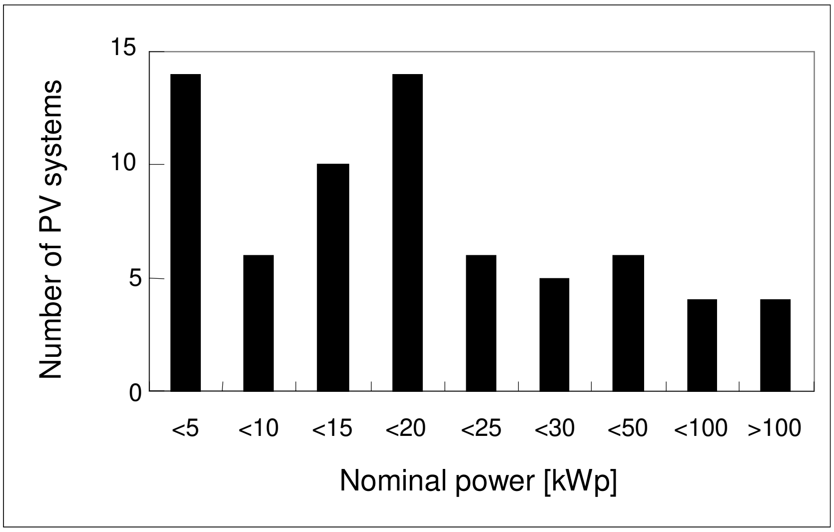


Figure 6.7.1: Distribution of nominal power for 70 Japanese PV systems in the database

Some systems have more than one year of operational data, but others have no operational data at all, and total number of datasets (operational years) is 71. Furthermore, due to some incompleteness of the input data, it is not possible to analyse all the datasets in the database. Only a fraction of datasets, which have reasonable indices of performance, are analysed below. These are 21 datasets measured during 1995 and 1996 at 16 systems, mostly grid-connected and include four grid-connected hybrid and one stand-alone system.

Figure 6.7.2 shows the annual final yield of these systems as a function of irradiation in the array plane. The cluster of data at the upper right of the figure are the data for a series of systems installed at the same site. Figure 6.7.3 and Figure 6.7.4 shows the distribution of annual final yield and performance ratio of these 21 systems, respectively. The average annual yield seems to be around 1 100 h/y, and the average performance ratio seems to be around 0.75, but there are very large variations for these indices of performance.

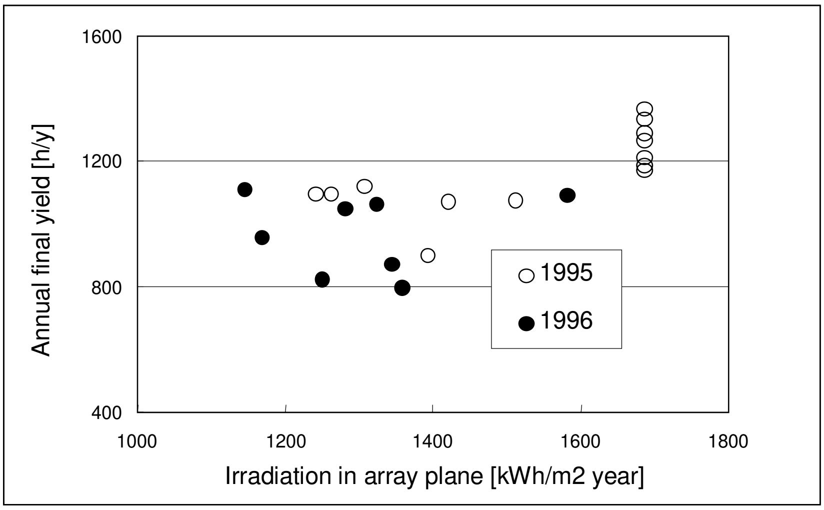


Figure 6.7.2: Annual final yield vs. irradiation in array plane for 21 PV systems in 1995 and 1996

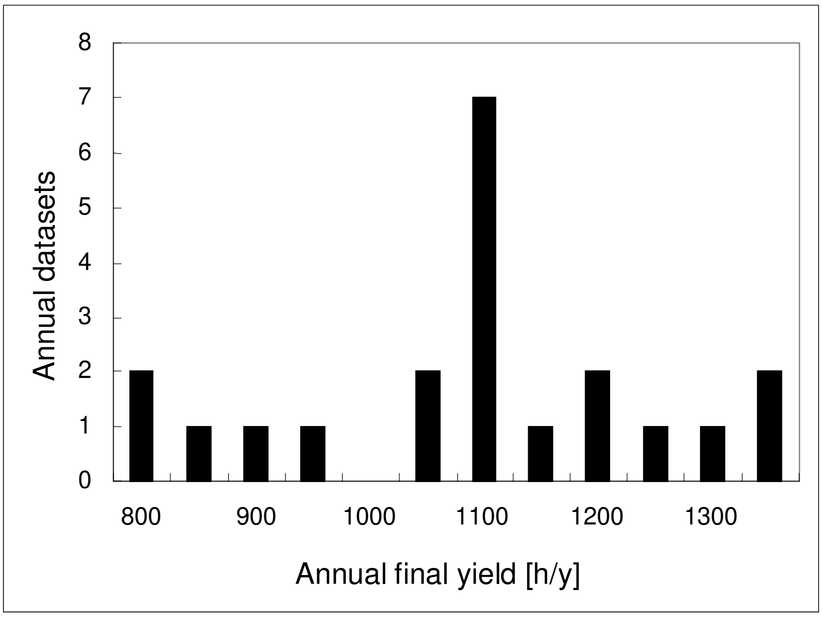


Figure 6.7.3: Distribution of annual final yield for 21 PV systems in 1995 - 1996

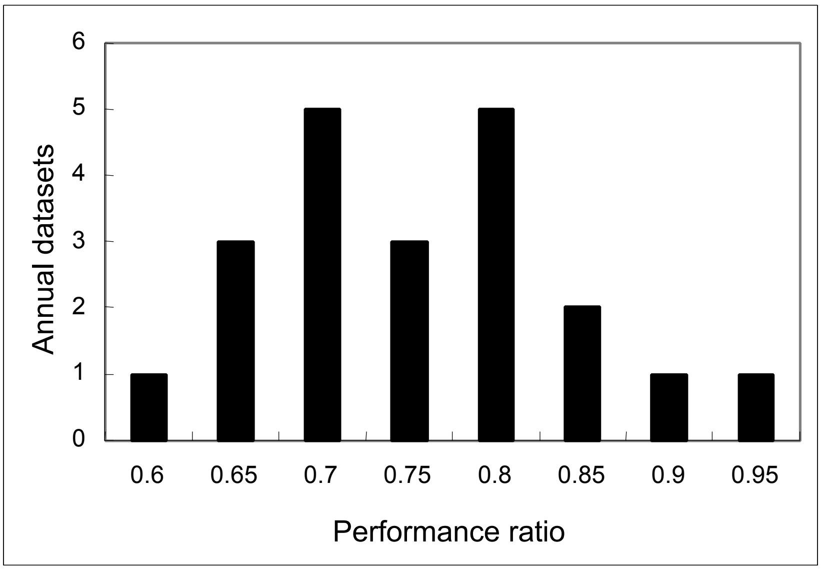


Figure 6.7.4: Distribution of performance ratio for 21 PV systems in 1995 - 1996

6.7.4 Typical examples of operational performances

As typical examples, three PV systems installed in FY 1993 under the field test program of NEDO are described in this section. All the systems are using single crystalline silicon PV modules. The main loads of these systems are the lighting and air-conditioning of the building. The outline of the systems and their locations are summarized in Table 6.7.4. Some of the typical annual operational performances of three grid-connected PV systems in 1996 are shown in Figures 6.7.5 – 6.7.10.

Table 6.7.4: Outline and location of the example PV systems

No.	Name	Latitude	Longitude	N. Power	Type of Cell
1)	Ichinoseki City I-Dome	38.90 (N)	141.16 (E)	20 kWp	Single Crystal Si
2)	Nursing Home Myokenso	35.40 (N)	134.62 (E)	30 kWp	Single Crystal Si
3)	Hijikawa Town Museum	33.45 (N)	132.70 (E)	20 kWp	Single Crystal Si

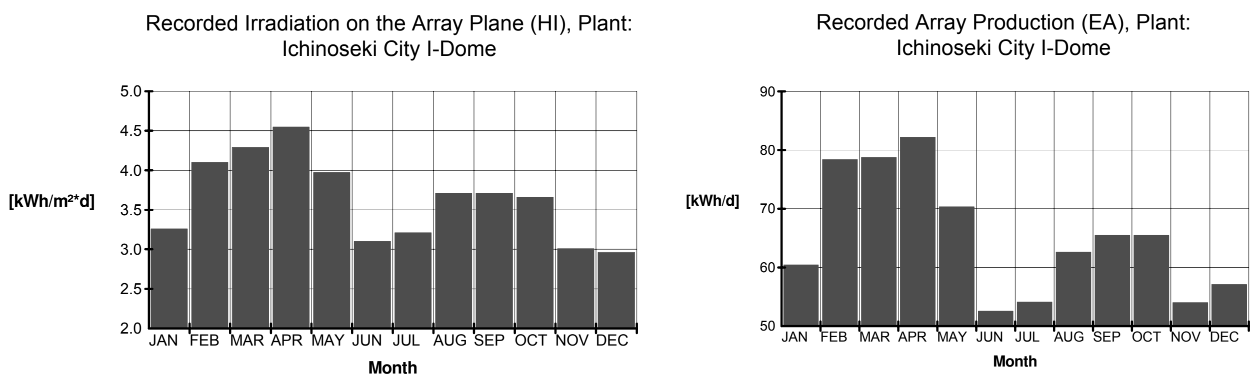


Figure 6.7.5: Monthly irradiation in array plane and monthly PV array output for a selected system

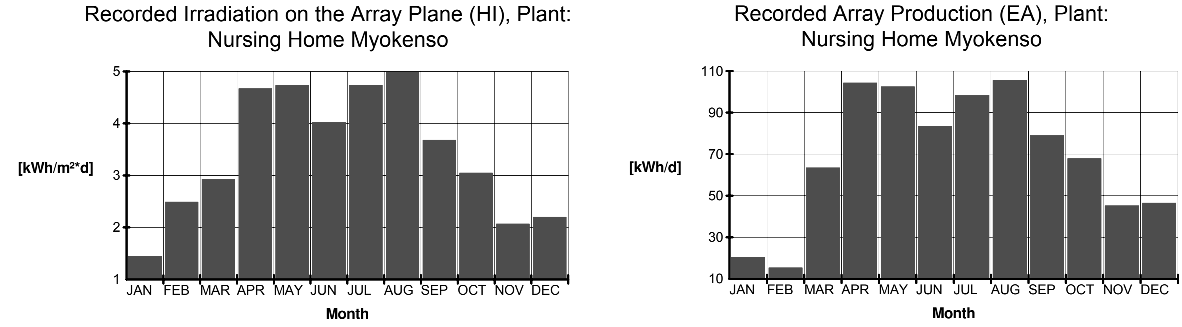


Figure 6.7.6: Monthly irradiation in array plane and monthly PV array output for a selected system

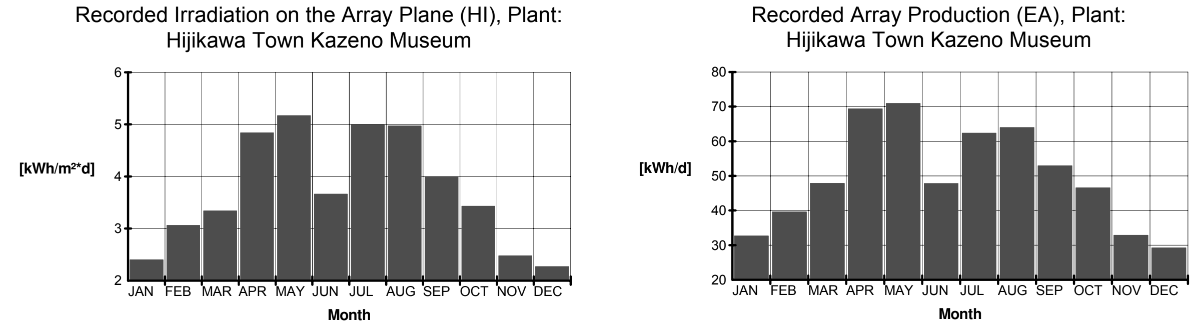


Figure 6.7.7: Monthly irradiation in array plane and monthly PV array output for a selected system

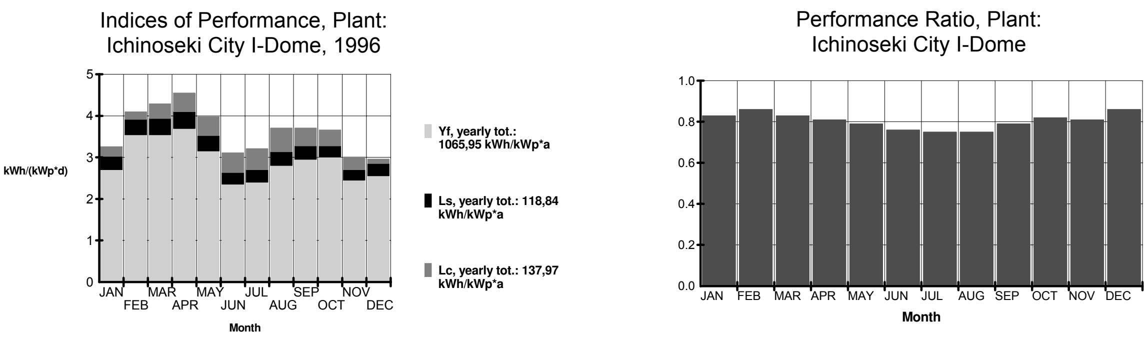


Figure 6.7.8: Monthly final yield, array capture losses and system losses as well as monthly performance ratio (PR) for a selected system

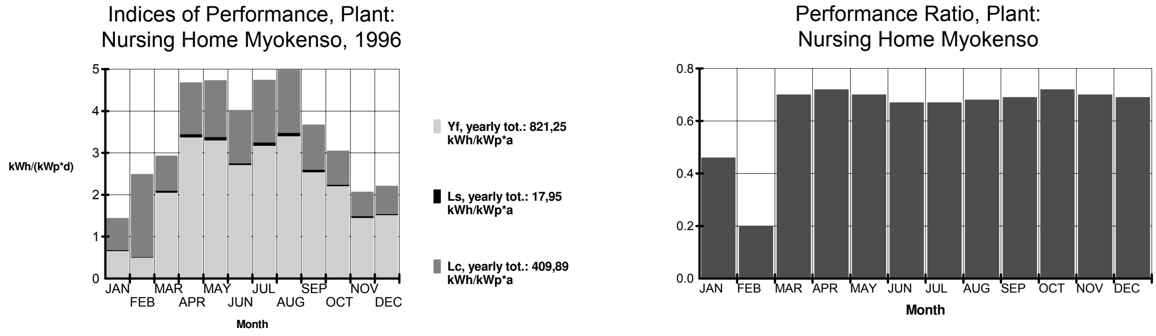


Figure 6.7.9: Monthly final yield, array capture losses and system losses as well as monthly performance ratio (PR) for a selected system

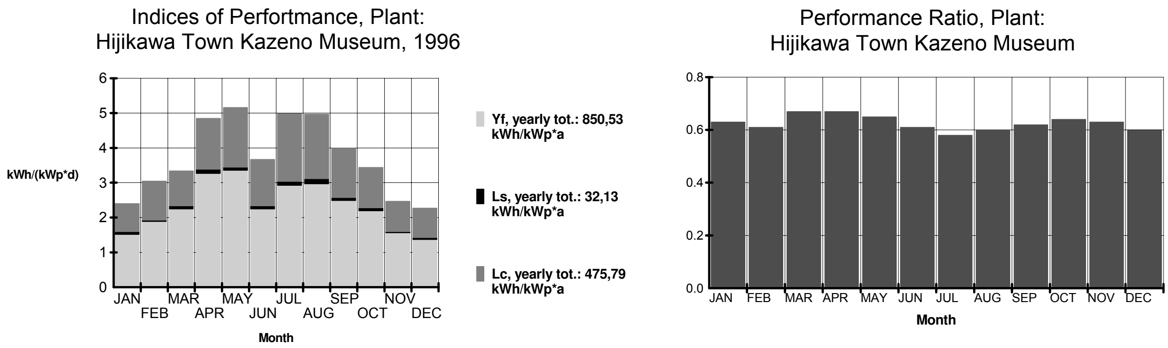


Figure 6.7.10: Monthly final yield, array capture losses and system losses as well as monthly performance ratio (PR) for a selected system

6.7.5 Discussions

A large part of the PV systems installed in Japan during the last few years under several different programmes are operating in good condition, and the resulting operational performances are good in general. It is important to continue monitoring these systems for a long period to evaluate long term operational performance of the systems.

The total capacity of PV systems installed in Japan is increasing rapidly during the last few years because of the governmental promotion programmes, namely the Field Test Programme and the Monitoring Programme of Residential PV Systems. It is estimated to be approaching 100 MW at the end of FY 1998. The operational data gathered and analysed in these monitoring programmes will help improve operational performance of the existing systems and also help design of the future systems.

Some of the monitored data, especially in the early stage of the monitoring programme, showed unusual values because of the troubles in the data collection / transmission systems. In the case of batch monitoring systems using mass storage media, such as floppy disks and MO disks, it is difficult to notice inconsistent data immediately. On-line monitoring using telephone lines is highly recommended.

6.8 Netherlands

6.8.1 Reported systems in the context of the national programme

The Dutch government Policy Document on Energy Conservation states the intention that renewable sources should make a significant contribution of at least 5 % to the country's energy supply by the year 2010. In order to achieve this objective, several programmes are being carried out under management of the Netherlands Agency for Energy and the Environment (NOVEM). NOVEM acts on behalf of several Dutch government departments, in particular the Ministry of Economic Affairs and of Housing, Planning and Environment, as well as the International Organizations such as the International Energy Agency and the European Union. The long-term goal of the photovoltaic solar energy programme is to create the right conditions for solar cells to make a major contribution to the Netherlands energy supply. A considerable amount of the programme budget is spent on solar cell research, but considerable effort is also being devoted to system research and demonstration programmes, with emphasis on grid-connected systems and the integration of solar panels in buildings. Experience is being gained through PV projects ranging from facades to roofs in dwellings and commercial buildings. The reported systems fit in the learning process, which involves technical and non-technical issues. Technical issues comprise evaluation of system components, system layout, grid connection, safety and building integration. Non-technical issues comprise economics, ownership, legal aspects, maintenance and home guarantees.

6.8.2 Description of the PV systems and their location

In total twelve systems have been reported with the number of grid-connected systems (eight) exceeding the number of stand-alone systems (four). The location of the reported systems is evenly distributed across the country and from a statistical point of view the number of solar hours ranges from 1 000 in the middle and eastern part of the country to 1 100 in the north western part. Because of the flat character of the country the altitude is considered as being not relevant.

PV system information in terms of identification, name, location and characteristic issues is available in Table 6.8.1.

Table 6.8.1: PV system information

Plant identification	Plant name	Plant characteristics	Location	Specific issues, points of interest
11000	HHW AC18	grid-connected, 2.43 kWp	Heerhugowaard	- system reliability - inverter reliability - system performance - different orientations - applied integration technology
11001	HHW AC20	grid-connected, 2.34 kWp	Heerhugowaard	- system reliability - inverter reliability - system performance - different orientations - applied integration technology
11002	HHW SU02	grid-connected, 2.43 kWp	Heerhugowaard	- system reliability - inverter reliability - system performance - different orientations - applied integration technology
11003	HHW SU04	grid-connected, 2.34 kWp	Heerhugowaard	- system reliability - inverter reliability - system performance - different orientations - applied integration technology
11004	de Wijk	grid-connected, 7.526 kWp	de Wijk	- effectiveness of inverters in master slave operation - PV-system operational behaviour
11007	a-Si centrale	grid-connected, 1 kWp	Petten	- operational behaviour, key issues: ageing effects on modules, cabling, support
11008	p-Si centrale	grid-connected, 1 kWp	Petten	- operational behaviour, constructions and safety aspects
11009	Zero Energy House	grid-connected, 3.3 kWp	Zandvoort	- physical roof integration concept - operational behaviour
11012	Woubrugge	grid-connected, 3,6 kWp	Woubrugge	- evaluation of advanced
11013	10 kWp plant	grid-connected, 10 kWp	Petten	- demonstration of modular standardized systems - cost effectiveness of standardization of construction and support structure - the effect of undersized inverters on yield figures
11014	PV-Abri	stand-alone, 0.2 kWp	Petten	- system sizing, system performance
11015	Solarweir			- energy service, system sizing
11016	PV Street Posts			- energy service, system sizing
11018	Helofyte filter			- energy service, system sizing

6.8.3 Yield figures, system losses, system performance and efficiency figures (GCS)

For the comparison of PV systems normalized performance indicators are used. These indicators are obtained by dividing the system energies by the nominal power. This feature simplifies evaluation of performance data. The following parameters of Table 6.8.2 apply:

Table 6.8.2: Overview of normalized performance indicators

Parameter	Symbol	Unit	
Nominal power	P_0	[kWp]	Design value of the PV array output at the maximum power point under standard test conditions
Reference Yield	Y_r	[h/d]	H_I divided by $G_{I,STC}$, or the total daily in plane irradiation divided by STC reference in-plane irradiance
Array Yield	Y_A	[h/d]	Daily average energy output $E_{A,day}$ per kWp of installed PV array
Final Yield	Y_f	[h/d]	The useful output of the PV plant per kWp installed
Capture losses	L_C	[h/d]	Y_r - Y_A
System losses	L_S	[h/d]	Y_A - Y_f
Performance ratio	PR	-	Y_f / Y_r

The daily values are usually averaged over the recording period, usually one month. The daily system performance values Y_r, Y_A and Y_f are superimposed for each day for each month and are presented in a bar graph for 6-monthly or yearly summaries.

Figures 6.8.1, 6.8.2 and 6.8.3 present a typical representation of performance behaviour of a grid-connected system. The final yield of the system is 30 % lower than expected, caused by the malfunctioning of the cascade operation of the inverters and the imperfect power point tracking. Efficiency figures show a rather poor inverter efficiency for the reasons explained, but rather poor array efficiency figures as well and hence a poor overall system efficiency.

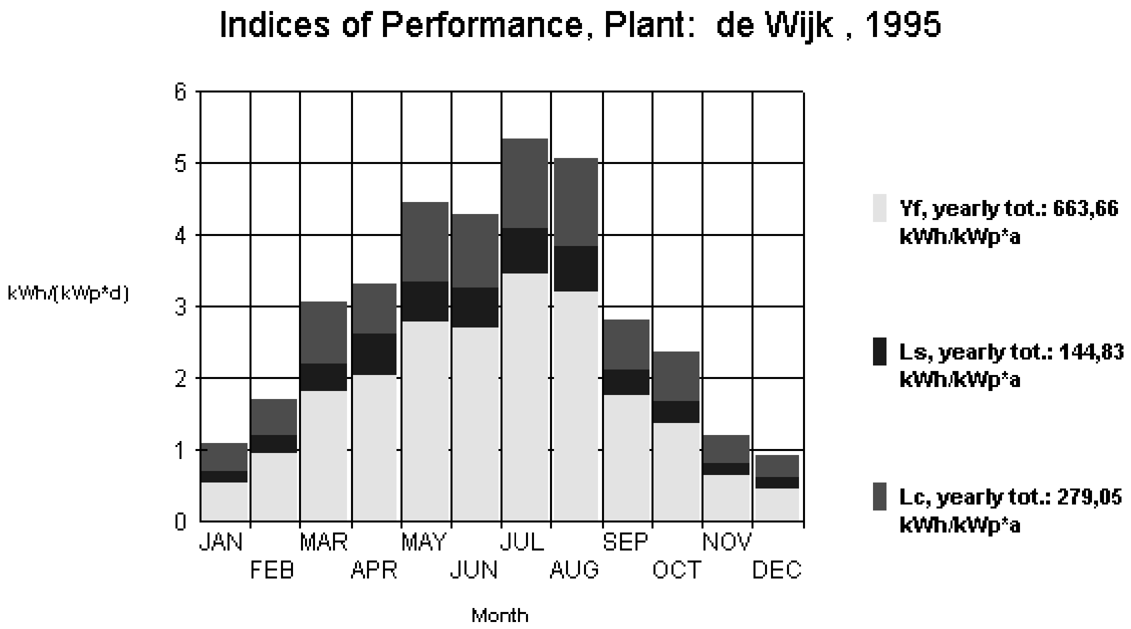


Figure 6.8.1: Monthly superimposed performance values for the grid-connected plant "de Wijk"

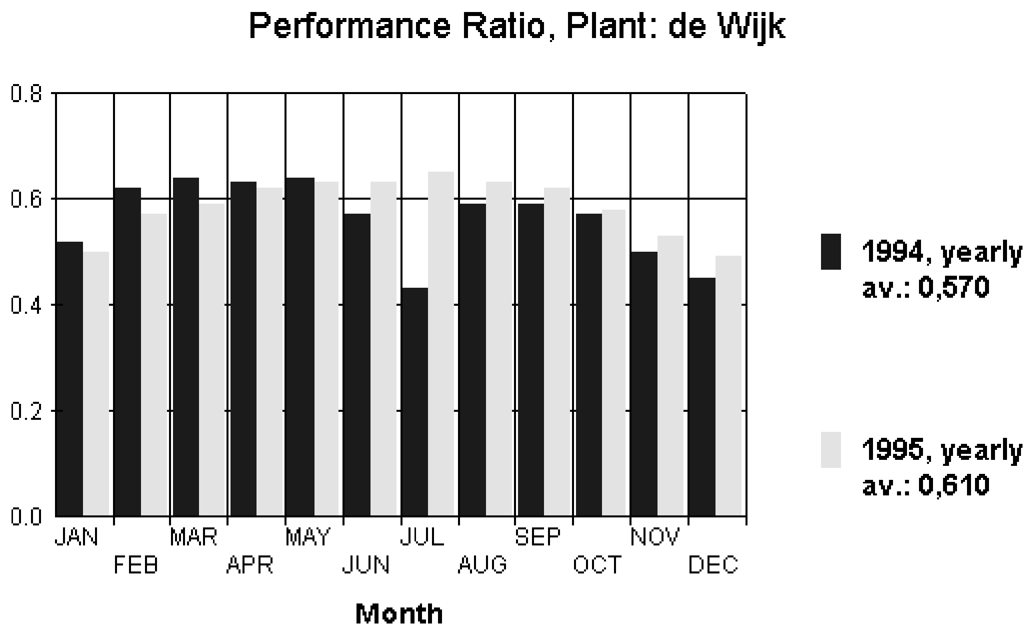


Figure 6.8.2: Monthly performance ratio figures of the grid-connected system "de Wijk" over a two years period

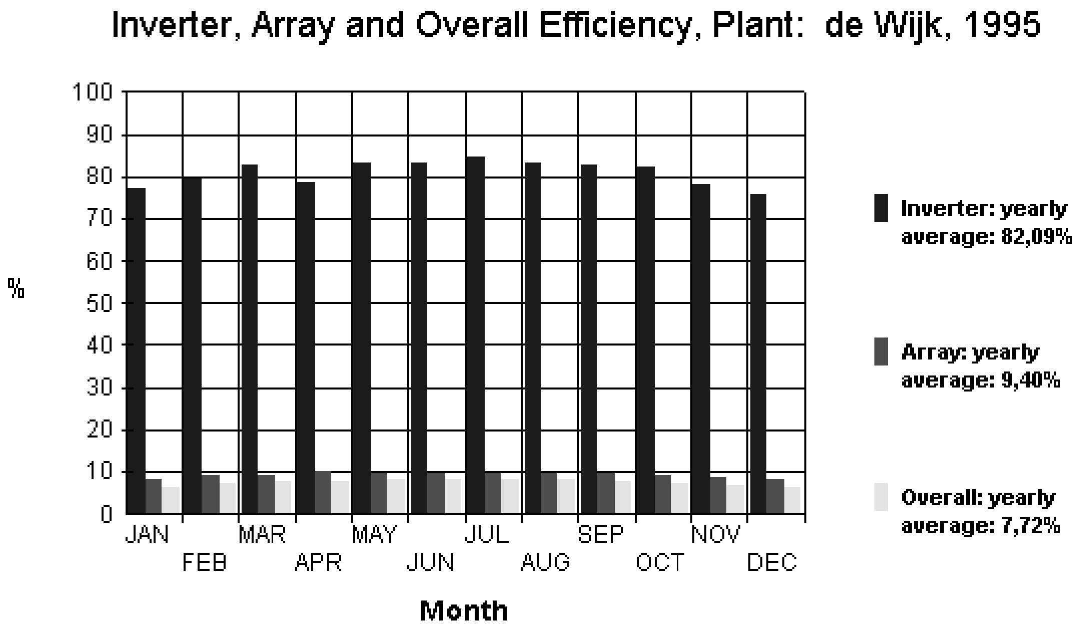


Figure 6.8.3: Monthly efficiency figures of the grid-connected system "de Wijk" over a one year period

6.8.4 Monthly mean values, yearly sums (GCS)

A specific feature in the PVreport programme enables the visualization of monthly energy sums on a yearly basis. As an example Figure 6.8.4 shows clearly the mismatch of energy from the utility E_{FU} and energy from the PV system E_{IO} over the year and in addition the mismatch of energy to utility E_{TU} and E_{FU}.

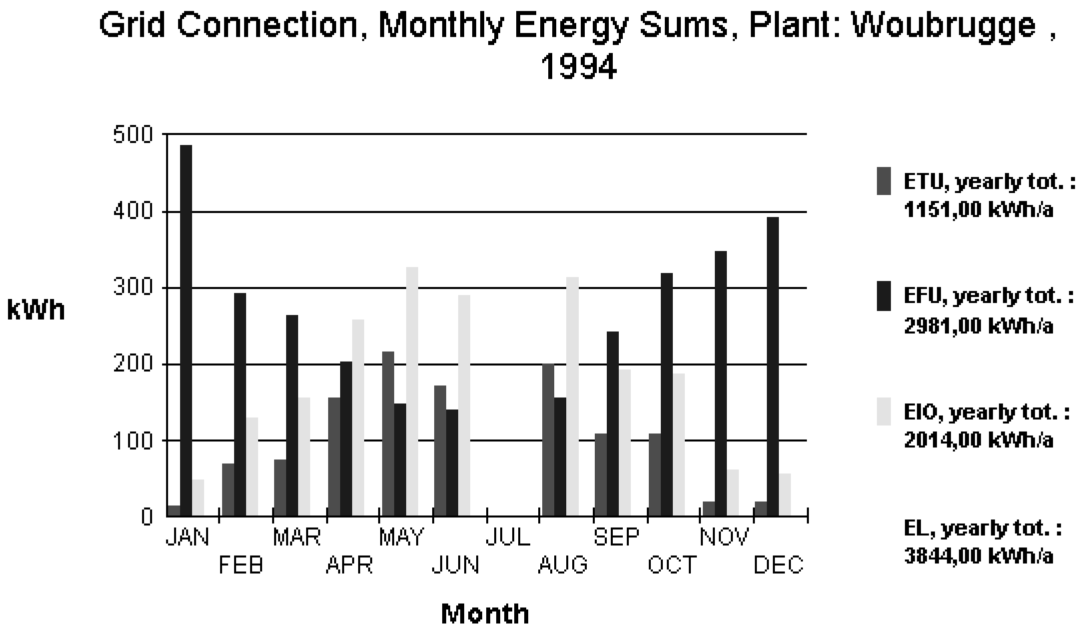


Figure 6.8.4: Monthly energy values and yearly sums of the grid-connected system "Woubrugge"

6.8.5 Performance values for stand-alone systems

Present issues for performance evaluation of stand-alone systems in terms of performance ratio are considered as being inadequate. The performance ratio gives a normalized indication of the useful energy that has been delivered to the loads. Poor performance figures can be caused by a bad system efficiency and an inadequate use of solar energy. Figure 6.8.5 presents some characteristic values of a stand-alone system (PV-Abri) and the figure shows clearly that there exists a great surplus of energy in summer, which phenomenon is emphasised in Figure 6.8.6. The required capacity of the battery increases strongly as the array yield in wintertime does not cover the required load energy. Because of high battery costs and the limited life expectancy, a large storage capacity is considered as being a disadvantage. Storage of the energy surplus in summer for the coverage of energy shortage in winter is therefore not an option. For that reason the PV generator is oversized by a factor 4. These considerations play an important role in the sizing of stand-alone systems. The "Matching Factor" (MF), introduced by WIP in Munich, being the product of performance ratio and the PV array fraction (see section 5.2), shows how well a stand-alone system matches the electrical consumption. For the system under consideration MF = 0.28, which represents an average performing system, taking into account that figures of MF = 0.6 are achievable.

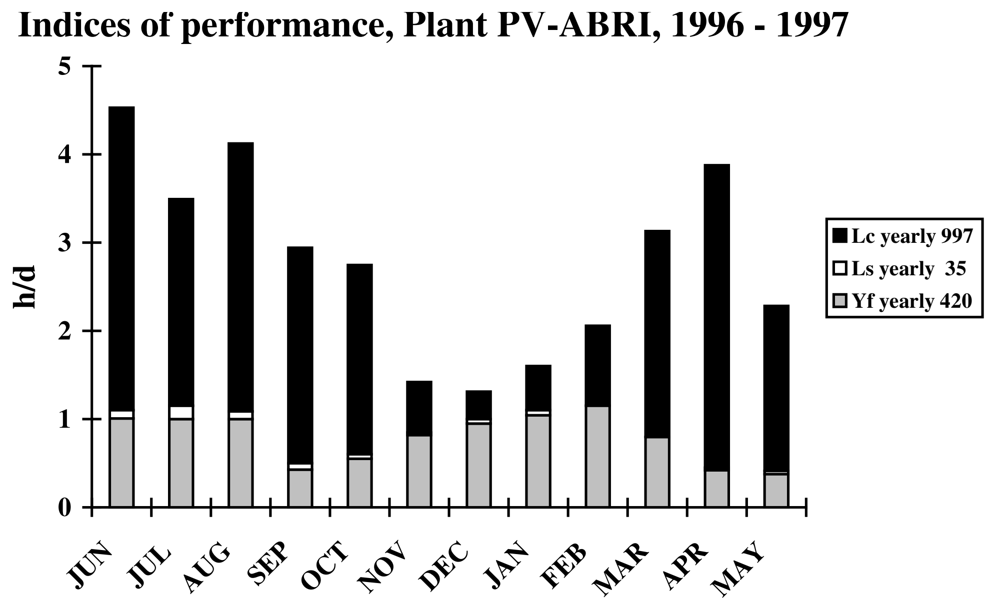


Figure 6.8.5: Monthly superimposed performance values and yearly sums of the stand-alone system "PV-ABRI"

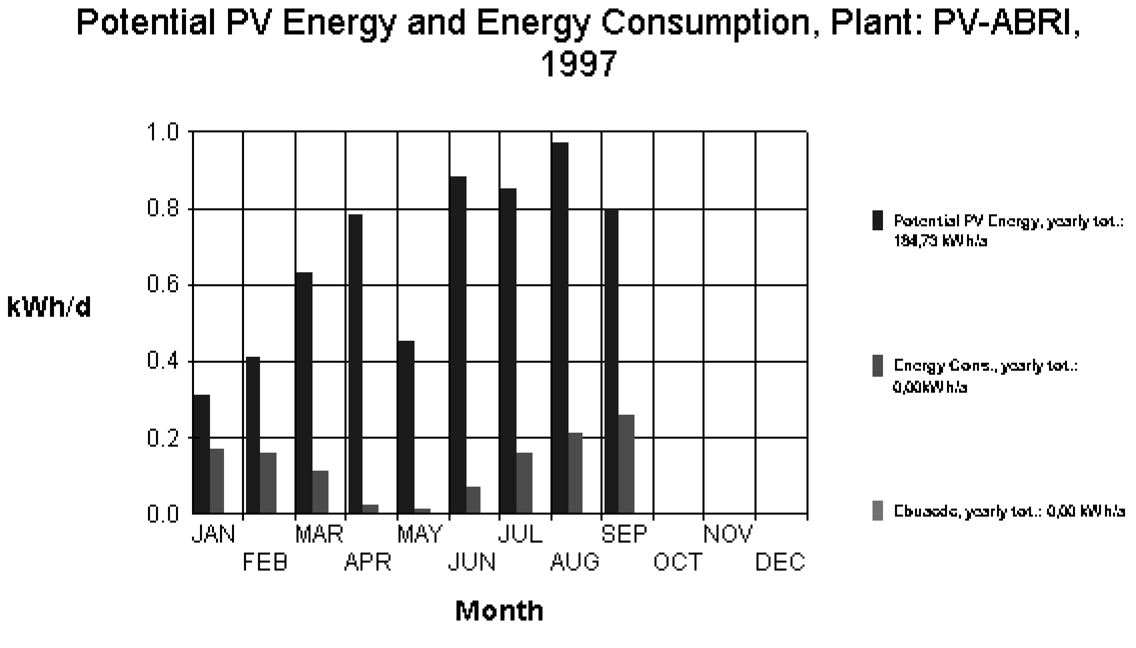


Figure 6.8.6: Monthly values and yearly sums of available PV energy and energy consumption of the stand-alone system "PV-ABRI"

6.8.6 Performance figures of multiple systems

Figure 6.8.7 addresses the yearly performance ratio figures of the grid-connected systems and enables comparison of performance figures of multiple systems. The performance ratio varies between 0.6 and 0.8, with an exception of „de Wijk“. Another figure addresses the presentation of the performance ratio versus nominal power (Figure 6.8.8).

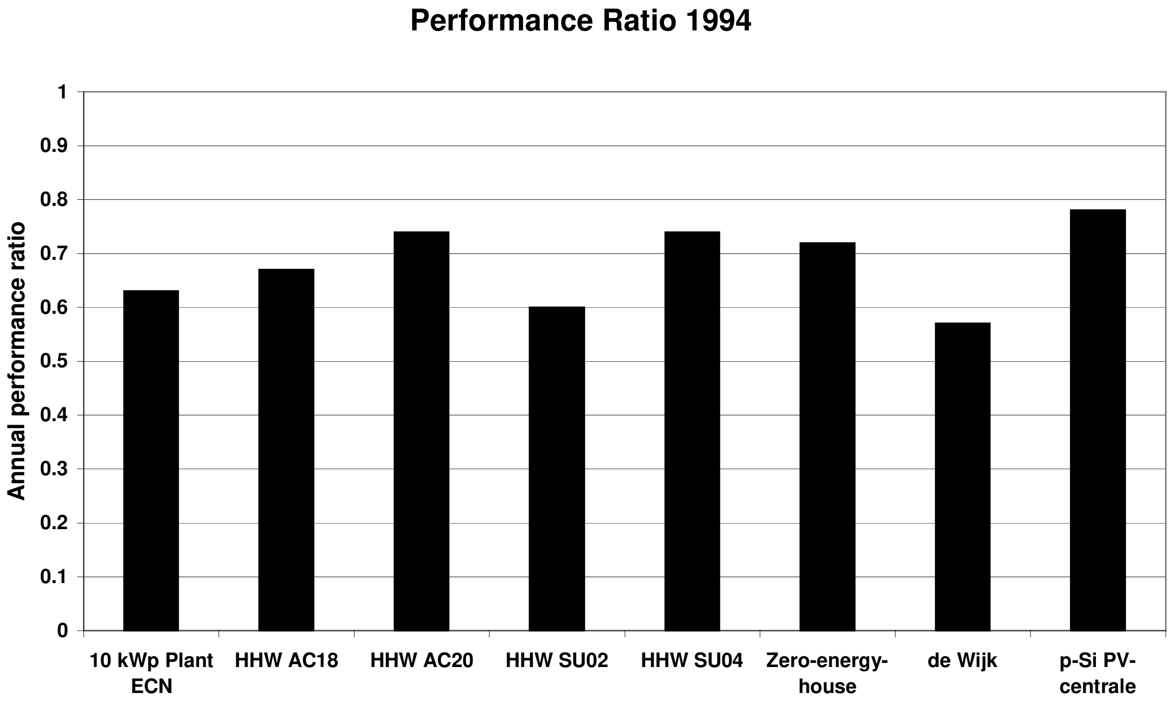


Figure 6.8.7: Performance ratio figures of grid-connected systems over a one year period

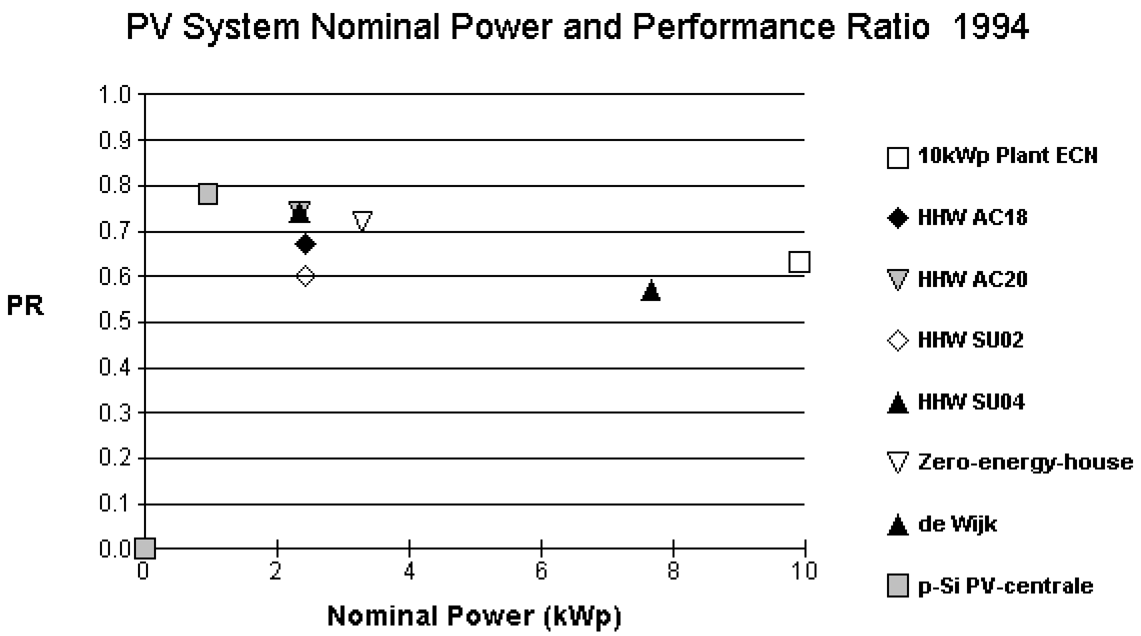


Figure 6.8.8: Performance ratio versus nominal power of grid-connected systems

6.8.7 Summary of results

The following characteristic yearly values of reported grid-connected p-Si systems can be derived:

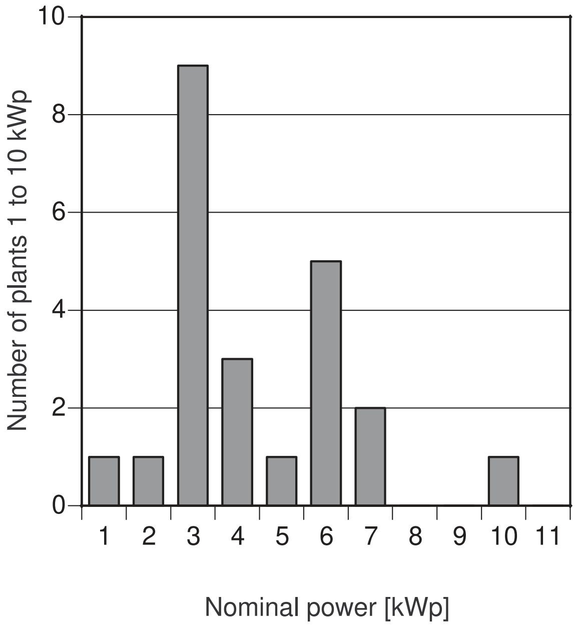
Total nominal power:	P_0	=	34	kWp
Average array efficiency:	$\eta_{A,mean}$	=	9.71	%
Average global in-plane irradiation:	H_I	=	1 023	$kWh/(m^2{\cdot}y)$
Average reference yield:	Y_r	=	2.80	h/d
Average array yield:	Y_A	=	2.31	h/d
Average final yield:	Y_f	=	1.92	h/d
Average performance ratio:	PR	=	0.67	
Overall PV plant efficiency:	η_{tot}	=	8.65	%
Average inverter efficiency:	η_I	=	87.8	%
Annual final yield:	Y_f	=	705	h/y

6.9 Switzerland

From 1994 onwards data from three national PV programmes were collected for the IEA-PVPS Database (PVbase):

- National PV Promotion Programme, from 1992-1996,
- National Programme “PV in Vocational Schools”, from 1993 – ongoing,
- National Programme in Photovoltaic Energy Conversion, from 1996 – ongoing.

The PV systems chosen for the IEA-PVPS database are mainly R&D projects within the national programmes where continuous monitoring was carried out for at least one year. All the project holders were requested to monitor and evaluate the PV systems according to the EU Guidelines „Photovoltaic System Monitoring“ and to make monthly datasets available for the IEA-PVPS Task 2 database in a pre-defined format. To date, data from 43 Swiss PV systems have been entered into the database (PVbase). The nominal power of these plants ranges from 1 kWp to 560 kWp and totals 1 524 kWp. Only five plants are mounted in a facade and are of a building integrated type (BIPV). The other 38 plants are south facing and have a sloped mounting. All 43 plants are grid-connected power stations. Some plants are owned by the federal or canton administration, some are owned by private or public organizations and some are privately owned. They are located in all the geographical regions of Switzerland at various altitudes ranging from 200 m to 3 600 m above sea level.



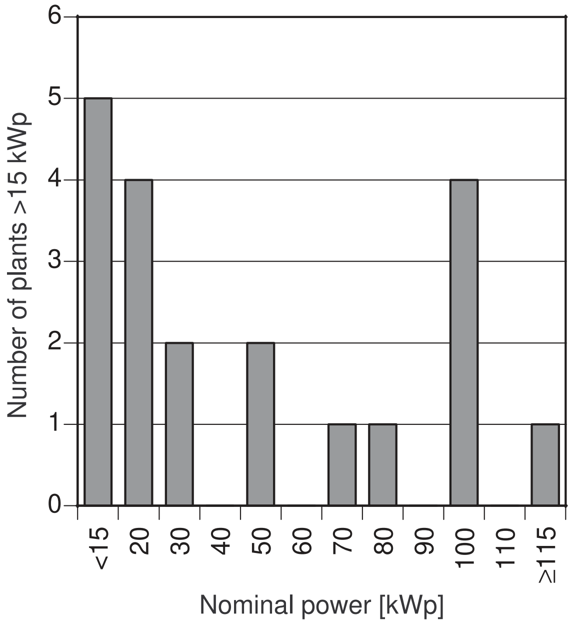


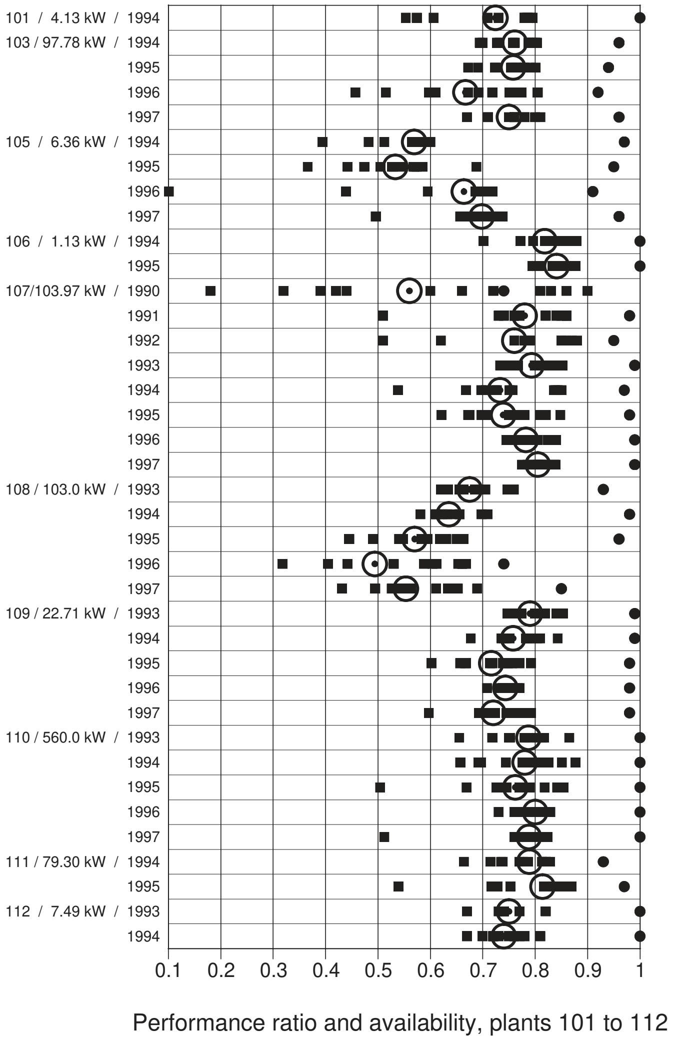
Figure 6.9.1: Nominal power (1 kWp to 10 kWp) of the 43 Swiss grid-connected PV systems in the IEA-PVPS database (PVbase)

Figure 6.9.2: Nominal power (> 15 kWp) of the 43 Swiss grid-connected PV systems in the IEA-PVPS database (PVbase)

In addition to the general information of the 43 grid-connected PV systems a total of 1 440 monthly datasets of operational data was collected and imported into the IEA-PVPS database. The annual datasets range from one to eight years of operational data per plant, totalling 120 operational years. The following evaluation focuses mainly on the operational performance of the 43 plants. No specific distinction as to the location, altitude, orientation of the array and size of the plant was made.

6.9.1 Performance and availability (part 1)

Figure 6.9.3, Figure 6.9.5 and Figure 6.9.7 show annual and monthly values of the performance ratio and the availability of all 43 plants from the years 1990 to 1997 (where datasets are available) totalling 120 operational years. The first column on the left shows the plant number, the nominal power and the year of measurement. Because of insufficient or inconsistent information available only datasets from 43 plants within the range of 101 to 160 were considered representative. The monthly values of the performance ratio are represented by a square dot and the annual value by a circle. The round dot shows the annual value of the availability of the plants calculated by the difference of the value „1“ and the outage fraction (O).



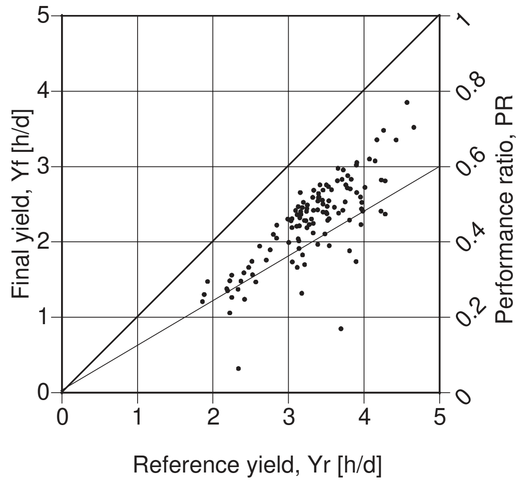
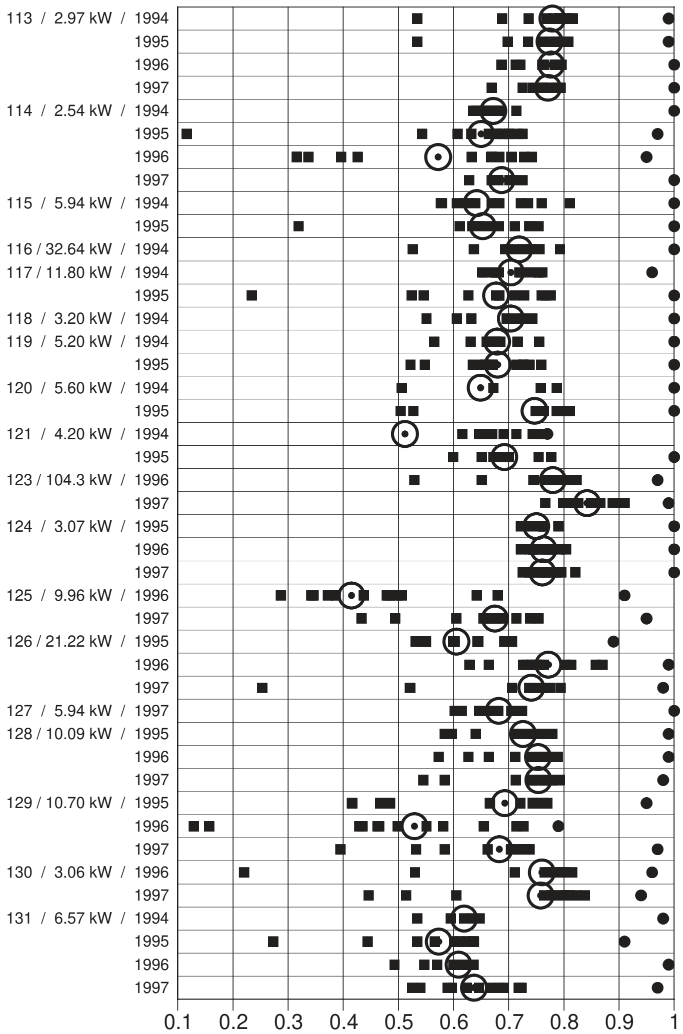


Figure 6.9.3: Performance ratio and availability, 1 440 monthly and 120 annual datasets, sorted by plant number and year, from 43 Swiss plants (part 1)

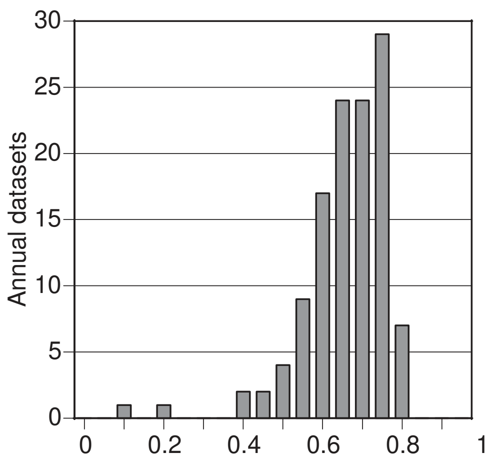
Figure 6.9.4: Reference yield vs. final yield, 120 annual datasets from all 43 Swiss plants

Figure 6.9.4 shows the annual values of the reference yield (Y_r) and the final yield (Y_f) for the 120 operational years of the 43 plants. The mean value of the reference yield is 3.32 h/d and for the final yield 2.27 h/d giving an average performance ratio of 0.69 (Figure 6.9.6) at an availability of 95 % (Figure 6.9.8) for all the plants.

6.9.2 Performance and availability (part 2)



Performance ratio and availability, plants 113 to 131

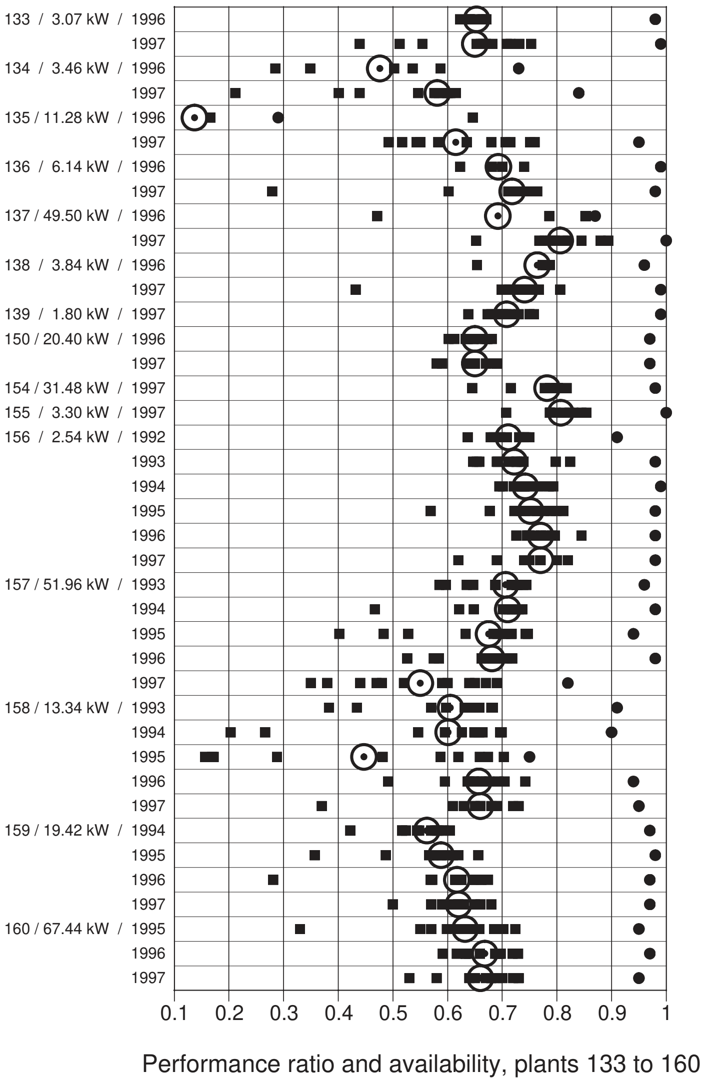


Performance ratio, PR

Figure 6.9.5: Performance ratio and availability, 1 440 monthly and 120 annual datasets, sorted by plant number and year, from 43 Swiss plants (part 2)

Figure 6.9.6: Histogram of the performance ratio, 120 annual datasets from all 43 Swiss plants

6.9.3 Performance and availability (part 3)



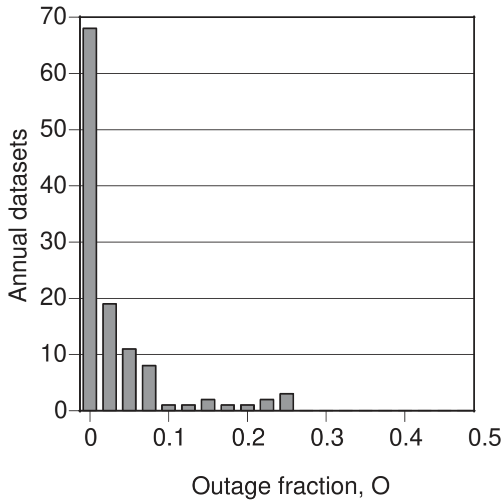


Figure 6.9.7: Performance ratio and availability, 1 440 monthly and 120 annual datasets, sorted by plant number and year, from 43 Swiss plants (part 3)

Figure 6.9.8: Histogram of outage fraction (O) from 120 annual datasets from all 43 Swiss plants

The mean outage fraction (O) for the 120 years of operation of the 43 plants is 0.05 (Figure 6.9.8). This high value of 95 % availability is due to the fact that most of the plants are monitored as part of a R&D project and are therefore closely watched by the operator at all times. Any malfunctioning is usually rectified within a short period of time.

6.9.4 Selected data from all 43 plants

For the following evaluation and normalized presentation one set of annual operational data for each of the 43 plants was selected. The criterion for the selection was a high availability of the plant. The results should therefore be representative for a well maintained and operating grid-connected PV plant.

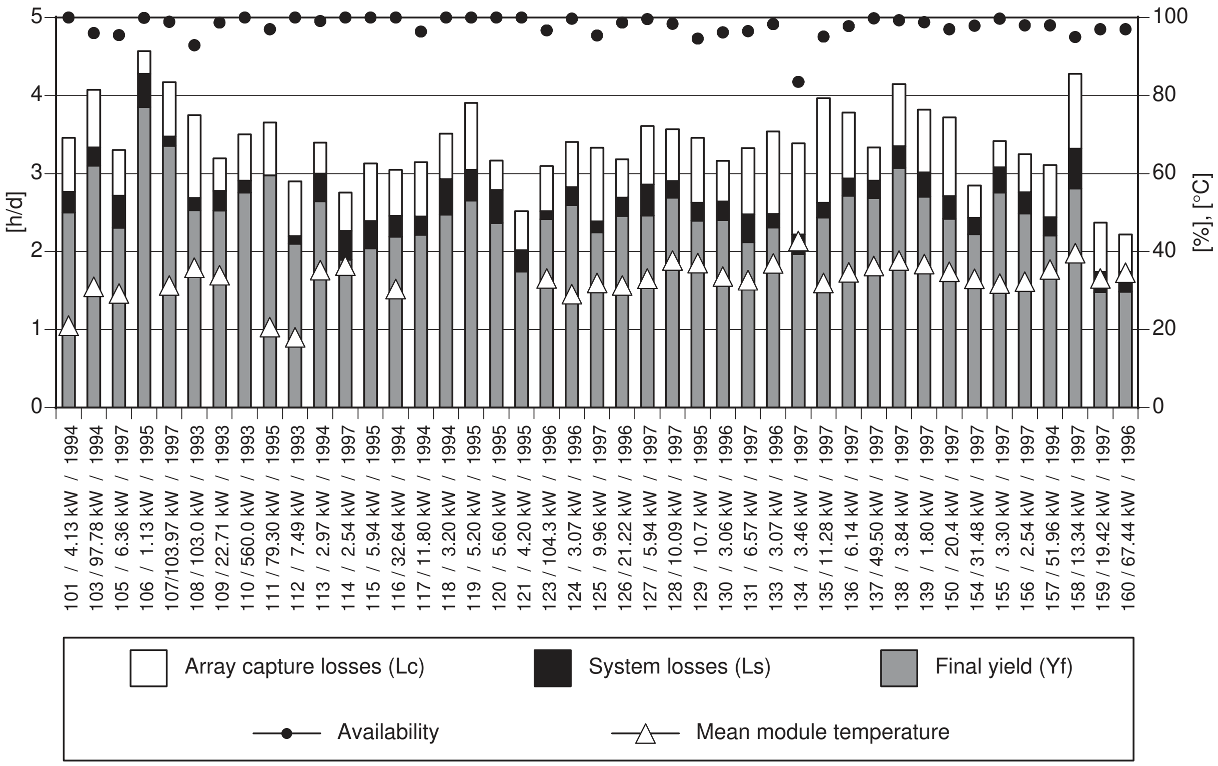
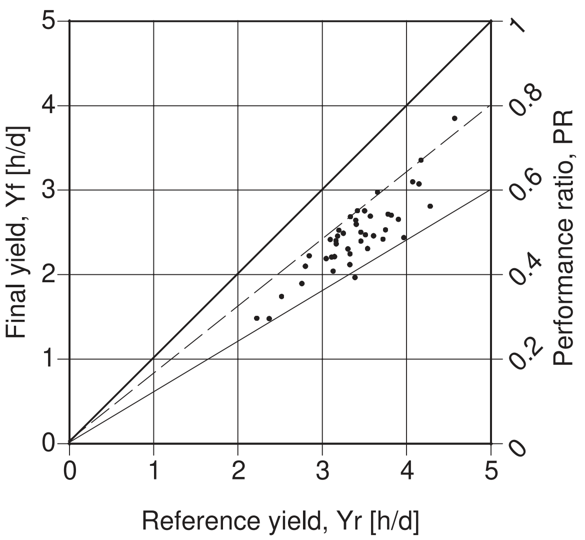


Figure 6.9.9: Yield and losses, availability and module temperature of the 43 Swiss systems (selected years)



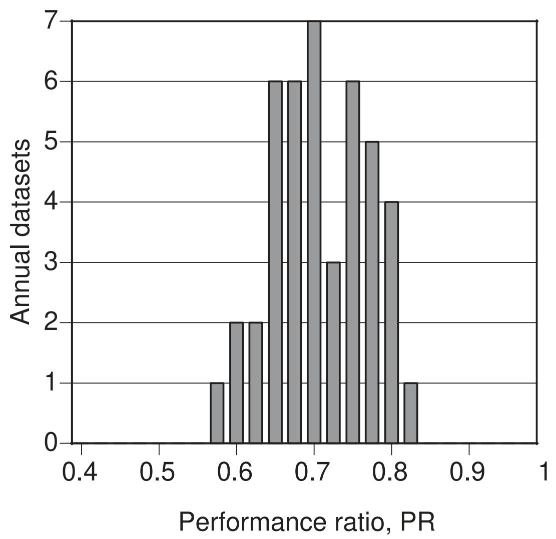
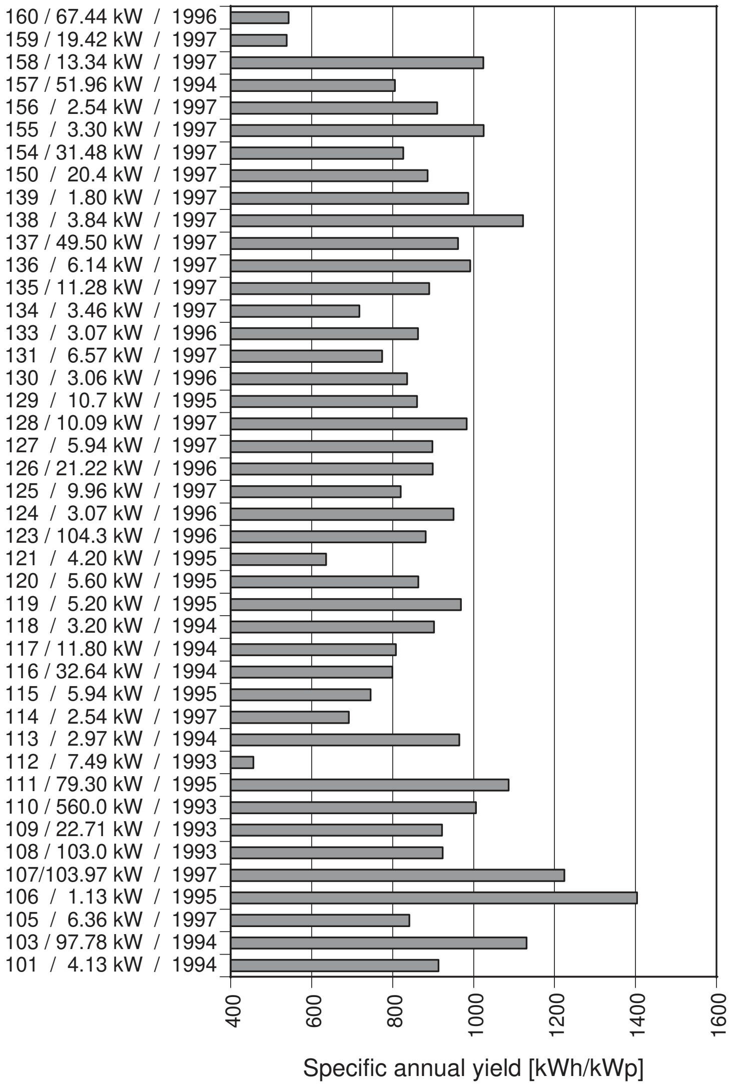


Figure 6.9.10: Final yield vs. reference yield of the 43 Swiss systems

Figure 6.9.11: Performance ratio of the 43 Swiss systems (selected years)

Annual Yield



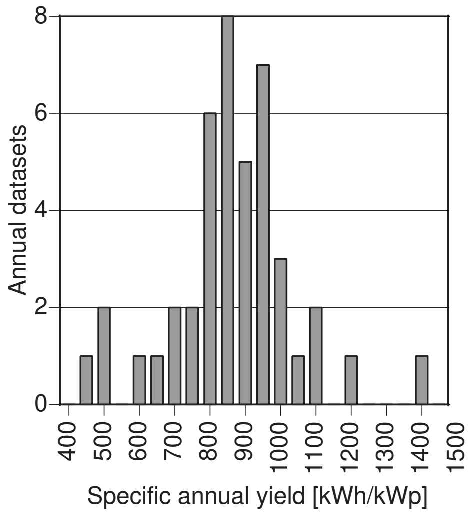
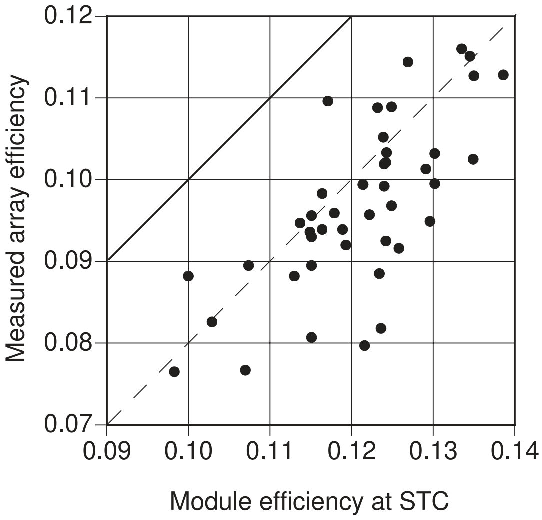


Figure 6.9.12: Specific annual yield of the 43 Swiss systems (selected years)

Figure 6.9.13: Specific annual yield of the 43 Swiss systems (selected years)

Array efficiency



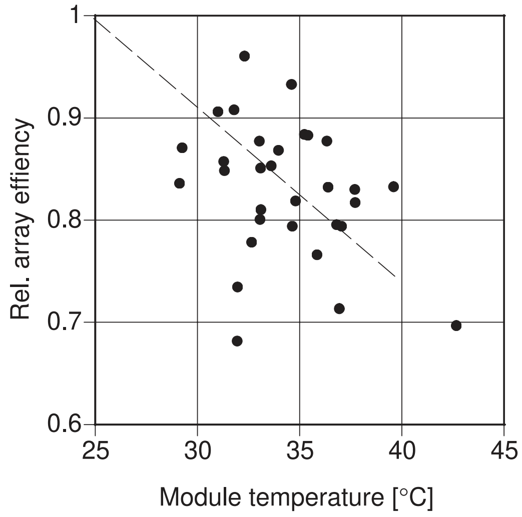


Figure 6.9.14: Array efficiency of the 43 Swiss systems (selected years)

Figure 6.9.15: Array efficiency of the 43 Swiss systems (selected years)

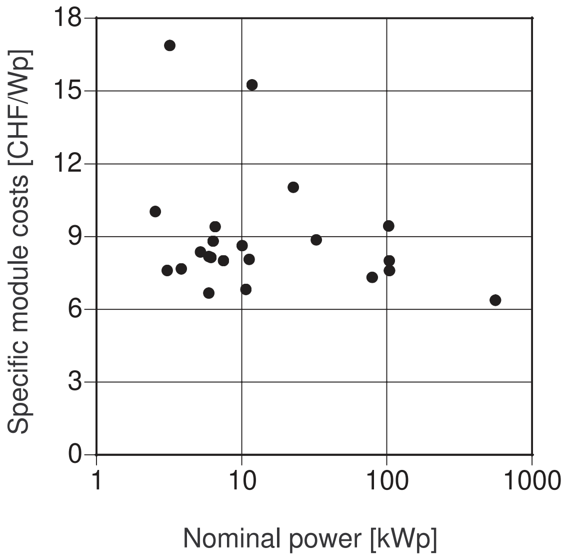
6.9.5 Interpretation of results for the selected years of all 43 plants

In this evaluation no distinction has been made as to the mounting of the PV array and to the type of mounting. Some of the plants are free-standing with an optimum orientation to the sun, some are vertical and others are also integrated into a building's facade. All these factors also have an influence on the system performance.

- Performance ratio
  The mean performance ratio (PR) is 0.723 at an availability of 98 % (Figure 6.9.10 and Figure 6.9.11).
- Specific annual yield
  The mean annual yield is 948 h/y (Figure 6.9.12 and Figure 6.9.13).
- Array efficiency
  The measured annual array efficiency at a mean module temperature of 35 °C is about 20 % below the module efficiency at STC (Figure 6.9.14 and Figure 6.9.15).

6.9.6 Costs

From the 43 PV systems in the database only 22 have data on the cost of the modules and 25 on the cost of the whole plant. The specific costs have not been adjusted to the current year.



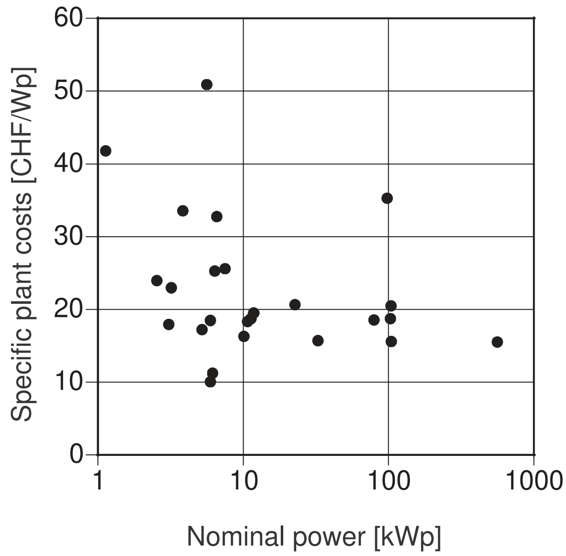


Figure 6.9.16: Specific module costs for 22 PV systems of the 43 plants in CHF / Wp

Figure 6.9.17: Specific plant costs for 25 of the 43 plants in CHF / Wp

6.9.7 Conclusion

The 43 grid-connected Swiss PV systems in the IEA-PVPS database represent about 4 % by number or 16 % by nominal power of 1 100 currently installed grid-connected systems with a total nominal power of 9.3 MWp (Dec. 1998). The average annual yield of 948 h/y corresponds closely with the results of studies carried out on annual samples of about 200 systems by the Swiss Electricity Producer and Distributor Association (VSE) and others since 1989.

7 EXPERIENCES

7.1 Lessons learnt

The significant experiences and lessons learnt are very different from country to country depending on the type of system, the monitoring programme and the background information which is available about the PV systems in the database and from other sources. In the following, the previous results are summarized and interpreted here for each country taking into account the available background information.

Austria
In Austria, monitoring data are mainly collected for grid-connected PV plants, although the largest number of installations is represented by stand-alone systems (43.5 % of the total installed PV power of 2.2 MWp). It was found that grid-connected installations are able to reach yearly performance ratio values higher than 0.7, especially in Alpine regions, while facade projects have shown bad monthly performance ratios in the range of 0.35 to 0.4 in summer and 0.55 to 0.7 in winter. The annual final yield ranges from 400 h/y to 800 h/y for six selected grid-connected PV systems.

The monitoring and measuring initiatives delivered useful information for developing solar strategies and new programmes for the installation of PV applications.

European Union
Within the European Photovoltaic Demonstration Programmes, vast experiences could be gained by analytical monitoring of more than 80 systems in a wide application range covering an installed PV power of over 2.4 MWp. Since 1984, monitoring has provided feedback to system operators and thus developed into a key element for good maintenance.

In the beginning there was much concern about the impact of mismatch losses on the output of larger PV systems and the emphasis was on the on-site measurements of the PV array current versus voltage characteristics. With higher reliability and improved quality of PV modules, system aspects and the acquisition of operational data became more important during the course of the programme.

The minimum of monitoring that is required to guarantee results has been introduced and involves at least the measurement of the in-plane irradiation together with supplied energy and supply availability. In order to follow the main trends in system technology, monitoring will be developed towards integrated remote monitoring and independent monitoring will decrease.

France
France has focused its efforts on stand-alone systems which can be split into two categories:

- domestic systems for rural electrification
- professional PV systems

For the first category of stand-alone systems, the performance analysis in terms of performance ratio (PR) shows that the PR does not properly reflect the technical operation of a system (component degradation, low efficiency components) as is the case for grid-connected systems.

Using the matching factor (MF) [1] to characterize the PV system operation allows a better illustration of the performance of PV hybrid systems. A high value of MF indicates that the solar part properly matches the electrical load and limits the back-up contribution. A new factor (usage factor) has been introduced to highlight the difference of PV system operation and allows easy detection of PV systems which present technical problems.

The analysis of the system performance in terms of PR for the second category shows that stand-alone systems designed for professional applications present very low values of PR (0.05 to 0.25), which is the consequence of a conscious oversizing for reliability reasons.

From the analysis of operational data from stand-alone systems in France, it was learnt that contrary to grid-connected systems, the performance ratio alone cannot be used to describe the proper operation of stand-alone systems from a technical point of view.

Ongoing development will involve:

- More detailed and more reliable monitoring campaigns, which are feasible even for small remote systems.
- Several years of measurements to better appreciate the evolution of user behaviour.
- The use of simulation tools to evaluate the influence of new component sizes to increase the system performance.

Germany
Due to a growing interest in grid-connected PV systems and due to the introduced demonstration projects and new initiatives by utilities (rate-based incentives, green pricing), Germany has concentrated on the technical evaluation of PV systems connected to the utility grid. By now most of the 2 000 PV systems within the 1 000-Roofs-PV-Programme have operated for five years and longer so that conclusions can be drawn on long-term performance of a very large number of PV systems.

From the analysis of 88 PV systems in the IEA-PVPS database, it was learnt that the average annual final yield fluctuates only slightly from one year to another around a value of about 700 h/y. However, there is considerable scattering around this average value for individual systems ranging from 400 h/y to 950 h/y and they achieve PR values between 0.4 and 0.82 (PR_{mean} = 0.67). One unexpected loss factor is clearly identified among high and very high array capture losses (L_C in the order of 1.5 h/d): There is a *systematic deviation* of - 5 % to - 15 % of the measured PV nominal power from the rated power specified in the data sheets from the manufacturer. As a consequence of these results, the manufacturers of PV modules have improved the accuracy of their module quoting with respect to STC performance during recent years.

A second major loss factor was detected in the analysis and was investigated within the reduced yield analysis [2] in more detail: *Partial shading of the PV array* leads to a significant reduction of the energy yield of the system. This was measured in numerous systems and can cause annual energy losses of up to 22 % in extreme cases [2]. In order to avoid unnecessary energy losses, a position with as little shading as possible should be chosen for the PV array during the planning phase.

The *susceptibility of the systems to failures*, particularly regarding inverters, has clearly decreased. The PV array has continued to be the most reliable component. Repair costs have increased since the first years after installation. The main reason appears to be that the guarantee on many inverters has expired and that installation companies rarely feel obliged to make repairs free of charge. The inverters of the 40 systems achieve a mean annual efficiency of 88 % and a mean annual availability of 97.1 %.

The investigation of the operational behaviour of the 40 reported PV systems has identified further *potential for optimization*:

- improving efficiencies of components by the selection of high efficiency modules and inverters
- avoiding diode, wiring and mismatch losses
- avoiding MPP inverter losses by optimum components matching
- avoiding high module temperatures by suitable measures of module integration into the building during installation
- avoiding array coverage due to dirt and snow on the PV array surface
- reducing array shading as much as possible during the planning phase

External environmental effects play a negligible role. No cases of lightning striking a PV system are known. Also, in the course of the system operation there have been neither accidents nor fires. This indicates that the 1 000-Roofs-PV-systems are distinguished by a consistently high safety standard.

Israel

The Israeli systems documented in the IEA-PVPS Task 2 database are all located at a research institute in an arid desert (Latitude 30.8° N; altitude above sea-level 475 m; annual global horizontal irradiation 2 000 kWh/(m^2·y); annual rainfall 90 mm). The environmental conditions are highly stressful for system components. As a result, a number of performance characteristics are worthy of mention.

With respect to the *electrical performance of trackers*, experience with the single, horizontal axis, sun-tracking systems was disappointing. In general the system output was found to be lower than the designers had expected. In the case of simple tracking vs. static (Figure 6.5.1), large winter angles of incidence resulted in poor system performance. In the case of mirror-enhanced tracking versus simple tracking (Figure 6.5.2), two effects combined to reduce system output: Summer performance was reduced due to high mirror-enhanced module temperatures; and winter performance was reduced due to non-uniform illumination (an effect that could have been reduced by re-positioning the mirrors). On the other hand, the two-axis tracking system performed more or less according to expectations.

Concerning the *mechanical performance of trackers*, both one-axis and two-axis trackers were found to perform initially in a trouble-free manner. The two-axis tracker (PV system IEC2ax) performed in a trouble-free manner during all of 1993 and the first eight months of 1994. Thereafter, one of its motors failed and the owners decided not to repair it. On the other hand, the one-axis tracker (common to both systems PAZNSm and PAZNS) has performed in a trouble free manner for more than ten years.

With respect to *inverter performance*, frequent inverter failure is observed in winter time, among all of the grid-connected systems (IEC2ax, PAZNSm, PAZsta, PAZNS). Observation suggests that on cold, cloudy days, the sudden occurrence of full-sun conditions creates large current transients which, when combined with the relatively large array voltage, blow the protective fuses in the inverters.

Analysis of *mirror enhancement* showed that V-trough mirrors enhance system performance during days with clear skies (system PAZNSm vs. PAZNS) but not on cloudy days. This is because the amount of diffuse sky radiation reflected by the mirrors is compensated by a comparable amount of sky radiation that is blocked out by the mirrors themselves. Secondly, under clear sky conditions, the array power output is less than the geometrical enhancement factor owing to reduced voltages caused by elevated module temperatures. Finally, mirrors must be positioned with great care in order to prevent non-uniform illumination of the modules at all times of the year. This is not difficult to achieve with two-axis trackers [3], but requires some detailed calculations in the case of one-axis trackers.

Japan

Grid-connected systems are dominant in Japan because of the well-developed utility grid throughout the country. Large parts of the 70 analysed systems, which were installed under different R&D and promotion programmes, are working in good condition and perform as expected. The total capacity of PV systems in Japan is increasing rapidly due to governmental promotion programmes (approx. 100 MWp at the end of 1998). The operational data gathered and analysed in monitoring programmes will help improve the operational performance of the existing systems and also help in the design of future PV systems.

The annual final yield ranges between 800 h/y and 1 350 h/y and the average annual yield seems to be around 1 100 h/y for 21 grid-connected PV systems monitored in 1995 and 1996. The average annual performance ratio is around 0.75 for those grid-connected systems, but there are very large variations of the PR value ranging from 0.6 to 0.95.

Netherlands

In the Netherlands, considerable effort is being devoted to system research and demonstration programmes, with emphasis on grid-connected systems and the integration of photovoltaics in buildings (BIPV). Experience is being gained through PV projects ranging from facades to roofs in dwellings and commercial buildings. The twelve systems reported (eight grid-connected, four stand-alone systems) contribute to the learning process, which involves technical and non-technical issues.

The analysis of a selected PV system (PV plant: de Wijk, 1995) shows that the annual final yield of the system is 30 % lower than expected, caused by malfunctioning of the cascade operation of the inverters and the imperfect power point tracking. Accordingly the efficiency figures represent a rather poor inverter efficiency (annual mean: η_I = 82.1 %) and an additionally poor array efficiency ($\eta_{A,mean}$ = 9.4 %) resulting in a poor overall system efficiency (η_{tot} = 7.7 %).

From another grid-connected system (Woubrugge, 1994) it was learnt that the energy from the utility grid E_{FU} and the energy from the PV system E_{IO} are not matched when considering the monthly energy sums over the course of one year.

With respect to the evaluation of stand-alone systems, performance evaluation in terms of performance ratio (PR) is considered as being inadequate, because poor PR values may be caused by a bad system efficiency or an inadequate use of solar energy. Analysing a stand-alone system (PV plant PV-Abri), which shows a great surplus of PV energy in summer and an energy shortage in winter, results in a rather bad performance ratio (PR = 0.28).This is due to the fact that, because large storage capacities are not a favourable option, the PV array is oversized by a factor of 4. Using the matching factor (MF) being the product of the performance ratio and the solar fraction [1], allows determination of how well a stand-alone system matches the electrical consumption. For the system under consideration (PV-Abri), the matching factor is MF = 0.28, representing an average performing SAS, taking into account that figures of MF = 0.6 are achievable.

Switzerland
In Switzerland, efforts of the three national programmes are focusing on the promotion and monitoring of grid-connected PV plants which sum up to 1 100 currently installed systems with a nominal power of 9.3 MWp (December 1998). The 43 selected PV systems in the IEA-PVPS database are all grid-connected power stations with an installed PV power between 1 kWp and 560 kWp (total of 1 524 kWp).

Analytical monitoring was carried out for all of the 43 PV systems resulting in 120 annual datasets, which were evaluated with respect to the operational performance. One of the results, the histogram of the annual performance ratios shows a broad range of PR values between 0.4 and 0.8 (Figure 6.9.6). The mean value of the annual reference yield is Y_r = 3.32 h/d and of the final yield Y_f = 2.27 h/d giving an average performance ratio of PR = 0.69 at an availability of 95 % for all the 43 plants and 120 operational years. This high value of 95 % availability is due to the fact that most of the plants are monitored as part of the R&D projects and therefore are closely watched by the operator at all times. Any malfunctioning is usually rectified within a short period of time.

These performance figures are compared to a selected evaluation of the same 43 PV plants, but considering the data from only one operational year with a high availability for each system. The following results should therefore be representative of a well maintained grid-connected PV system performing well: The mean annual yield is 948 h/y (43 datasets) compared to 828 h/y before (120 datasets). The mean annual performance ratio has increased from PR = 0.69 (120 datasets) to PR = 0.72 (43 datasets) at an availability of 98 %. The measured annual array efficiency at a mean module temperature of T_m = 35 °C is about 20 % below the nominal array efficiency at STC.

7.2 Problems encountered

There is generally scarce information available on the problems of PV systems with respect to operational performance and reliability. From the systems in two countries, the following experiences are reported:

Germany
At 100 of the 2 000 grid-connected PV systems within the 1 000-Roofs-PV-Programme, *technical inspections* of the first PV systems distributed all over the country were executed shortly after their installation by TÜV Rheinland. The aim was to determine the technical status of these installations and to establish whether the systems correspond to the technological state-of-the-art.

In the beginning of the installation phase in 1991, no guidelines were available on how to install PV systems. While the programme proceeded with continuing installations, a guideline of recommended practice was developed by a group of national experts. There was a need to rapidly transfer the knowledge of the experts and communicate it to the local installers and technicians. TÜV Rheinland was commissioned to produce a handbook on the installation of PV systems and tried to transfer the state-of-the-art of PV system installation to the established installers by special training courses and seminars.

Serious installation faults concerning the DC side of the system (disconnection of devices, lightning/overvoltage protection, circuit wires, generator junction box) and the AC port to the utility grid (external disconnecting switch) were detected during the first inspections in 1991. In Lower Saxony and Saxony, where each of the 322 PV systems were inspected shortly after their installation, the identified and reported "unacceptable" faults had to be eliminated, before the approval for releasing the subsidies (70 % of the total investment cost) were given. The "acceptable" installation faults, considerable shading and disorientation (> 45° from South) of the PV array, were reported only, but had no influence on the payment of the granted money.

The initial problem was that PV specific guidelines for the installation of such systems did not exist in the very beginning of the programme and that the local system installer had negligible or insufficient information. As the programme, training courses, information dissemination and last but not least "learning by doing" continued, gradual improvements in the system installation occurred, leading to a consistently high safety standard of the 2 000 installed PV systems in Germany.

A second technical problem concerns the connection of the PV system to the utility grid and the *regulations for this grid connection* issued by the utilities. In addition to the existing standards for the installation and operation of electrical systems, to which PV systems belong, the Association of German Electric Utilities (VDEW e.V.) issued a "Guideline for parallel operation of private power generating systems with the low voltage grid of an electric utility" in July 1991. An important requirement of this guideline is the installation of a continuously accessible external disconnecting switch (with the exception of triple-phase undervoltage monitoring for single-phase delivery inverter). However, this external disconnecting switch is often very expensive compared to the total system cost. Thus, it is also a market barrier to the introduction of grid-connected photovoltaics.

A solution could be a "device for grid monitoring with dedicated switching devices in series", which is currently accepted as an option for single-phase delivery systems. From the viewpoint of lowering market barriers, the aim is that this automatic, safe monitoring will also be permitted for three-phase delivery systems after they have proven themselves in practice.

Israel

From the installed Israeli PV systems, which are operating in an arid desert at an annual global horizontal irradiation of 2 000 kWh/($m^2 \cdot y$), a problem with respect to module degradation was encountered:

The Solarex SM-146 modules (in systems PAZNSm, PAZsta, PAZNS), the Siemens SM55 modules (system IEC2ax) and the Arco Solar M53 module (in system BGsing) all exhibit, to varying degrees, the phenomenon of EVA browning [3]. The consequent rate of module performance degradation, in the case of the Solarex modules, has been quantified [4] as approximately 0.5 % per year for modules without mirror enhancement and 1 - 2 % per year for modules with mirror enhancement.

In addition to EVA browning, the Siemens SM55 modules exhibit a whitening in the vicinity of the junction boxes and along the principal cell connections (i.e. those parallel to the module’s long axis). This phenomenon appears to be related to moisture penetration and may, possibly, be associated with organic growth. The rate of module performance degradation has been quantified [5] at approximately 0.9 % per year for these modules.

No visible degradation of any kind is evident for the AEG PQ/10/40/01 module (system BGpoly). The measured module degradation rate (0.2 % per year) over ten years, is insignificantly small [5].

The Arco Solar G4000, amorphous Si, module (system BGamor) may or may not have undergone EVA browning, since the latter, if present, would be difficult to observe owing to the particular construction of the module. However, the measured performance degradation rate is, on average, 3.8 % per year [5].

7.3 References

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[2] B. Decker, J. Grochowski: "Reduced yield analysis of the 1 000-Roofs-PV-Programme", Final Report, BMBF, Contract No. 0329588, August 1997 (in German)

[3] D. D. Sumner, C. M. Whitaker, L. E. Schlueter: "Carrisa Plains Photovoltaic Power Plant 1984 - 1987 Performance", 20th IEEE PV Specialists Conference, Sept. 1998, Las Vegas, NV, USA (IEEE, Piscataway, NJ, USA, 1988), pp 1289-1292

[4] D. Berman, D. Faiman: "EVA browning and the time-dependence of I-V curve parameters on PV modules with and without mirror-enhancement in a desert environment", Solar Energy Materials and Solar Cells vol. 45 (1997) p. 401

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8 CONCLUSIONS

As part of the IEA-PVPS Programme, Task 2 is collecting and analysing operational data from PV plants in various types of systems (grid-connected, stand-alone, hybrid systems) spread all over the world. Within the first phase of Task 2 work an international database on operational performance of PV systems and subsystems was developed and updated. The IEA-PVPS Task 2 database is design for the normalized analysis and representation of the operational data from different PV applications. Providing relevant information on the long-term performance and reliability of PV plants, on sizing and performance prediction for stand-alone systems and on performance improvements of PV systems is considered to be the clear benefit of the Task 2 database.

This report has laid particular emphasis on the analysis of operational performance of PV components and systems. It illustrates the operational behaviour of the systems by suitable graphs and presents the detailed results in a normalized form. Data from more than 260 PV systems integrated in the IEA-PVPS database have been evaluated, which allows comparisons between typical PV systems in different countries under different climatic conditions and systems of different load pattern.

Making use of the national monitoring activities within PV promotion programmes in Task 2 countries was the most common approach for collecting PV system data for the IEA-PVPS Task 2 database. Most of the systems in the database can be associated with national programmes under which data were originally monitored and evaluated. These national demonstration programmes in the countries participating in IEA-PVPS Task 2 largely reflect the priorities of each country.

There is an increasing emphasis on grid-connected PV systems, particular on the integration of PV into existing structures. Japan, Germany, the Netherlands, Switzerland and Austria have programmes to promote residential PV installations. Due to the emphasis in those countries, grid-connected PV systems including grid-connected hybrid systems are dominant in the IEA-PVPS database with a share of 80 %. Israel is focusing on adapting PV to its specific climate. France considers PV power systems as a potential source of electricity in remote rural areas where it has been demonstrated that PV is cheaper than extending the grid. Thus France is focusing on stand-alone systems in rural electrification programmes and contributes a major part of the stand-alone data in the IEA-PVPS database.

A problem encountered in the data collection was the access to the available monitored data by the country representative of Task 2. In the case of direct access due to an involvement of the participant in the national monitoring initiatives or campaigns at the same time, transfer and checking of data was easier and faster. In other cases, where the monitored data had to be processed by third parties not directly involved in IEA activities, data collection took considerably more effort and was time consuming. Additionally, any inconsistency detected in the monthly datasets was more difficult to solve without having direct access to the monitored data and to the background information on the system monitoring.

PV systems of different configurations and at different locations can be readily compared by evaluating their normalized system performance indices such as yields, losses and efficiencies. Yields are energy quantities normalized to nominal array power. Component and overall PV plant efficiencies are normalized to array area. Losses are the differences between yields and the performance ratio is the ratio of two yields. For the evaluation of operational data and for the presentation of results, normalized performance indicators are being used. This feature simplifies the performance assessment of the different PV systems in the IEA-PVPS database.

From the analysis of data in the IEA-PVPS database of 260 PV plants the following annual performance ratios can be expected for the different types of systems:

- grid-connected PV systems PR = 0.6 ... 0.8
- stand-alone systems without back-up PR = 0.1 ... 0.6
- stand-alone systems with back-up PR = 0.3 ... 0.6

The distribution of annual performance ratio (PR) calculated of 170 grid-connected PV systems shows that the PR significantly differs from plant to plant and ranges between 0.25 and 0.9 with an average PR value of 0.66 for 170 PV systems. It was found that well maintained PV systems operating well show an average PR value of typically 0.72 at an availability of 98 %. A tendency for increasing annual PR values during the past years has been observed.

In the early nineties (1992-1997), large grid-connected power plants showed annual PR values between 0.4 and 0.7 due to partial and total failures and a high non-availability of the PV plants as described in section 6.6. From recent large, grid-connected PV power installations with excellent inverter efficiencies, the annual PR may achieve values greater than PR = 0.8. As a result, grid-connected systems have generally improved in efficiency due to further improvements in component efficiency and optimized system design. The module efficiency is clearly improving and the manufacturers' rating of PV module nominal power is closer to the monitored and realistic value. As high efficiency inverters have been developed for grid-connected systems during the last years, the inverter efficiency is also tending to increase.

A major loss factor was detected for PV plants having partial shading of the PV array, which leads to a significant reduction of the energy yield of that system. In order to avoid unnecessary energy losses, a position with as little shading as possible should be chosen for the PV array during the planning phase.

In the years 1992 to 1996, maintenance efforts had been recorded for four large grid-connected PV systems in Italy. Experimental data showed that plant non-availability ranges from 15 % to 30 % in terms of working hours, because of the time spent for detecting and locating the failure, for diagnosis and for supplying the parts to be replaced. The main causes of total failures were identified to be inverter unreliability in the order of 50 % and other critical components such as medium voltage equipment, power factor and filtering components. For all the four plants taken into consideration, it was found that the cost of the replaced components were nearly always similar to the cost related to manpower.

During the last years, the susceptibility of grid-connected PV systems to failures, particularly regarding DC/AC inverters, has clearly decreased. The PV array has continued to be the most reliable component. The inverters of grid-connected systems achieve mean annual efficiency figures of higher than 88 % and a mean availability of better than 97 %.

Despite good results, which have been obtained in many of the grid-connected systems, the investigation of the operational behaviour of the reported PV systems has identified further potential for optimization:

- improving efficiencies of components by the selection of high efficiency modules and inverters
- avoiding diode, wiring and mismatch losses
- avoiding MPP inverter losses by optimum components matching
- avoiding high module temperatures by suitable measures of module integration into the building during installation
- avoiding array coverage due to dirt and snow on the PV array surface
- reducing array shading as much as possible during the planning phase

The performance analysis of data from stand-alone and stand-alone hybrid systems has revealed that the operational performance not only depends on the component efficiency, but also on system design and load pattern. Annual performance ratios range from 0.2 to 0.6 for off-grid domestic applications depending whether they have a back-up system and from 0.05 to 0.25 for off-grid professional systems, which are often oversized for reliability reasons. The performance analysis of stand-alone systems in terms of performance ratio (PR) has shown that in contrast to grid-connected systems, the PR alone cannot be used to describe the proper operation of stand-alone systems from a technical point of view.

Using the matching factor (MF), which is the product of the performance ratio (PR) and the array fraction (F_A), gives a better illustration of the performance of hybrid systems. A high value of the matching factor indicates that the solar part properly matches the electrical load and limits the back-up contribution. For the reported stand-alone systems, annual MF values between 0.2 and 0.6 were achieved highlighting better performance of hybrid systems in general in comparison to stand-alone systems without back-up. Nevertheless, the considered hybrid systems have not been designed as such but as a juxtaposition of two energy sources (solar PV and conventional). The wide MF range demonstrates that an optimization in the design phase is needed. A more detailed analysis concerning the operation of stand-alone systems will necessitate:

- more detailed and more reliable monitoring campaigns, which are at present feasible even for small remote systems with the development of integrated data loggers
- several years of measurement to better appreciate the evolution of user behaviour over time
- the use of simulation tools to evaluate the influence of new component sizes or new regulation strategies to increase the system performance

Experiences from one-axis and two-axis tracking systems were gained from Israeli installations in an arid desert (latitude 30.80° North; altitude above sea-level 475 m; annual global horizontal irradiation 2 000 kWh/(m^2·y); annual rainfall 90 mm). With respect to the electrical performance of trackers, the results of single, horizontal axis sun-tracking systems were disappointing. In general the system output was found to be lower than the designers had expected. On the other hand, the two-axis tracking system performed more or less according to expectations.

Analysis of mirror enhancement showed that V-trough mirrors enhance system performance during days with clear skies but not on cloudy days. As a result, mirrors must be positioned with great care in order to prevent non-uniform illumination of the modules at all times of the year. This is not difficult to achieve with two-axis trackers, but requires some detailed calculations in the case of one-axis trackers.

New national PV promotion programmes are being launched in various IEA-PVPS countries, which will lead to a rapid growth of installations and, possibly, to an increased amount of monitoring data. This will give benefits to PV system performance evaluation and enable the preparation of guidelines for supervision and maintenance aspects. Good maintenance is important, particular for rate based financed PV systems and Green Power schemes in order to promote the use of photovoltaics.

ANNEX A TABLES

A – 1 List of fields and minimum fields

IEA-PVPS Task 2 Database Format: Structure of "PVbase" Programme

Page #	Type of data	Minimum Field X #	Field #	Parameter	Type	Unit	Range
PAGE 1	*General Information*		1	ID number	Integer		unique
		X 1	2	Name of Plant	Char		unique
		X 2	3	Country	Char		
		X 3	4	Installation date	Integer		
			5	Plant owner	Char		
			6	Plant designer	Char		
			7	Plant installer	Char		
			8	Plant user	Char		
			9	Plant operator	Char		
			10	Contact person	Char		
			11	Contact organisation	Char		
			12	City	Char		
			13	Zip	Char		
			14	Street	Char		
			15	Box	Char		
			16	Phone	Char		
			17	Fax	Char		
			18	Telex	Char		
			19	E-mail	Char		
PAGE 2	*General Information*	X 4	20	Type of project	Char		R & D Production
PAGE 3	*General Information*	X 5	21	Type of plant	Char		Grid-connected Stand-alone Grid-connected hybrid Stand-alone hybrid
		X 6	22	Typical use	Char		Telecommunication Cath. protection Warning/monitor Other Professional Water pumping Fencing Mountain farm Other Rural Domestic Appartments Office Factory Vacation house Hotel Refuges Other Housing Power station Other
		X 7	23	Mounting	Char		Free-standing Sloped roof Flat roof Facade Sound barrier Other
			24	Integrated mounting	Integer		0 or 1
PAGE 4	*General Information*	X 8	25	Latitude CH = 47° (N)	Decimal	°	–90 (S) ... +90 (N)
		X 9	26	Longitude CH = -7° (O)	Decimal	°	–180 (O) … +180 (W)
		X 10	27	Altitude	Decimal	m	> 0
PAGE 5	*System Data*	X 11	28	PV plant nominal power @STC (used for all calculations)	Decimal	kW	> 0
PAGE 6	*Design Data*		29	Daily global irradiation, horizontal (H)	Decimal	kWh/m^2*d	> 0
			30	Daily global irradiation, in array plane (Hi)	Decimal	kWh/m^2*d	> 0
			31	Daily direct irradiation (Hd)	Decimal	kWh/m^2*d	> 0
			32	Ambient air temperature (Tam)	Decimal	° C	

			33	Daily load (EL,AC + EL,DC)	Decimal	kWh/d	> 0
PAGE 7	***Design***		34	Daily PV array output (EA)	Decimal	kWh/d	> 0
			35	Daily useful energy (Euse = EL + ETU)	Decimal	kWh/d	> 0
	Data		36	Daily energy from all back-up generators	Decimal	kWh/d	0 or > 0
			37	Fraction of total system input energy contributed by PV array (FA)	Decimal	dimensionless	0 ... 1
		X 12	38	DC/DC converter	Integer		0 or 1
		X 13	39	DC back-up generator	Integer		0 or 1
		X 14	40	DC load	Integer		0 or 1
PAGE 8	***System***	**X 15**	41	DC storage	Integer		0 or 1
	Data	**X 16**	42	DC/AC inverter	Integer		0 or 1
		X 17	43	AC back-up generator	Integer		0 or 1
		X 18	44	AC load	Integer		0 or 1
		X 19	45	Grid connection	Integer		0 or 1
		X 20	46	Number of arrays	Integer		> 0
		X 21	47	Array ID Nr.	Integer		> 0
		X 22	48	Module manufacturer	Char		
		X 23	49	Module type	Char		
PAGE 9	***System***	**X 24**	50	P nom @ STC	Decimal	W	> 0
	Data		51	V nom @ STC	Decimal	V	> 0
			52	Short circuit current I_{SC}	Decimal	A	> 0
			53	Open circuit voltage V_{OC}	Decimal	V	> 0
		X 25	54	Module area	Decimal	m^2	> 0
			55	By-pass diodes	Integer		0 or 1
		X 26	56	No. of modules per string	Integer		> 0
			57	Blocking diodes	Integer		0 or 1
			58	Overvoltage protection	Integer		0 or 1
			59	String fuse	Integer		0 or 1
		X 27	60	No. of strings per array	Integer		> 0
		X 28	61	Tracking	Char		none seasonal one-axis two-axis
PAGE 10	***System***						
	Data	**X 29**	62	Tilt angle	Decimal	°	> 0
		X 30	63	Azimuth angle	Decimal	°	E = 90°; S = 180°; W = 270°
			64	Tracking axis	Char		none polar vertical north-south east-west
		X 31	65	Concentrator	Integer		0 or 1
		X 32	66	Nominal power of all arrays @ STC (Pnom)	Decimal	kW	> 0
		X 33	67	Module area of all arrays	Decimal	m^2	> 0
		X 34	68	Total number of modules	Integer		> 0
		X 35	69	No. of DC/DC converters	Integer	—	> 0
		X 36	70	DC/DC ID Nr.	Integer		> 0
		X 37	71	Nominal power	Decimal	kW	> 0
		X 38	72	DC/DC manufacturer	Char		
		X 39	73	DC/DC type/model	Char		
PAGE 11	***System***		74	DC/DC control	Char		ON/OFF Partial disconnected Series control Shunt control Other
	Data						
			75	DC/DC max power tracking	Integer		0 or 1
		X 40	76	Nominal power of all DC/DC converters	Decimal	kW	> 0

PAGE 12	*System Data*	**X 41**	77	No. of inverters	Integer		> 0
		X 42	78	Inverter ID	Integer		> 0
		X 43	79	Mode of operation	Char		parallel one per array Master/Slave Other
		X 44	80	Nominal power of inverter	Decimal	kW	> 0
		X 45	81	Inverter manufacturer	Char		
		X 46	82	Inverter type/model	Char		
			83	Inverter MPP tracker	Integer		0 or 1
			84	Inverter control	Char		Line-commutated Self-commutated
			85	Frequency	Decimal	Hz	50…60
			86	Grid connection	Char		1 Phase 3 Phase 3 P+N
Page 12a	*System Data*		87	Inverter input voltage (Vdc)	Decimal	V	> 0
			88	Inverter output voltage (Vac)	Decimal	V	> 0
			89	Efficiency at Pnom	Decimal	dimensionless	0 … 1
			90	Efficiency 0.1 Pnom	Decimal	dimensionless	0 … 1
			91	THD	Decimal	dimensionless	> 0
			92	Galvanic insulation	Integer		0 or 1
			93	Stand-by losses	Decimal	kW	> 0
			94	Losses at no load	Decimal	kW	> 0
		X 47	95	Nominal power of all inverters (Pnom AC)	Decimal	kW	> 0
PAGE 13	*System Data*	**X 48**	96	Storage manufacturer	Char		
		X 49	97	Storage type/model	Char		
		X 50	98	Accumulator type	Char		Lead acid Nickel-cadmium Other
		X 51	99	Storage nominal voltage	Decimal	V	> 0
		X 52	100	Capacity @ 10 h	Decimal	Ah	> 0
		X 53	101	Capacity @ 100 h	Decimal	Ah	> 0
PAGE 14	*System Data*	**X 54**	102	Diesel	Char		0 or 1
		X 55	103	Diesel output power	Decimal	kW	> 0
		X 56	104	Wind	Char		0 or 1
		X 57	105	Wind output power	Decimal	kW	> 0
		X 58	106	Other	Char		0 or 1
		X 59	107	Other output power	Decimal	kW	> 0
PAGE 15	*Economic Data*	**X 60**	108	Currency of investment cost	Char		DEM, ATS, ITL, CHF, …
		X 61	109	Base year for costs	Integer	yyyy	> 1990
		X 62	110	Cost of PV modules	Integer	currency	> 0
			111	Cost of cabeling	Integer	currency	> 0
			112	Cost of structures	Integer	currency	> 0
			113	Cost of DC DC conditioner	Integer	currency	> 0
		X 63	114	Cost of storage	Integer	currency	> 0
		X 64	115	Cost of inverter	Integer	currency	> 0
			116	Cost of total AC back-up	Integer	currency	> 0
			117	Cost of total DC back-up	Integer	currency	> 0
			118	Cost of planning & design	Integer	currency	> 0
			119	Cost of engineering	Integer	currency	> 0
			120	Cost of installation	Integer	currency	> 0
			121	Cost of transport	Integer	currency	> 0
			122	Other costs	Integer	currency	> 0
		X 65	123	Turn-key cost	Integer	currency	> 0
			124	Owner`s contribution to investment cost	Decimal	dimensionless	0…1
			125	Cost of monitoring system hardware	Integer	currency	> 0
PAGE 16	*Operational Data*		126	Total PV array power @ STC	Float	kW	> 0
			127	Measured PV array power @ STC	Float	kW	> 0
			128	Date of measurement	Date		
			129	Monthly data from	Date	d.m.yy	
			130	Monthly data to	Date	d.m.yy	
		X 66	131	Reference device	Char		* Pyranometer * Reference cell * Potential irradiation ... calculated from PV module

PAGE 17	*Operational Data*	**X 67**	132	Currency of maintentance cost	Char		DEM, ATS, ITL, CHF, ...
		X 68	133	Base year for maintenance cost	Integer	yyyy	> 1990
			134	Maintenance cost from	Date	d.m.yy	
			135	Maintenance cost to	Date	d.m.yy	
			136	Maintenance cost of PV modules	Integer	currency	> 0
			137	Maintenance cost of rewiring	Integer	currency	> 0
			138	Maintenance cost of structures	Integer	currency	> 0
			139	Maintenance cost of DC DC conditioner	Integer	currency	> 0
			140	Maintenance cost of storage	Integer	currency	> 0
			141	Maintenance cost of inverter	Integer	currency	> 0
			142	Maintenance cost of DC back-up generator	Integer	currency	> 0
			143	Maintenance cost of AC back-up generator	Integer	currency	> 0
			144	Fuel cost of back-up generator	Integer	currency	> 0
			145	Maintenance cost of planning	Integer	currency	> 0
			146	Maintenance cost of engineering	Integer	currency	> 0
			147	Maintenance cost of labour	Integer	currency	> 0
			148	Maintenance cost of transport	Integer	currency	> 0
			149	Other maintenance costs	Integer	currency	> 0
		X 69	150	Average maintenance / year	Integer	currency	> 0
			151	Owner`s contribution to maintenance cost	Decimal	dimensionless	0…1
PAGE 18	*Operational Data*		152	Currency of energy cost	Char		DEM, ATS, ITL, CHF, …
			153	Base year for energy cost	Integer	yyyy	> 1990
			154	Energy sold from	Date	d.m.yy	
			155	Energy sold to	Date	d.m.yy	
			156	Energy sold to utility	Decimal	kWh	> 0
			157	Amount paid by utility	Decimal	currency	> 0
			158	Price for energy sold	Decimal	currency / kWh	> 0
			159	Average payment from utility / year	Decimal	currency	> 0
PAGE 19	*Operational Data*		160	General remarks to plant	Longvar		
PAGE 20	*Operational Data*	**X 70**	161	Daily global irradiation, horizontal (H)	Decimal	kWh/m^2*d	> 0
		X 71	162	Daily global irradiation, in array plane (Hi)	Decimal	kWh/m^2*d	> 0
		X 72	163	Daily direct irradiation (Hd)	Decimal	kWh/m^2*d	> 0
		X 73	164	Ambient air temperature (Tam), daily average weighted by the irradiation	Decimal	° C	> 0
		X 74	165	Module temperature (TA), daily average weighted by the irradiation	Decimal	° C	> 0
PAGE 21	*Operational Data*	**X 75**	166	Daily load (EL,AC + EL,DC)	Decimal	kWh/d	> 0
		X 76	167	Daily PV array output (EA)	Decimal	kWh/d	> 0
		X 77	168	Fraction of total system input energy contributed by PV array (FA)	Decimal	dimensionless	0 ... 1
		X 78	169	Monitoring fraction (M)	Decimal	dimensionless	0 ... 1
		X 79	170	Outage fraction (O)	Decimal	dimensionless	0 ... 1
PAGE 22	*Operational Data*	**X 80**	171	Monthly PV array output (EA)	Decimal	kWh/month	> 0
		X 81	172	Output energy from DC/DC converter (EC)	Decimal	kWh/month	> 0
		X 82	173	Energy supplied to storage (ESI)	Decimal	kWh/month	> 0
		X 83	174	Energy drawn from storage (ESO)	Decimal	kWh/month	> 0
		X 84	175	DC energy input to inverter (EII)	Decimal	kWh/month	> 0
		X 85	176	AC energy output from inverter (EIO)	Decimal	kWh/month	> 0
PAGE 23	*Operational Data*	**X 86**	177	Energy to AC loads (EL,AC)	Decimal	kWh/month	> 0
		X 87	178	Energy to DC loads (EL,DC)	Decimal	kWh/month	> 0
		X 88	179	Energy supplied to utilty grid (ETU)	Decimal	kWh/month	> 0
		X 89	180	Energy drawn from utility grid (EFU)	Decimal	kWh/month	> 0
		X 90	181	Energy from ac back-up generator (EBU,AC)	Decimal	kWh/month	> 0
		X 91	182	Energy from dc back-up generator (EBU,DC)	Decimal	kWh/month	> 0

A – 2 Comparison of recorded and derived parameters in IEC Standard 61724 and in EU Guidelines

	Recorded Parameter	**IEC 61724 Standard**	**EU Guidelines, 4.3, March 97**	
	PARAMETER	EQ SYMBOL	SYMBOL	UNIT
1)	**Meteorology**			
	Irradiance, total (global)		G	$W\ m^{-2}$
	Global or direct irradiance, in the array plane	G_I	G_I	$W\ m^{-2}$
	Ambient air temperature in the shade	T_{am}	T_{am}	°C
	Wind speed	S_W		$m\ s^{-1}$
2)	**Photovoltaic Array**			
	Output voltage	V_A	V_A	V
	Output current	I_A	I_A	A
	Output power	P_A	* P_A	kW
	Module temperature	T_m		
3)	**Energy Storage**			
	Operating voltage	V_S	V_S	V
	Current to storage	I_{TS}	I_{SI}	A
	Current from storage	I_{FS}	I_{SO}	A
	Power to storage	P_{TS}	* P_{SI}	kW
	Power from storage	P_{FS}	* P_{SO}	kW
4)	**Load**			
	Load voltage	V_L	V_S	V
	Load current	I_L	I_L	A
	Load power	P_L	* P_L	kW
	Power to all dedicated AC loads		$P_{L,AC}$	kW
5)	**Utility Grid**			
	Utility voltage	V_U		V
	Current to utility grid	I_{TU}		A
	Current from utility grid	I_{FU}		A
	Power to utility grid	P_{TU}	P_{TU}	kW
	Power from utility grid	P_{FU}	P_{FU}	kW
6)	**Back-up Sources**			
	Output voltage	V_{BU}	V_S	V
	Output current	I_{BU}	$I_{BU,DC}$	A
	Output power	P_{BU}	* P_{BU}	kW
	Power from auxiliary ac generator		$P_{BU,AC}$	kW

Additional recorded parameters			
Converter			
DC line voltage (battery voltage)		V_S	V
Converter output current		I_C	A
Power from Converter		* P_C	kW
Inverter			
DC line voltage (battery voltage)		V_S	V
Inverter/rectifier DC current (+/-)		I_{II}	A
Inverter/rectifier DC power (+/-)		* P_{II}	kW
Inverter/rectifier AC power (+/-)		P_{IO}	kW
Availability of system			
Non-availability to load		t_{NAV}	h
DC Power	* Although the EU Guidelines do not specifically mention to calculate all the power values in real time, it is recommended in the IEC 61724 Standard.		
DC power to/from subsystems	* P_{dc} $I_{dc} \cdot V_S / 1000$ kW		
Additional parameters			
Recording parameters			
Recording interval	τ_r	τ_r = 1	h
Reporting period	τ	τ = 1 Month	h
Duration of monitoring activity	t_{MA}	t_M	h
Availability of monitored data	1 A_{MD} t_{MA} / τ	F_M t_M / τ	——
Photovoltaic Array			
Nominal Power = (Module power at STC) • (Number of modules in the array)	P_0	P_0	kW
Array Area = (Module area) • (Number of modules in the array)	A_a	A_A	m^2
Nominal Array Efficiency at STC	$\eta_{A,nom}$ $P_0 / (A_a \cdot G_{I,ref})$	$\eta_{A,nom}$ $P_0 / (A_A \cdot G_{STC})$	——

	Derived parameters		IEC 61724 Standard			EU Guidelines, 4.3, March 97		
	PARAMETER	EQ	SYMBOL			SYMBOL		UNIT
	Availability of monitored data	1	A_{MD}	t_{MA} / τ		F_M	t_M / τ	—
	Energies, for reporting period τ	2	$E_{i,\tau}$	$\tau_r \cdot \Sigma_\tau P_i$		$E_{i,\tau}$	$\tau_r \cdot \Sigma_\tau P_i$	kWh
1)	**Meteorology**							
	STC reference inplane irradiance		$G_{I,ref}$	= 1000		G_{STC}	= 1000	$W\ m^{-2}$
	Standard test conditions (IEC 904.3)		STC			STC		—
	Total solar energy on array plane				*	$E_{S,A}$	$H_I \cdot A_A$	kWh
	Daily global or direct irradiation, in the plane of the array	3	$H_{I,d}$	$24 \cdot \tau_r \cdot (\Sigma_\tau G_I) / t_{MA} / 1000$				$kWh\ m^{-2}\ d^{-1}$
2)	**Electrical Energy Quantities**		**for specified reporting period τ**			**for specified reporting period τ**		
	Net energy from array		$E_{A,\tau}$	$\tau_r \cdot \Sigma_\tau P_A$				kWh
	Array output energy					E_A		kWh
	Net energy to load		$E_{L,\tau}$	$\tau_r \cdot \Sigma_\tau P_L$				kWh
	Energy to loads					E_L		kWh
	Net energy to storage	4	E_{TSN}	$E_{TS} - E_{FS}$		E_{TS}	$(E_{SI} - E_{SO})^+$	kWh
	Net energy from storage	5	E_{FSN}	$E_{FS} - E_{TS}$		E_{FS}	$(E_{SO} - E_{SI})^+$	kWh
	(Net) energy to utility grid	6	E_{TUN}	$E_{TU} - E_{FU}$	*	E_{TU}		kWh
	(Net) energy from utility grid	7	E_{FUN}	$E_{FU} - E_{TU}$	*	E_{FU}		kWh
	Total system input energy	8	E_{in}	$E_A + E_{BU} + E_{FUN} + E_{FSN}$		E_{in}	$E_A + E_{BU} + E_{FU} + E_{FS}$	kWh
	Useful Energy supplied by the system				*	E_{use}	$E_L + E_{TU}$	kWh
	Total system output energy	9	E_{use}	$E_L + E_{TUN} + E_{TSN}$				kWh
	Fraction of total system input energy contributed by PV array	10	$F_{A\ in}$	E_A / E_{in}		F_A	E_A / E_{in}	—
	Direct PV energy contribution to Euse				*	$E_{use,PV}$	$F_A \cdot E_{use}$	kWh
	Load efficiency	11	η_{LOAD}	E_{use} / E_{in}				—
3)	**BOS Component Performance**							
	BOS efficiency	12	η_{BOS}	$(E_L + E_{TSN} - E_{FSN} + E_{TUN} - E_{FUN}) / (E_A + E_{BU})$				—
4)	**System Performance Indices**		**for specified reporting period τ**			**for specified reporting period τ**		
	Outage fraction				*	O	t_{NAV} / τ	—
			Daily mean values			Daily mean values		
	Array yield	13	Y_A	$E_{A,d} / P_0$		Y_A	$E_{A,day} / P_0$	$h\ d^{-1}$
	Final Yield				*	Y_f	$E_{use,PV,day} / P_0$	$h\ d^{-1}$
	Final PV system yield	14	Y_f	$Y_A \cdot \eta_{LOAD}$				$h\ d^{-1}$
	Reference yield	15	Y_r	$\tau_r \cdot (\Sigma_{day} G_I) / G_{I,ref}$		Y_r	$H_{I,day}$	$h\ d^{-1}$
	Array capture losses	16	L_C	$Y_r - Y_A$		L_C	$Y_r - Y_A$	$h\ d^{-1}$
	System Losses (Inverter)				*	L_S	$Y_A - Y_f$	$h\ d^{-1}$
	BOS losses	17	L_{BOS}	$Y_A \cdot (1 - \eta_{BOS})$.				$h\ d^{-1}$
	Performance ratio				*	PR	Y_f / Y_r	—
	Performance ratio	18	R_P	Y_f / Y_r				—
			for specified reporting period τ			for specified reporting period τ		
	Mean array efficiency	19	$\eta_{A,mean}$	$E_A / (A_a \cdot \tau_r \cdot \Sigma_\tau G_I)$,		$\eta_{A,mean}$	$E_A / E_{S,A}$	—
	Overall PV plant efficiency				*	η_{tot}	$E_{use,PV} / E_{S,A}$	—
	Overall PV plant efficiency	20	η_{tot}	$\eta_{A,mean} \cdot \eta_{LOAD}$				
	Additional derived parameters		**for specified reporting period τ**			**for specified reporting period τ**		
	Storage Battery							
	Coulomb recharge fraction of the storage				*	ρ_Q	${}_\tau I_{SI} / {}_\tau I_{SO}$	—
	Energy recharge fraction of the storage				*	ρ_E	E_{SI} / E_{SO}	—
	Power Conditioner / Inverter							
	Converter efficiency				*	η_C	E_C / E_A	—
	Energy efficiency of the inverter				*	η_I	E_{IO} / E_{II}	—
	Load							
	Energy to loads				*	E_L	$E_{L,AC} + E_{L,DC}$	kWh
	Back-up Sources							
	Energy from back-up system				*	E_{BU}	$E_{BU,AC} + E_{BU,DC}$	kWh

ANNEX B

B – 1 Glossary of terms and abbreviations

A_A	array area
Ademe	Agence de l’ Environnement et de la Maîtrise de l’ Energie (French Agency for the Environment and Energy Management)
AM	air mass
A_{MD}	availability of monitored data
ANIT	Italian PV industry
a-Si	amorphous silicon
AUS	Australia
AUT	Austria
BFE	Bundesamt für Energie (Swiss Federal Office of Energy)
BIPV	building integrated photovoltaics
BMBF	Bundesministerium für Bildung und Forschung (German Federal Ministry of Education and Research)
BMWi	Bundesministerium für Wirtschaft und Technologie (German Federal Ministry of Economy and Technology)
BOS	balance of system
CHE	Switzerland
c-Si	crystalline silicon
DEU	Germany
E_A	array output energy
E_{BU}	energy from back-up
E_{CONS}	electricity consumption of the users of grid-connected systems
EdF	Electricité de France (French national electric utility)
E_{FS}	net energy from storage
E_{FU}	net energy from utility grid
E_{II}	DC energy input to inverter
E_{IN}	total system input energy
E_{IO}	AC energy output from inverter
E_L	energy to loads
EMC	electromagnetic compatibility
ENEA	Ente per le Nuove Tecnologie l’ Energia e l’ Ambiente (Italian Agency for New Technology, Energy and Environment)
ENEL	Italian national electric utility
E_{TS}	net energy to storage
E_{TU}	net energy to utility grid
EU	European Union
E_{use}	useful energy supplied by the system
$E_{use,PV}$	direct PV energy contribution to E_{use}
F_A	fraction of total system input contributed by PV array
F_S	solar fraction
F_d	direct use fraction
FRA	France
FY	fiscal year
GC	grid-connected
G_I	global or direct irradiance in the array plane
G_{STC}	global irradiance at standard test conditions
H_I	daily global or direct irradiation in the plane of the array

IEA	International Energy Agency
IEC	International Electrotechnical Commission
I_{SC}	short circuit current
ISES	International Solar Energy Society
ISR	Israel
ITA	Italy
JPN	Japan
JRC	European Commission Joint Research Centre
kWh	kilowatt hour
kWp	kilowatt peak
L_C	array capture losses
L_S	system losses
mc	multicrystalline
mc-Si	multicrystalline silicon
M	monitoring fraction
MF	matching factor
MPP	maximum power point
MW	megawatt
N	north
NEDO	New Energy and Industrial Technology Development Organization (Japan)
NLD	Netherlands
NOVEM	Netherlands Agency for Energy and the Environment
NUFF	new unified file format
O	outage fraction
OECD	Organization for Economic Cooperation and Development
P_0	nominal power at STC
PLUG	photovoltaic low-cost utility generator
PR	performance ratio
p-Si	polycrystalline silicon
PV	photovoltaics
PVbase	IEA-PVPS Task 2 database programme
PVreport	IEA-PVPS Task 2 report programme
PVPS	photovoltaic power systems
R&D	research & development
SAS	stand-alone systems
STC	standard test conditions
T_{am}	ambient air temperature
T_m	module temperature
Y_A	array yield
Y_f	final yield
Y_r	reference yield
V_{OC}	open circuit voltage
VSE	Swiss Electricity Producer and Distributor Association
VDEW	Vereinigung Deutscher Elektrizitätswerke e.V. (Association of German Electric Supply Companies)
WIP	Wirtschaft und Infrastruktur & Co Planungs-KG (German Consultant)
η	efficiency value
$\eta_{A,mean}$	mean array efficiency
η_{A0}	nominal array efficiency at its rated power P_0
η_I	energy efficiency of the inverter
η_{tot}	overall PV plant efficiency

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ANNEX C PUBLICATIONS

C – 1 List of publications

[1] Clavadetscher, L.
First Publication of Swiss data in the IEA database
(Erste Vergleiche der Anlagen-Performance, in German),
Proceedings of National PV Seminar, Fribourg, Switzerland, 4 / 5 April 1995, 103

[2] Faiman, D.; Berman, D.
EVA browning and the time-dependence of I-V curve parameters on PV modules with and without mirror-enhancement in a desert environment
Solar Energy Materials and Solar Cells, Vol. 45, 1997, 401

[3] Faiman, D.
Investigation of PV module behaviour under outdoor desert conditions
Israel Ministry of National Infrastructure Report No. RD-03-99, Jerusalem, April 1999

[4] Jahn, U.; Niemann, M.; Blaesser, G.; Dahl, R.; Castello, S.; Clavadetscher, L.; Faiman, D.; Mayer, D.; van Otterdijk, Karel.; Sachau, J.; Sakuta, K.; Yamaguchi, M.; Zoglauer, M.
International Energy Agency Task 2 Database on Photovaoltaic Power Systems: Statistical and Analytical Evaluation of PV Operational Data
Proceedings 2nd World Conference on Photovoltaic Solar Energy Conversion (PVSEC`98), Vienna, Austria, 6-10 July 1998, Vol. III, 2802-2805

[5] Jahn, U.; Niemann, M.; Decker, B.; Meier, H.; Blaesser, Clavadetscher, L.; Faiman, D.; Mayer, D.; van Otterdijk, Karel.; Zoglauer, M.
Datenbank der Internationalen Energieagentur zur statistischen und analytischen Auswertung von Photovoltaik-Betriebsdaten (in German)
Proceedings 13. Symposium Photovoltaische Solarenergie, Ostbayerisches Technologie Transfer Institut e.V. (OTTI), Regensburg, Germany, 1998, 142-146

[6] Jahn, U.; Tegtmeyer, D.; Rieks, H.; Rindelhardt, U.; Teichmann, G.
PV Covers Electricity Demand: How Private Users of 200 PV Systems Match their Energy Consumption to the PV Production
Proceedings 13th European Photovoltaic Solar Energy Conference (PVSEC`95), Nice, France, 23 - 27 October 1995, Vol. II, 2247-2250

[7] Jahn, U.; Grimmig, B.; Nasse, W.
Analyse von PV-Betriebsdaten mit Hilfe der IEA-PVPS-Datenbank (in German)
Proceedings 15. Symposium Photovoltaische Solarenergie, Ostbayerisches Technologie Transfer Institut e.V. (OTTI), Regensburg, Germany, 2000

[8] Mayer, D.; Carlen, P.
Operational Performance of Stand-alone PV Systems
Proceedings 14th European Photovoltaic Solar Energy Conference (PVSEC`97), Barcelona, Spain, 30 June - 4 July 1997, Vol. II, 2593-2596

[9] Sakuta, K.; Kurokawa, K; Sugiyama, H.; Sakamoto, K.; Ohshiro, T.; Matsuo, T.; Katagiri, T.
System Monitoring Database and Performance Analysis in Japanese Field Test Programme
Proceedings 14th European Photovoltaic Solar Energy Conference (PVSEC`97), Barcelona, Spain, 30 June - 4 July 1997, Vol. II, 2046-2049

[10] Zoglauer, M.; Bergmann, W.; Scheibenreiter, P.
Austrian 200 kWp Photovolatic Rooftop Programme: Accompanying Scientific Monitoring Programme
Proceedings 13th European Photovoltaic Solar Energy Conference (PVSEC`95), Nice, France, 23 - 27 October 1995, Vol. I, 672-674

C – 2 Workshops organized by Task 2 members

[1] National Workshop in Switzerland:
Date and Place: 17 May 1994, Burgdorf, Switzerland,
Topic: Normalized Evaluation of grid-connected PV Systems

Annex D

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D - 1 Austria

IEA PVPS TASK 2 REPORT PROGRAMME

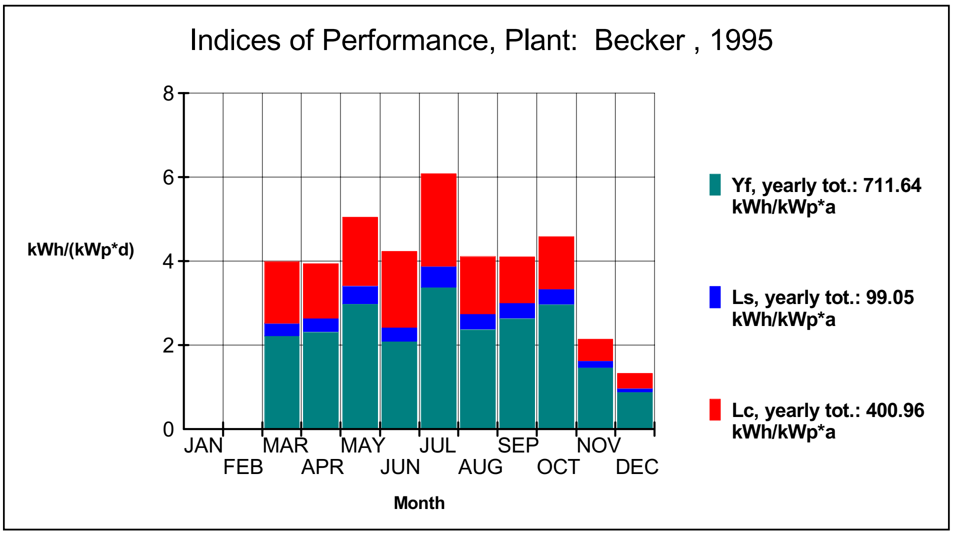
Photovoltaic Database Report

Plant Name:	**Becker**		
Country:	Austria		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	3.18 kW_p	Array area:	25.60 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Becker**		
Country:	Austria		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	3.18 kW_p	Array area:	25.60 m²



Year:	1995	1996		
Availab. of monitored data:	0.83	0.25	AMD	[ ]
Calculated Month:	10	3		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	1212	289	HI sum	[kWh/m^2]
Ambient air temperature:			Tam avr	[˚C]
System Energies:				
Energy output from inverter:	2263	598	EIO sum	[kWh]
Useful energy:	1	0	Euse sum	[kWh]
PV array fraction:	1	1	FA	[ ]
Energy consumption:			Econ sum	[kWh]
System Performance Indices:				
Reference yield:	3.96	3.21	Yr avr	[h/d]
Final yield:	2.32	2.09	Yf avr	[h/d]
Array capture losses:	1.31	0.88	Lc avr	[h/d]
System losses:	0.32	0.24	Ls avr	[h/d]
Performance Ratio:	0.59	0.65	PR	[ ]
Array efficiency:	8.3	9	eta A	[%]
Inverter efficiency:	87.8	89.8	eta inv	[%]
Overall plant efficiency:	7.3	8.1	eta tot	[%]
Utility Grid:				
Energy to utility grid:	-	-	ETU sum	[kWh]
Energy from utility grid:	-	-	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

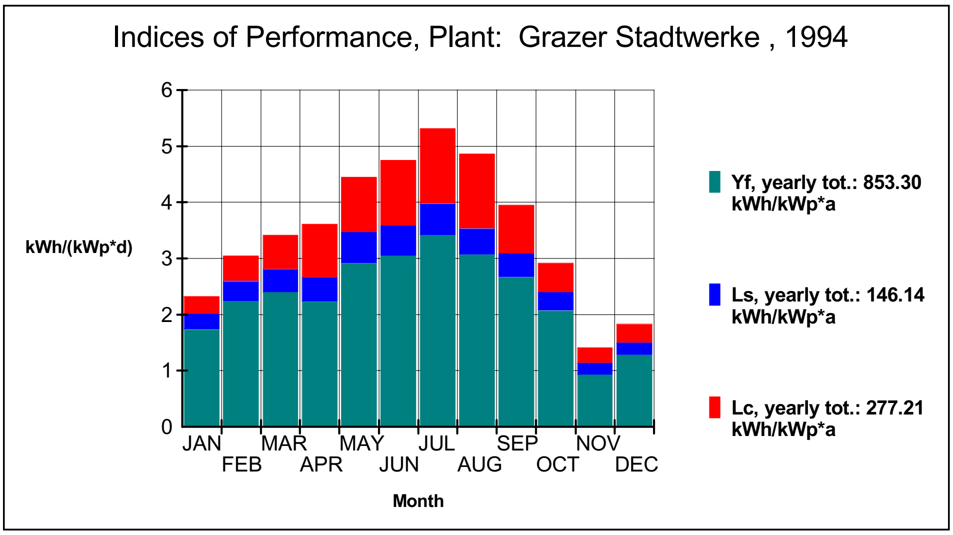
Photovoltaic Database Report

Plant Name:	**Grazer Stadtwerke**		
Country:	Austria		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	2.12 kW_p	Array area:	17.00 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Grazer Stadtwerke**		
Country:	Austria		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	2.12 kW_p	Array area:	17.00 m²

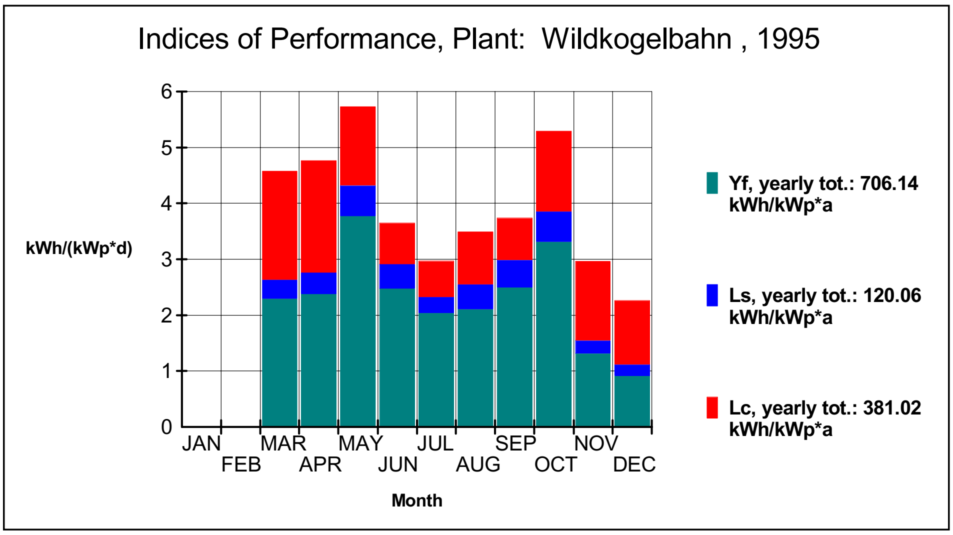


Year:	1994		
Availab. of monitored data:	1.00	AMD	[ ]
Calculated Month:	12		
Meteorology:			
Glob. Irradiation, horizontal:		H sum	[kWh/m^2]
Irradiation, in array plane:	1277	HI sum	[kWh/m^2]
Ambient air temperature:		Tam avr	[˚C]
System Energies:			
Energy output from inverter:	1809	EIO sum	[kWh]
Useful energy:	0	Euse sum	[kWh]
PV array fraction:	1	FA	[ ]
Energy consumption:		Econ sum	[kWh]
System Performance Indices:			
Reference yield:	3.49	Yr avr	[h/d]
Final yield:	2.34	Yf avr	[h/d]
Array capture losses:	0.76	Lc avr	[h/d]
System losses:	0.4	Ls avr	[h/d]
Performance Ratio:	0.67	PR	[ ]
Array efficiency:	9.8	eta A	[%]
Inverter efficiency:	85.4	eta inv	[%]
Overall plant efficiency:	8.3	eta tot	[%]
Utility Grid:			
Energy to utility grid:	-	ETU sum	[kWh]
Energy from utility grid:	-	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Wildkogelbahn**		
Country:	Austria		
Type of plant:	Grid connected	Mounting:	Flat roof
Nominal Power:	4.72 kW_p	Array area:	37.00 m²



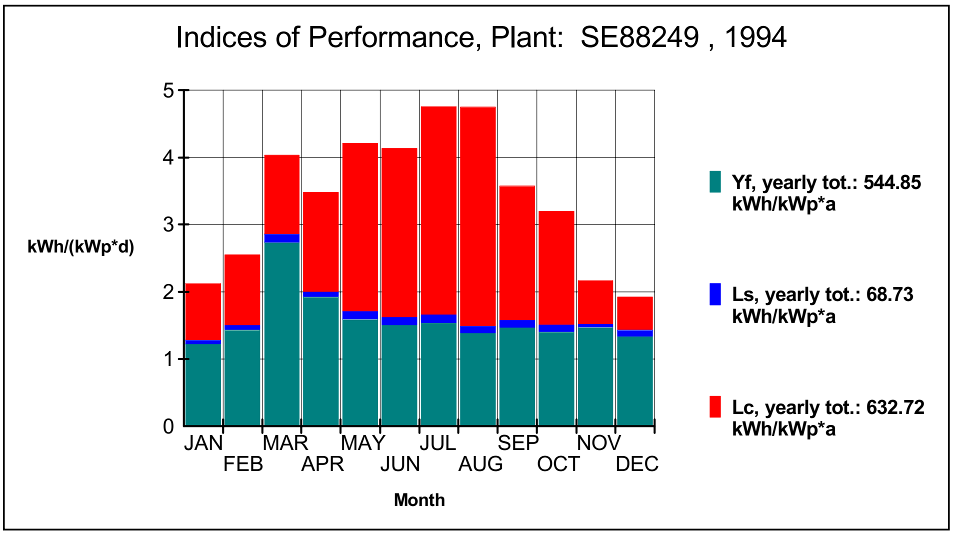
Year:	1995	1996		
Availab. of monitored data:	0.83	0.25	AMD	[ ]
Calculated Month:	10	3		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	1207	305	HI sum	[kWh/m^2]
Ambient air temperature:			Tam avr	[˚C]
System Energies:				
Energy output from inverter:	3333	807	EIO sum	[kWh]
Useful energy:	0	0	Euse sum	[kWh]
PV array fraction:	0.99	0.95	FA	[ ]
Energy consumption:			Econ sum	[kWh]
System Performance Indices:				
Reference yield:	3.94	3.39	Yr avr	[h/d]
Final yield:	2.31	1.89	Yf avr	[h/d]
Array capture losses:	1.24	1.13	Lc avr	[h/d]
System losses:	0.39	0.37	Ls avr	[h/d]
Performance Ratio:	0.58	0.56	PR	[ ]
Array efficiency:	8.7	8.6	eta A	[%]
Inverter efficiency:	85.5	83.5	eta inv	[%]
Overall plant efficiency:	7.5	7.2	eta tot	[%]
Utility Grid:				
Energy to utility grid:	-	-	ETU sum	[kWh]
Energy from utility grid:	-	-	EFU sum	[kWh]

D - 2 European Union

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**SE88249**		
Country:	Italy (EC)		
Type of plant:	Stand-alone hybrid	Mounting:	Freestanding
Nominal Power:	4.00 kW_p	Array area:	84.00 m²

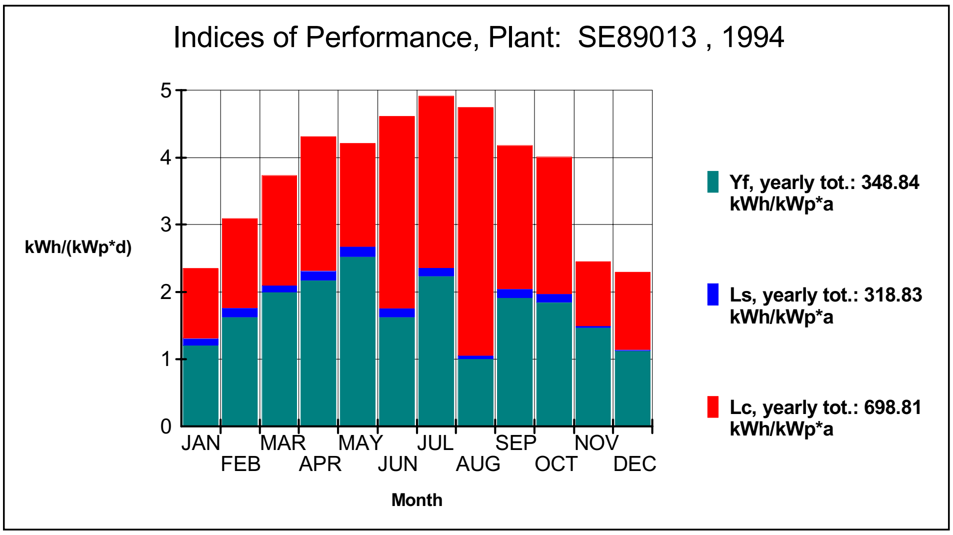


Year:	1994		
Availab. of monitored data:	0.99	AMD	[ ]
Calculated Month:	12		
Meteorology:			
Glob. Irradiation, horizontal:		H sum	[kWh/m^2]
Irradiation, in array plane:	1246	HI sum	[kWh/m^2]
Ambient air temperature:		Tam avr	[˚C]
System Energies:			
Energy output from inverter:	2112	EIO sum	[kWh]
Useful energy:	4503	Euse sum	[kWh]
PV array fraction:	0.51	FA	[ ]
Energy consumption:	2685	Econ sum	[kWh]
System Performance Indices:			
Reference yield:	3.41	Yr avr	[h/d]
Final yield:	1.49	Yf avr	[h/d]
Array capture losses:	1.73	Lc avr	[h/d]
System losses:	0.19	Ls avr	[h/d]
Performance Ratio:	0.44	PR	[ ]
Array efficiency:	2.3	eta A	[%]
Inverter efficiency:		eta inv	[%]
Overall plant efficiency:	2.2	eta tot	[%]
Utility Grid:			
Energy to utility grid:	0	ETU sum	[kWh]
Energy from utility grid:	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**SE89013**		
Country:	Germany (EC)		
Type of plant:	Stand-alone hybrid	Mounting:	Sloped roof
Nominal Power:	5.10 kW_p	Array area:	48.00 m²

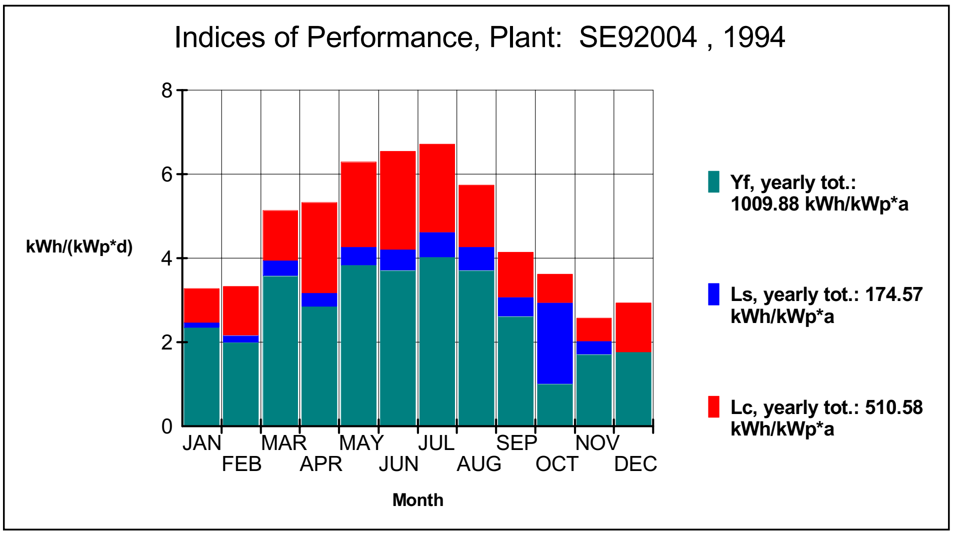


Year:	1993	1994		
Availab. of monitored data:	0.99	0.97	AMD	[ ]
Calculated Month:	12	12		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	1397	1366	HI sum	[kWh/m^2]
Ambient air temperature:			Tam avr	[˚C]
System Energies:				
Energy output from inverter:	6073	7197	EIO sum	[kWh]
Useful energy:	13517	13571	Euse sum	[kWh]
PV array fraction:	0.32	0.22	FA	[ ]
Energy consumption:	9152	9253	Econ sum	[kWh]
System Performance Indices:				
Reference yield:	3.84	3.74	Yr avr	[h/d]
Final yield:	1.19	0.96	Yf avr	[h/d]
Array capture losses:	1.99	1.91	Lc avr	[h/d]
System losses:	0.66	0.87	Ls avr	[h/d]
Performance Ratio:	0.31	0.26	PR	[ ]
Array efficiency:	5.1	5.2	eta A	[%]
Inverter efficiency:			eta inv	[%]
Overall plant efficiency:	4.7	4.6	eta tot	[%]
Utility Grid:				
Energy to utility grid:	0	0	ETU sum	[kWh]
Energy from utility grid:	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**SE92004**		
Country:	Spain (EC)		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	42.00 kW_p	Array area:	357.00 m²

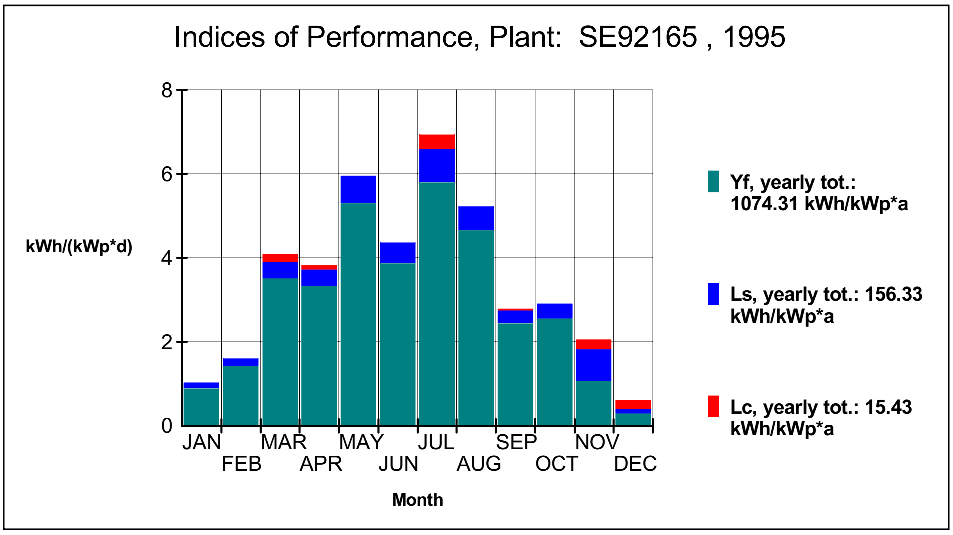


Year:	1993	1994		
Availab. of monitored data:	0.93	0.93	AMD	[ ]
Calculated Month:	12	12		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	1686	1695	HI sum	[kWh/m^2]
Ambient air temperature:			Tam avr	[˚C]
System Energies:				
Energy output from inverter:	39097	42415	EIO sum	[kWh]
Useful energy:	39097	42415	Euse sum	[kWh]
PV array fraction:	1	1	FA	[ ]
Energy consumption:			Econ sum	[kWh]
System Performance Indices:				
Reference yield:	4.61	4.63	Yr avr	[h/d]
Final yield:	2.55	2.76	Yf avr	[h/d]
Array capture losses:	1.7	1.4	Lc avr	[h/d]
System losses:	0.36	0.47	Ls avr	[h/d]
Performance Ratio:	0.55	0.60	PR	[ ]
Array efficiency:	7.4	8.2	eta A	[%]
Inverter efficiency:	87.5	85.3	eta inv	[%]
Overall plant efficiency:	6.5	7	eta tot	[%]
Utility Grid:				
Energy to utility grid:	39097	42415	ETU sum	[kWh]
Energy from utility grid:	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**SE92165**		
Country:	Germany (EC)		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	21.80 kW_p	Array area:	191.00 m²



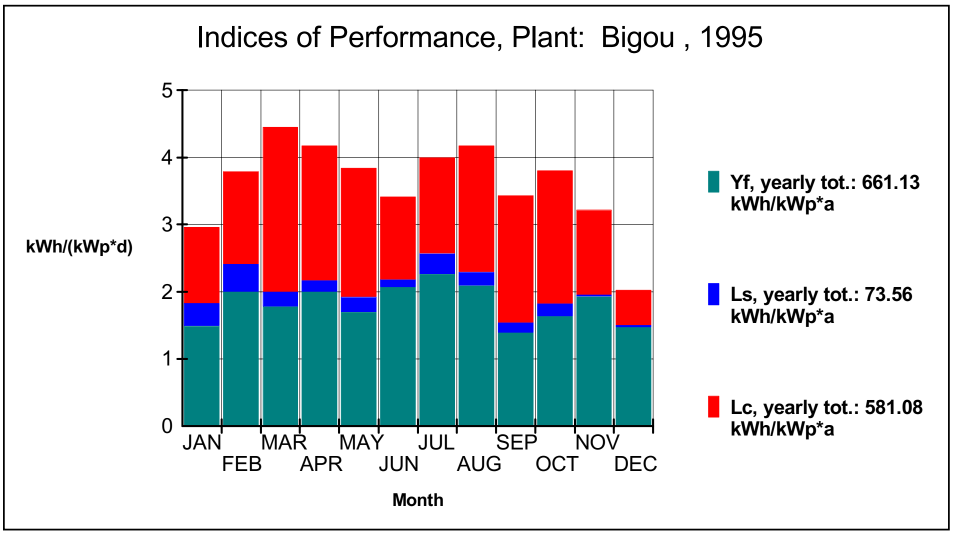
Year:	1994	1995	1996		
Availab. of monitored data:	0.99	0.96	0.97	AMD	[ ]
Calculated Month:	6	12	6		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	693	1246	724	HI sum	[kWh/m^2]
Ambient air temperature:				Tam avr	[˚C]
System Energies:					
Energy output from inverter:	12784	23420	13618	EIO sum	[kWh]
Useful energy:	12784	23420	13618	Euse sum	[kWh]
PV array fraction:	1	1	1	FA	[ ]
Energy consumption:				Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.75	3.4	3.99	Yr avr	[h/d]
Final yield:	3.17	2.93	3.44	Yf avr	[h/d]
Array capture losses:	0.19	0.04	0.08	Lc avr	[h/d]
System losses:	0.39	0.43	0.47	Ls avr	[h/d]
Performance Ratio:	0.85	0.86	0.86	PR	[ ]
Array efficiency:	10.9	11.3	11.2	eta A	[%]
Inverter efficiency:	89.1	87.3	87.9	eta inv	[%]
Overall plant efficiency:	9.7	9.8	9.8	eta tot	[%]
Utility Grid:					
Energy to utility grid:	12784	23420	13618	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

D - 3 France

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Bigou**		
Country:	France	Battery storage:	400 Ah / 24 V
Type of plant:	Stand-alone hybrid	Mounting:	Freestanding
Nominal Power:	0.54 kW_p	Array area:	5.76 m²

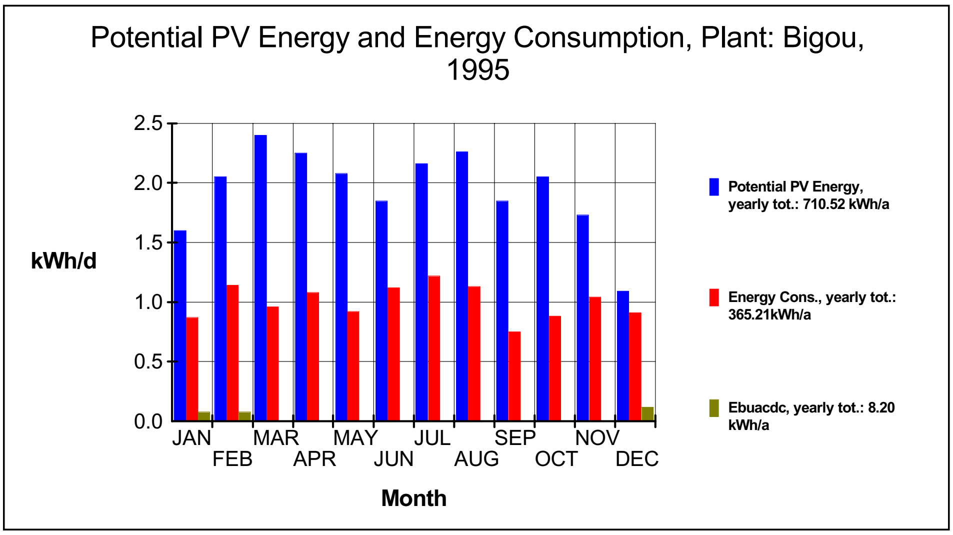


Year:	1994	1995	1996		
Availab. of monitored data:	0.75	1	0.25	AMD	[ ]
Calculated Month:	9	12	3		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	901	1316	260	HI sum	[kWh/m^2]
Ambient air temperature:	0	0	0	Tam avr	[˚C]
System Energies:					
Energy output from inverter:	0	0	0	EIO sum	[kWh]
Useful energy:	291	365	76	Euse sum	[kWh]
PV array fraction:	0.99	0.98	0.93	FA	[ ]
Energy consumption:	291	365	76	Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.28	3.61	2.89	Yr avr	[h/d]
Final yield:	1.94	1.81	1.46	Yf avr	[h/d]
Array capture losses:	1.18	1.59	1.14	Lc avr	[h/d]
System losses:	0.16	0.2	0.29	Ls avr	[h/d]
Performance Ratio:	0.60	0.50	0.52	PR	[ ]
Array efficiency:	8	8	8	eta A	[%]
Inverter efficiency:				eta inv	[%]
Overall plant efficiency:	5.6	4.7	4.7	eta tot	[%]
Utility Grid:					
Energy to utility grid:	0	0	0	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Bigou**		
Country:	France	Battery storage:	400 Ah / 24 V
Type of plant:	Stand-alone hybrid	Mounting:	Freestanding
Nominal Power:	0.54 kW_p	Array area:	5.76 m²

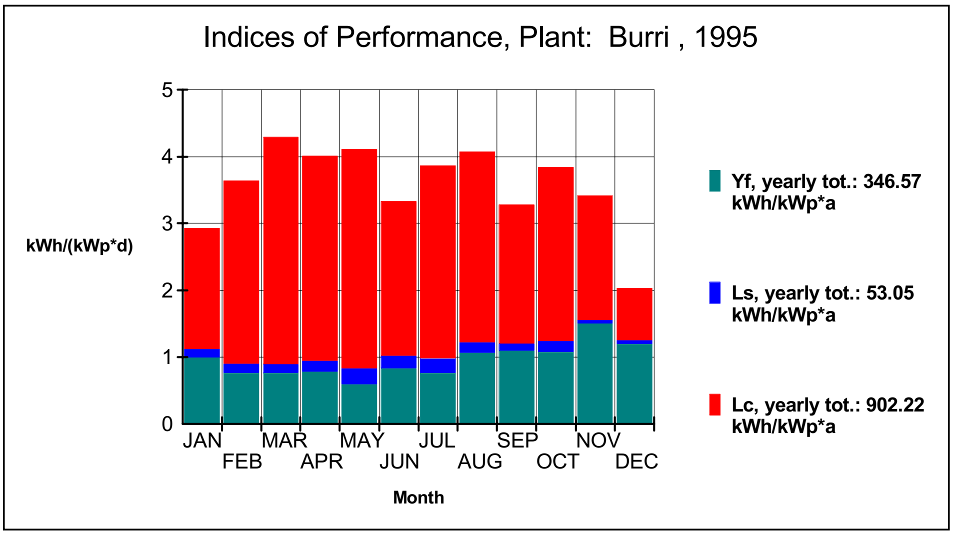


Year:	1994	1995	1996		
Availab. of monitored data:	0.75	1	0.25	AMD	[ ]
Calculated Month:	9	12	3		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	901	1316	260	HI sum	[kWh/m^2]
Ambient air temperature:	0	0	0	Tam avr	[˚C]
System Energies:					
Energy output from inverter:	0	0	0	EIO sum	[kWh]
Useful energy:	291	365	76	Euse sum	[kWh]
PV array fraction:	0.99	0.98	0.93	FA	[ ]
Energy consumption:	291	365	76	Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.28	3.61	2.89	Yr avr	[h/d]
Final yield:	1.94	1.81	1.46	Yf avr	[h/d]
Array capture losses:	1.18	1.59	1.14	Lc avr	[h/d]
System losses:	0.16	0.2	0.29	Ls avr	[h/d]
Performance Ratio:	0.60	0.50	0.52	PR	[ ]
Array efficiency:	8	8	8	eta A	[%]
Inverter efficiency:				eta inv	[%]
Overall plant efficiency:	5.6	4.7	4.7	eta tot	[%]
Utility Grid:					
Energy to utility grid:	0	0	0	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Burri**		
Country:	France	Battery storage:	750 Ah / 24 V
Type of plant:	Stand-alone hybrid	Mounting:	Freestanding
Nominal Power:	1.08 kW_p	Array area:	11.52 m²

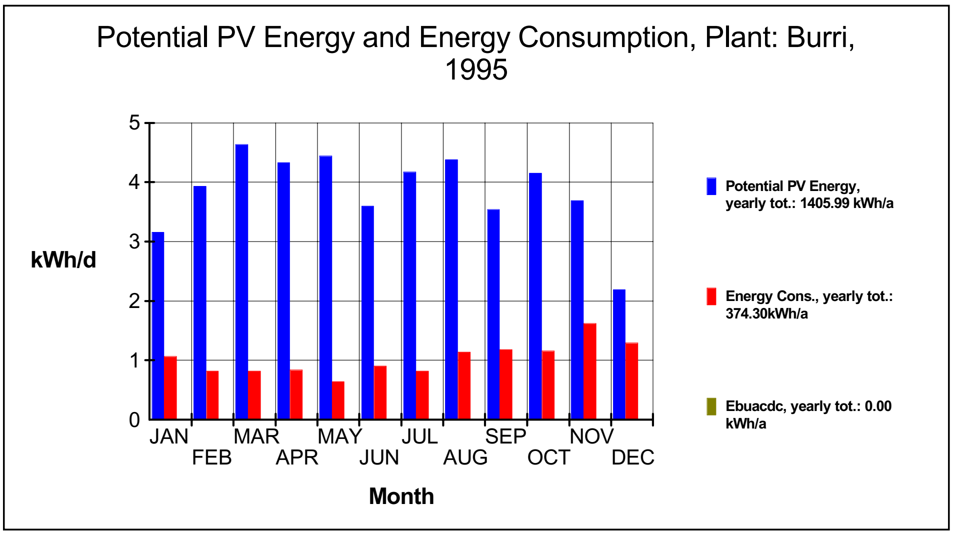


Year:	1994	1995	1996		
Availab. of monitored data:	0.75	1	0.25	AMD	[ ]
Calculated Month:	9	12	3		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	871	1302	272	HI sum	[kWh/m^2]
Ambient air temperature:	0	0	0	Tam avr	[˚C]
System Energies:					
Energy output from inverter:	0	0	0	EIO sum	[kWh]
Useful energy:	217	374	100	Euse sum	[kWh]
PV array fraction:	1	1	1	FA	[ ]
Energy consumption:	217	374	100	Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.17	3.57	3.02	Yr avr	[h/d]
Final yield:	0.73	0.95	1.03	Yf avr	[h/d]
Array capture losses:	2.32	2.47	1.87	Lc avr	[h/d]
System losses:	0.12	0.15	0.12	Ls avr	[h/d]
Performance Ratio:	0.23	0.27	0.36	PR	[ ]
Array efficiency:	2.5	2.9	3.6	eta A	[%]
Inverter efficiency:				eta inv	[%]
Overall plant efficiency:	2.2	2.5	3.2	eta tot	[%]
Utility Grid:					
Energy to utility grid:	0	0	0	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Burri**		
Country:	France	Battery storage:	750 Ah / 24 V
Type of plant:	Stand-alone hybrid	Mounting:	Freestanding
Nominal Power:	1.08 kW_p	Array area:	11.52 m²

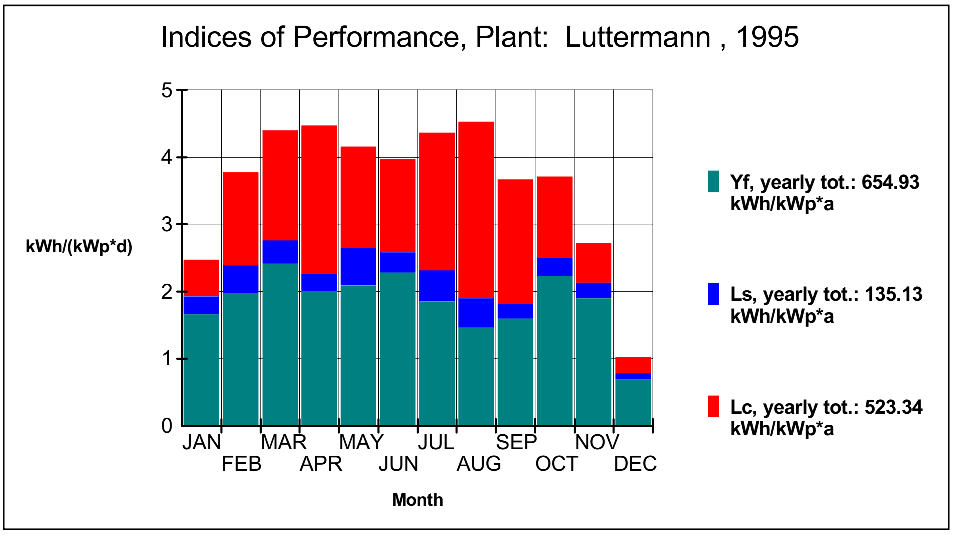


Year:	1994	1995	1996		
Availab. of monitored data:	0.75	1	0.25	AMD	[ ]
Calculated Month:	9	12	3		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	871	1302	272	HI sum	[kWh/m^2]
Ambient air temperature:	0	0	0	Tam avr	[˚C]
System Energies:					
Energy output from inverter:	0	0	0	EIO sum	[kWh]
Useful energy:	217	374	100	Euse sum	[kWh]
PV array fraction:	1	1	1	FA	[ ]
Energy consumption:	217	374	100	Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.17	3.57	3.02	Yr avr	[h/d]
Final yield:	0.73	0.95	1.03	Yf avr	[h/d]
Array capture losses:	2.32	2.47	1.87	Lc avr	[h/d]
System losses:	0.12	0.15	0.12	Ls avr	[h/d]
Performance Ratio:	0.23	0.27	0.36	PR	[ ]
Array efficiency:	2.5	2.9	3.6	eta A	[%]
Inverter efficiency:				eta inv	[%]
Overall plant efficiency:	2.2	2.5	3.2	eta tot	[%]
Utility Grid:					
Energy to utility grid:	0	0	0	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Luttermann**		
Country:	France	Battery storage:	750 Ah / 24 V
Type of plant:	Stand-alone hybrid	Mounting:	Freestanding
Nominal Power:	0.54 kW_p	Array area:	5.76 m²

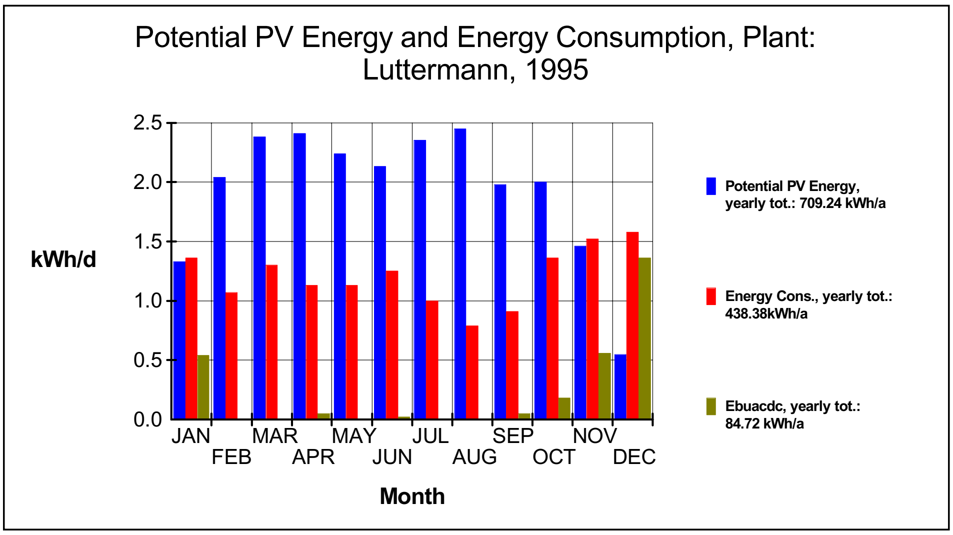


Year:	1994	1995	1996		
Availab. of monitored data:	0.75	1	0.416	AMD	[ ]
Calculated Month:	9	12	5		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	986	1313	477	HI sum	[kWh/m^2]
Ambient air temperature:	0	0	0	Tam avr	[˚C]
System Energies:					
Energy output from inverter:	0	0	0	EIO sum	[kWh]
Useful energy:	279	438	177	Euse sum	[kWh]
PV array fraction:	0.87	0.83	0.78	FA	[ ]
Energy consumption:	279	438	177	Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.59	3.6	3.17	Yr avr	[h/d]
Final yield:	1.63	1.8	1.62	Yf avr	[h/d]
Array capture losses:	1.68	1.43	1.30	Lc avr	[h/d]
System losses:	0.28	0.37	0.24	Ls avr	[h/d]
Performance Ratio:	0.48	0.50	0.51	PR	[ ]
Array efficiency:	5	5.6	6	eta A	[%]
Inverter efficiency:				eta inv	[%]
Overall plant efficiency:	4.3	4.8	5	eta tot	[%]
Utility Grid:					
Energy to utility grid:	0	0	0	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Luttermann**		
Country:	France	Battery storage:	750 Ah / 24 V
Type of plant:	Stand-alone hybrid	Mounting:	Freestanding
Nominal Power:	0.54 kW_p	Array area:	5.76 m²



Year:	1994	1995	1996		
Availab. of monitored data:	0.75	1	0.416	AMD	[ ]
Calculated Month:	9	12	5		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	986	1313	477	HI sum	[kWh/m^2]
Ambient air temperature:	0	0	0	Tam avr	[˚C]
System Energies:					
Energy output from inverter:	0	0	0	EIO sum	[kWh]
Useful energy:	279	438	177	Euse sum	[kWh]
PV array fraction:	0.87	0.83	0.78	FA	[ ]
Energy consumption:	279	438	177	Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.59	3.6	3.17	Yr avr	[h/d]
Final yield:	1.63	1.8	1.62	Yf avr	[h/d]
Array capture losses:	1.68	1.43	1.30	Lc avr	[h/d]
System losses:	0.28	0.37	0.24	Ls avr	[h/d]
Performance Ratio:	0.48	0.50	0.51	PR	[ ]
Array efficiency:	5	5.6	6	eta A	[%]
Inverter efficiency:				eta inv	[%]
Overall plant efficiency:	4.3	4.8	5	eta tot	[%]
Utility Grid:					
Energy to utility grid:	0	0	0	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

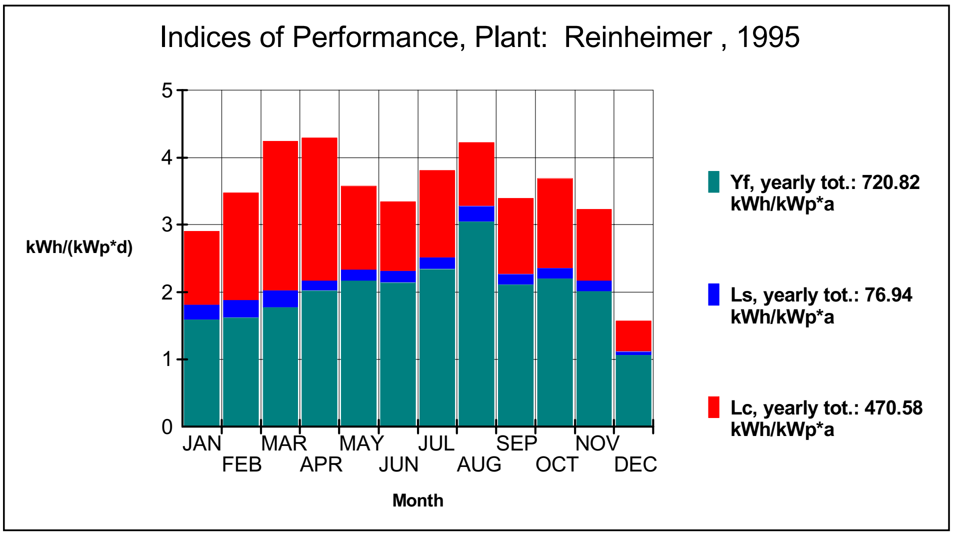
Photovoltaic Database Report

Plant Name:	**Reinheimer**		
Country:	France	Battery storage:	750 Ah / 24 V
Type of plant:	Stand-alone hybrid	Mounting:	Freestanding
Nominal Power:	1.08 kW_p	Array area:	11.52 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Reinheimer**		
Country:	France	Battery storage:	750 Ah / 24 V
Type of plant:	Stand-alone hybrid	Mounting:	Freestanding
Nominal Power:	1.08 kW_p	Array area:	11.52 m²

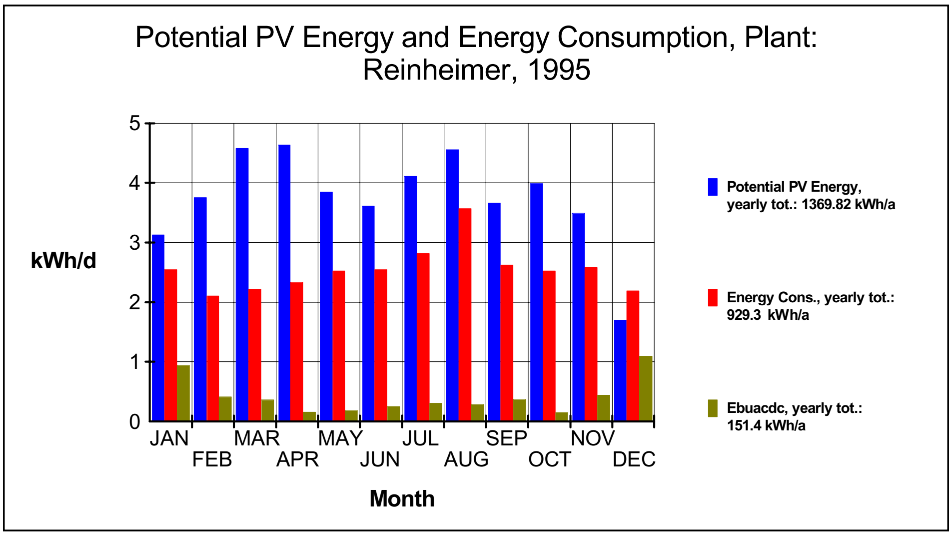


Year:	1994	1995	1996		
Availab. of monitored data:	0.75	1	0.25	AMD	[ ]
Calculated Month:	9	12	3		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	931	1268	385	HI sum	[kWh/m^2]
Ambient air temperature:	0	0	0	Tam avr	[˚C]
System Energies:					
Energy output from inverter:	0	0	0	EIO sum	[kWh]
Useful energy:	670	931	206	Euse sum	[kWh]
PV array fraction:	0.83	0.85	0.66	FA	[ ]
Energy consumption:	670	931	206	Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.39	3.48	4.29	Yr avr	[h/d]
Final yield:	1.86	1.97	1.39	Yf avr	[h/d]
Array capture losses:	1.27	1.29	2.04	Lc avr	[h/d]
System losses:	0.26	0.21	0.85	Ls avr	[h/d]
Performance Ratio:	0.55	0.57	0.33	PR	[ ]
Array efficiency:	5.9	5.9	5.0	eta A	[%]
Inverter efficiency:				eta inv	[%]
Overall plant efficiency:	5.2	5.4	4.0	eta tot	[%]
Utility Grid:					
Energy to utility grid:	0	0	0	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Reinheimer**		
Country:	France	Battery storage:	750 Ah / 24 V
Type of plant:	Stand-alone hybrid	Mounting:	Freestanding
Nominal Power:	1.08 kW_p	Array area:	11.52 m²



Year:	1994	1995	1996		
Availab. of monitored data:	0.75	1	0.25	AMD	[ ]
Calculated Month:	9	12	3		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	931	1268	385	HI sum	[kWh/m^2]
Ambient air temperature:	0	0	0	Tam avr	[˚C]
System Energies:					
Energy output from inverter:	0	0	0	EIO sum	[kWh]
Useful energy:	670	931	206	Euse sum	[kWh]
PV array fraction:	0.83	0.85	0.66	FA	[ ]
Energy consumption:	670	931	206	Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.39	3.48	4.29	Yr avr	[h/d]
Final yield:	1.86	1.97	1.39	Yf avr	[h/d]
Array capture losses:	1.27	1.29	2.04	Lc avr	[h/d]
System losses:	0.26	0.21	0.85	Ls avr	[h/d]
Performance Ratio:	0.55	0.57	0.33	PR	[ ]
Array efficiency:	5.9	5.9	5.0	eta A	[%]
Inverter efficiency:				eta inv	[%]
Overall plant efficiency:	5.2	5.4	4.0	eta tot	[%]
Utility Grid:					
Energy to utility grid:	0	0	0	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

D - 4 Germany

IEA PVPS TASK 2 REPORT PROGRAMME

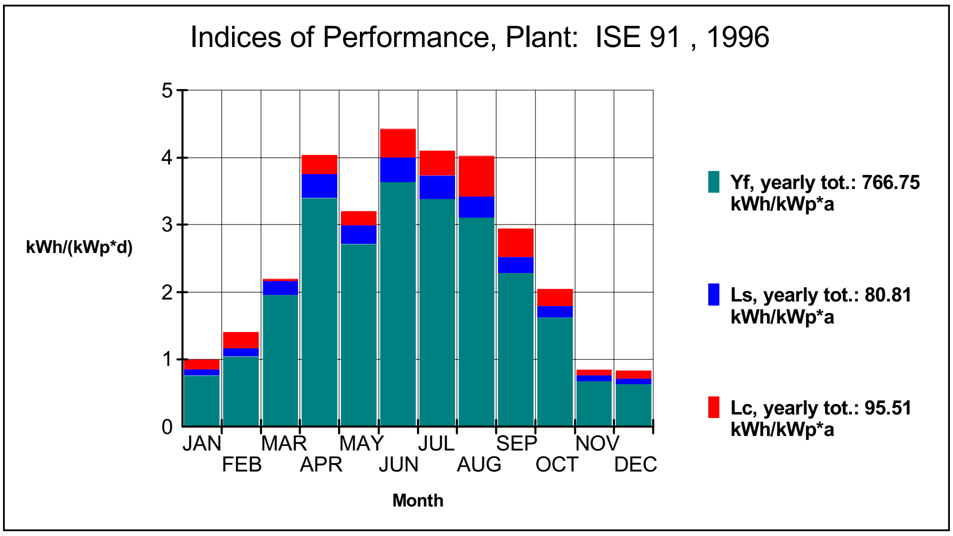
Photovoltaic Database Report

Plant Name:	**ISE 91**		
Country:	Germany		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	4.00 kW_p	Array area:	34.32 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**ISE 91**		
Country:	Germany		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	4.00 kW_p	Array area:	34.32 m²



Year:	1996		
Availab. of monitored data:	1	AMD	[ ]
Calculated Month:	12		
Meteorology:			
Glob. Irradiation, horizontal:		H sum	[kWh/m^2]
Irradiation, in array plane:	943	HI sum	[kWh/m^2]
Ambient air temperature:		Tam avr	[˚C]
System Energies:			
Energy output from inverter:	3067	EIO sum	[kWh]
Useful energy:	4279	Euse sum	[kWh]
PV array fraction:	0.74	FA	[ ]
Energy consumption:		Econ sum	[kWh]
System Performance Indices:			
Reference yield:	2.58	Yr avr	[h/d]
Final yield:	2.1	Yf avr	[h/d]
Array capture losses:	0.26	Lc avr	[h/d]
System losses:	0.22	Ls avr	[h/d]
Performance Ratio:	0.81	PR	[ ]
Array efficiency:	10.5	eta A	[%]
Inverter efficiency:	90.5	eta inv	[%]
Overall plant efficiency:	9.5	eta tot	[%]
Utility Grid:			
Energy to utility grid:	2637	ETU sum	[kWh]
Energy from utility grid:	1206	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

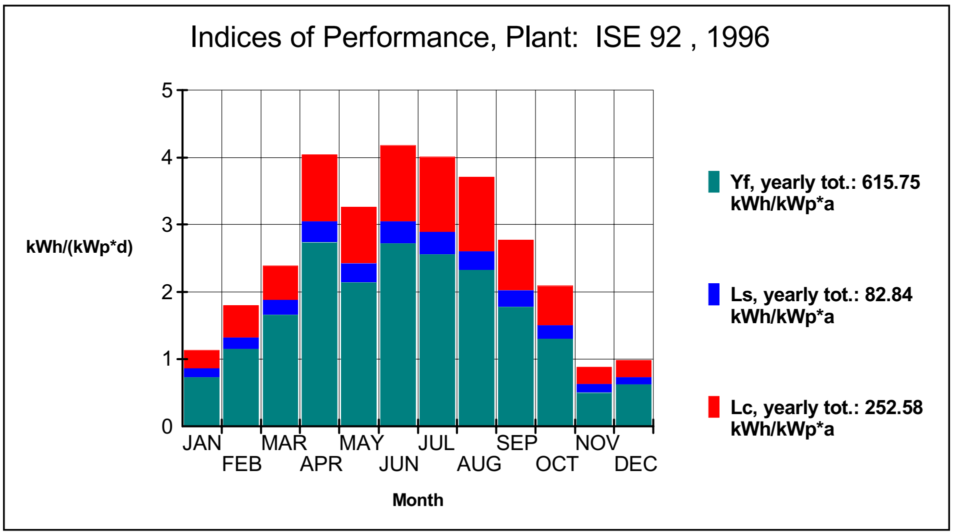
Photovoltaic Database Report

Plant Name:	**ISE 92**
Country:	Germany
Type of plant:	Grid connected
Nominal Power:	1.46 kW_p
Mounting:	Sloped roof
Array area:	12.59 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**ISE 92**		
Country:	Germany		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	1.46 kW_p	Array area:	12.59 m²



Year:	1996		
Availab. of monitored data:	0.99	AMD	[ ]
Calculated Month:	12		
Meteorology:			
Glob. Irradiation, horizontal:		H sum	[kWh/m^2]
Irradiation, in array plane:	951	HI sum	[kWh/m^2]
Ambient air temperature:		Tam avr	[˚C]
System Energies:			
Energy output from inverter:	899	EIO sum	[kWh]
Useful energy:	2988	Euse sum	[kWh]
PV array fraction:	0.33	FA	[ ]
Energy consumption:		Econ sum	[kWh]
System Performance Indices:			
Reference yield:	2.6	Yr avr	[h/d]
Final yield:	1.69	Yf avr	[h/d]
Array capture losses:	0.69	Lc avr	[h/d]
System losses:	0.23	Ls avr	[h/d]
Performance Ratio:	0.65	PR	[ ]
Array efficiency:	8.5	eta A	[%]
Inverter efficiency:	88.1	eta inv	[%]
Overall plant efficiency:	7.5	eta tot	[%]
Utility Grid:			
Energy to utility grid:	551	ETU sum	[kWh]
Energy from utility grid:	2083	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

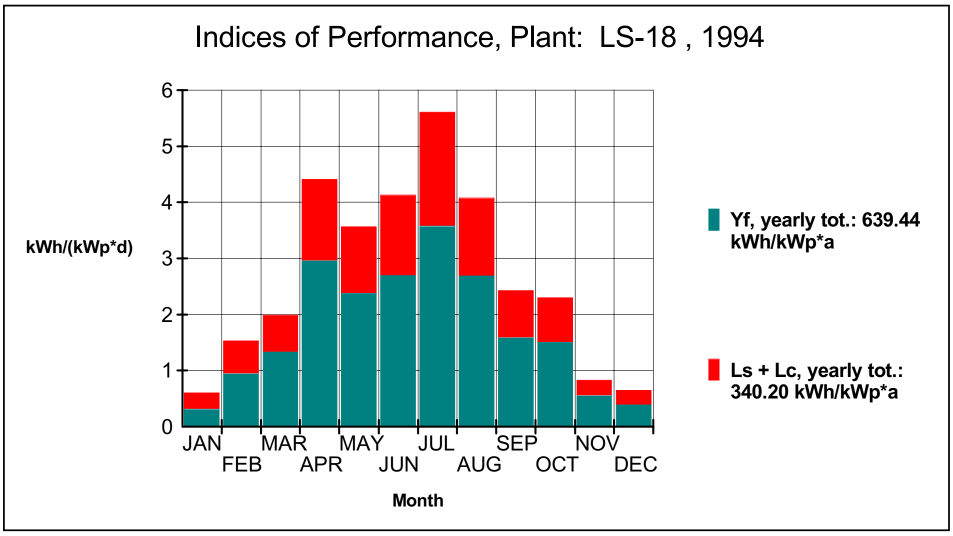
Photovoltaic Database Report

Plant Name:	**LS-18**		
Country:	Germany		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	1.80 kW_p	Array area:	14.40 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**LS-18**		
Country:	Germany		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	1.80 kW_p	Array area:	14.40 m²

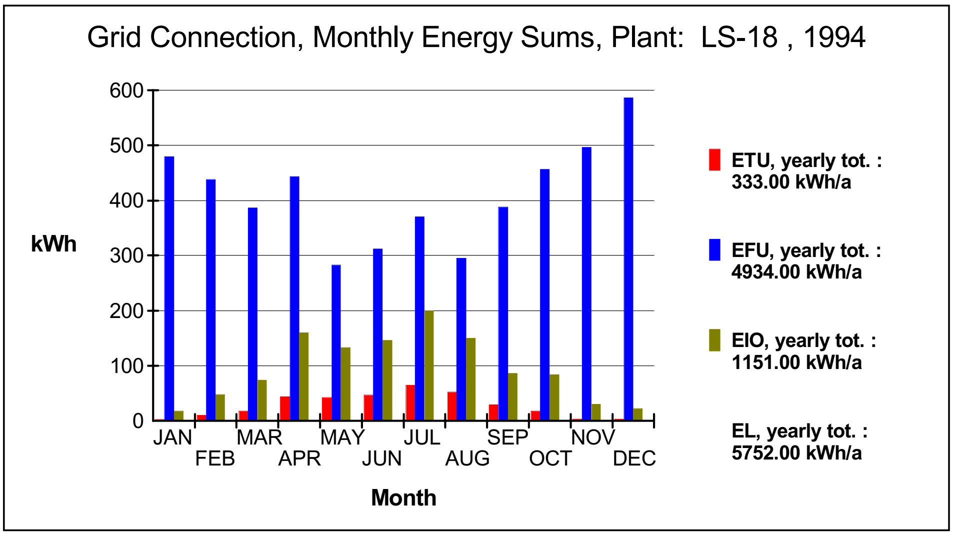


Year:	1993	1994	1995		
Availab. of monitored data:	0.83	1	1	AMD	[ ]
Calculated Month:	10	12	12		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	930	980	1009	HI sum	[kWh/m^2]
Ambient air temperature:				Tam avr	[˚C]
System Energies:					
Energy output from inverter:	1020	1151	1167	EIO sum	[kWh]
Useful energy:	5370	6085	2735	Euse sum	[kWh]
PV array fraction:	0.19	0.19	0.43	FA	[ ]
Energy consumption:				Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.05	2.68	2.76	Yr avr	[h/d]
Final yield:	1.86	1.75	1.77	Yf avr	[h/d]
Array capture losses:				Lc avr	[h/d]
System losses:				Ls avr	[h/d]
Performance Ratio:	0.61	0.65	0.64	PR	[ ]
Array efficiency:				eta A	[%]
Inverter efficiency:				eta inv	[%]
Overall plant efficiency:	7.6	8.2	8	eta tot	[%]
Utility Grid:					
Energy to utility grid:	382	333	110	ETU sum	[kWh]
Energy from utility grid:	4350	4934	1568	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**LS-18**		
Country:	Germany		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	1.80 kW_p	Array area:	14.40 m²



Year:	1993	1994	1995		
Availab. of monitored data:	0.83	1	1	AMD	[ ]
Calculated Month:	10	12	12		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	930	980	1009	HI sum	[kWh/m^2]
Ambient air temperature:				Tam avr	[˚C]
System Energies:					
Energy output from inverter:	1020	1151	1167	EIO sum	[kWh]
Useful energy:	5370	6085	2735	Euse sum	[kWh]
PV array fraction:	0.19	0.19	0.43	FA	[ ]
Energy consumption:				Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.05	2.68	2.76	Yr avr	[h/d]
Final yield:	1.86	1.75	1.77	Yf avr	[h/d]
Array capture losses:				Lc avr	[h/d]
System losses:				Ls avr	[h/d]
Performance Ratio:	0.61	0.65	0.64	PR	[ ]
Array efficiency:				eta A	[%]
Inverter efficiency:				eta inv	[%]
Overall plant efficiency:	7.6	8.2	8	eta tot	[%]
Utility Grid:					
Energy to utility grid:	382	333	110	ETU sum	[kWh]
Energy from utility grid:	4350	4934	1568	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

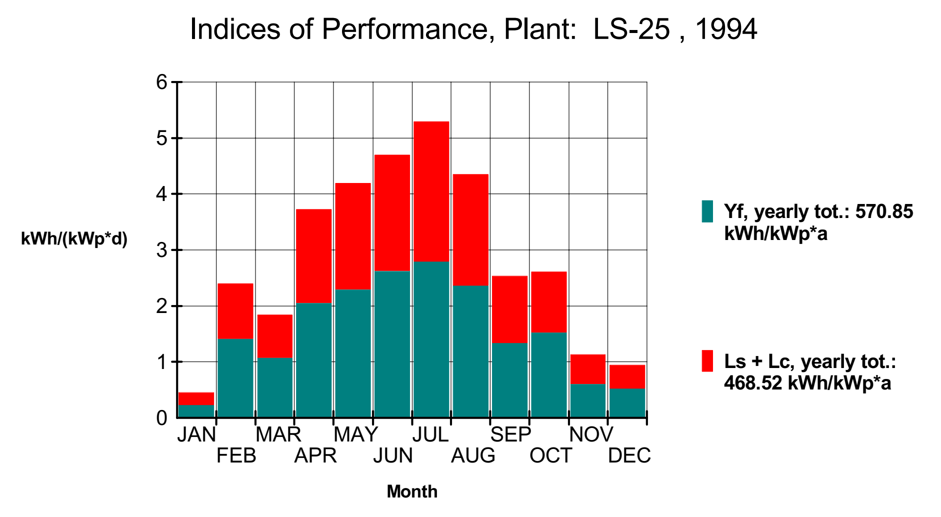
Photovoltaic Database Report

Plant Name:	**LS-25**		
Country:	Germany		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	2.23 kW_p	Array area:	15.12 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**LS-25**		
Country:	Germany		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	2.23 kW_p	Array area:	15.12 m²

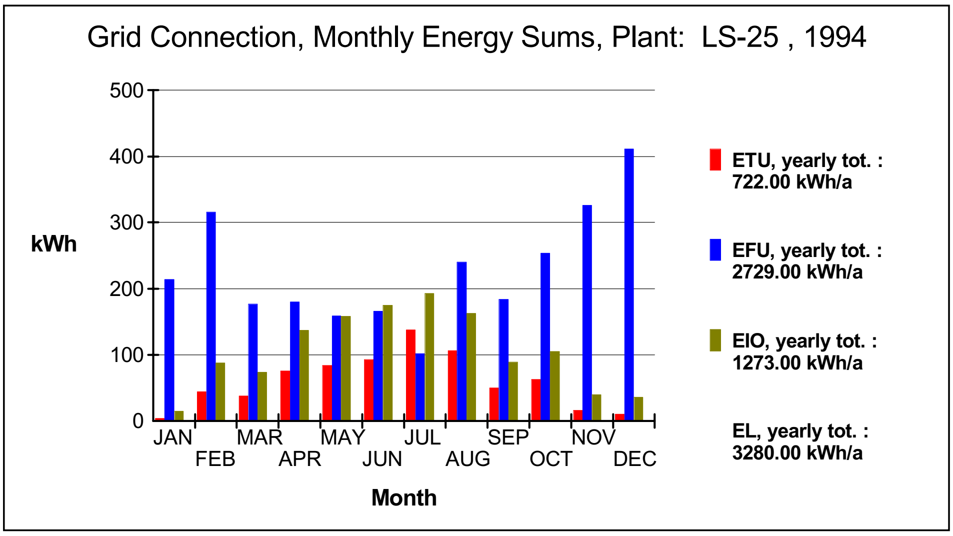


Year:	1993	1994		
Availab. of monitored data:	0.83	1	AMD	[ ]
Calculated Month:	10	12		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	920	1039	HI sum	[kWh/m^2]
Ambient air temperature:			Tam avr	[˚C]
System Energies:				
Energy output from inverter:	1285	1273	EIO sum	[kWh]
Useful energy:	4323	4002	Euse sum	[kWh]
PV array fraction:	0.30	0.32	FA	[ ]
Energy consumption:			Econ sum	[kWh]
System Performance Indices:				
Reference yield:	3.01	2.85	Yr avr	[h/d]
Final yield:	1.88	1.56	Yf avr	[h/d]
Array capture losses:			Lc avr	[h/d]
System losses:			Ls avr	[h/d]
Performance Ratio:	0.63	0.55	PR	[ ]
Array efficiency:			eta A	[%]
Inverter efficiency:			eta inv	[%]
Overall plant efficiency:	9.2	8.1	eta tot	[%]
Utility Grid:				
Energy to utility grid:	760	722	ETU sum	[kWh]
Energy from utility grid:	3038	2729	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**LS-25**		
Country:	Germany		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	2.23 kW_p	Array area:	15.12 m²



Year:	1993	1994		
Availab. of monitored data:	0.83	1	AMD	[ ]
Calculated Month:	10	12		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	920	1039	HI sum	[kWh/m^2]
Ambient air temperature:			Tam avr	[˚C]
System Energies:				
Energy output from inverter:	1285	1273	EIO sum	[kWh]
Useful energy:	4323	4002	Euse sum	[kWh]
PV array fraction:	0.30	0.32	FA	[ ]
Energy consumption:			Econ sum	[kWh]
System Performance Indices:				
Reference yield:	3.01	2.85	Yr avr	[h/d]
Final yield:	1.88	1.56	Yf avr	[h/d]
Array capture losses:			Lc avr	[h/d]
System losses:			Ls avr	[h/d]
Performance Ratio:	0.63	0.55	PR	[ ]
Array efficiency:			eta A	[%]
Inverter efficiency:			eta inv	[%]
Overall plant efficiency:	9.2	8.1	eta tot	[%]
Utility Grid:				
Energy to utility grid:	760	722	ETU sum	[kWh]
Energy from utility grid:	3038	2729	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

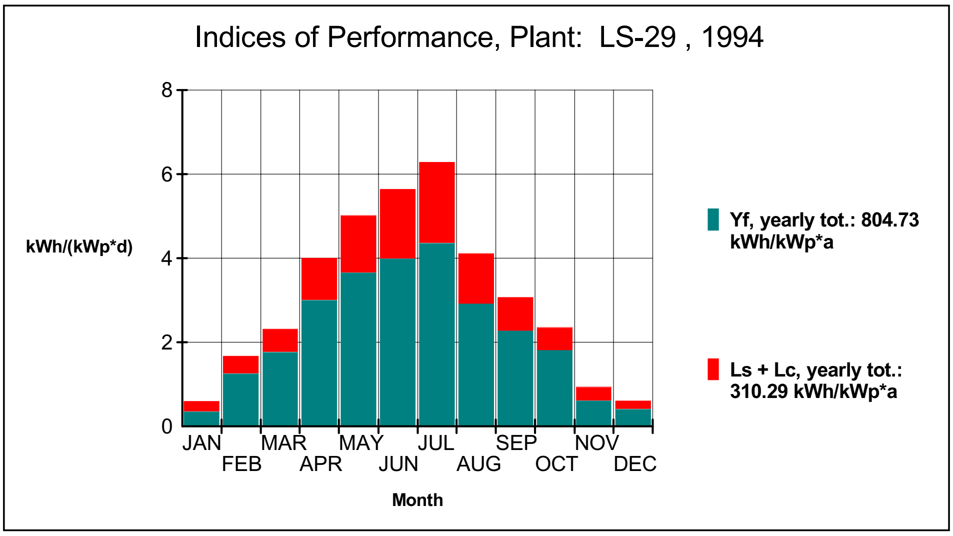
Photovoltaic Database Report

Plant Name:	**LS-29**		
Country:	Germany		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	1.48 kW_p	Array area:	10.08 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**LS-29**		
Country:	Germany		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	1.48 kW_p	Array area:	10.08 m²

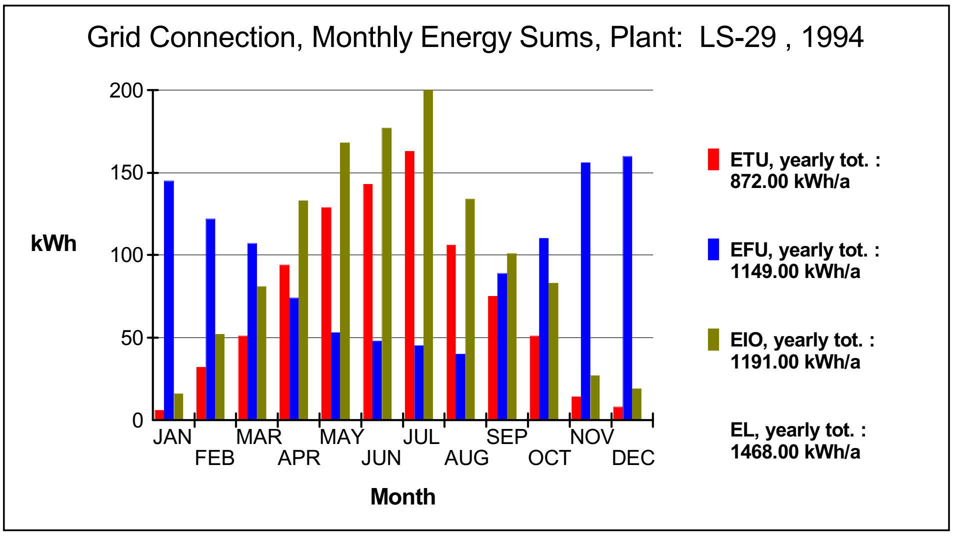


Year:	1993	1994	1995		
Availab. of monitored data:	0.75	1	1	AMD	[ ]
Calculated Month:	9	12	12		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	904	1115	1118	HI sum	[kWh/m^2]
Ambient air temperature:				Tam avr	[˚C]
System Energies:					
Energy output from inverter:	982	1191	1156	EIO sum	[kWh]
Useful energy:	1984	2340	2304	Euse sum	[kWh]
PV array fraction:	0.50	0.51	0.50	FA	[ ]
Energy consumption:				Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.29	3.05	3.05	Yr avr	[h/d]
Final yield:	2.41	2.2	2.13	Yf avr	[h/d]
Array capture losses:				Lc avr	[h/d]
System losses:				Ls avr	[h/d]
Performance Ratio:	0.73	0.72	0.70	PR	[ ]
Array efficiency:				eta A	[%]
Inverter efficiency:				eta inv	[%]
Overall plant efficiency:	10.8	10.6	10.3	eta tot	[%]
Utility Grid:					
Energy to utility grid:	902	872	863	ETU sum	[kWh]
Energy from utility grid:	1002	1149	1148	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**LS-29**		
Country:	Germany		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	1.48 kW_p	Array area:	10.08 m²



Year:	1993	1994	1995		
Availab. of monitored data:	0.75	1	1	AMD	[ ]
Calculated Month:	9	12	12		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	904	1115	1118	HI sum	[kWh/m^2]
Ambient air temperature:				Tam avr	[˚C]
System Energies:					
Energy output from inverter:	982	1191	1156	EIO sum	[kWh]
Useful energy:	1984	2340	2304	Euse sum	[kWh]
PV array fraction:	0.50	0.51	0.50	FA	[ ]
Energy consumption:				Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.29	3.05	3.05	Yr avr	[h/d]
Final yield:	2.41	2.2	2.13	Yf avr	[h/d]
Array capture losses:				Lc avr	[h/d]
System losses:				Ls avr	[h/d]
Performance Ratio:	0.73	0.72	0.70	PR	[ ]
Array efficiency:				eta A	[%]
Inverter efficiency:				eta inv	[%]
Overall plant efficiency:	10.8	10.6	10.3	eta tot	[%]
Utility Grid:					
Energy to utility grid:	902	872	863	ETU sum	[kWh]
Energy from utility grid:	1002	1149	1148	EFU sum	[kWh]

D - 5 Israel

IEA PVPS TASK 2 REPORT PROGRAMME

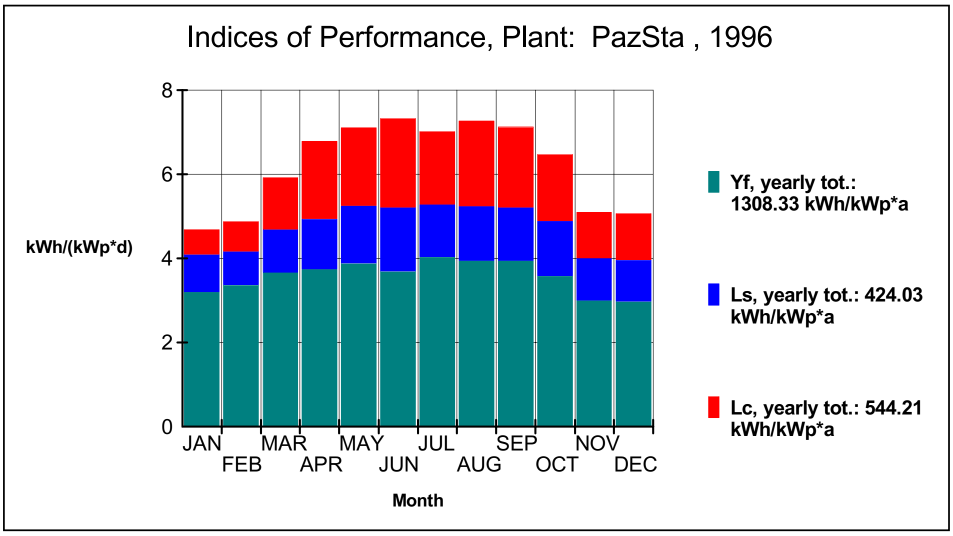
Photovoltaic Database Report

Plant Name:	**PazSta**		
Country:	Israel		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	2.88 kW_p	Array area:	28.49 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**PazSta**		
Country:	Israel		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	2.88 kW_p	Array area:	28.49 m²



Year:	1996		
Availab. of monitored data:	1	AMD	[ ]
Calculated Month:	12		
Meteorology:			
Glob. Irradiation, horizontal:		H sum	[kWh/m^2]
Irradiation, in array plane:	2277	HI sum	[kWh/m^2]
Ambient air temperature:		Tam avr	[˚C]
System Energies:			
Energy output from inverter:	3768	EIO sum	[kWh]
Useful energy:	3768	Euse sum	[kWh]
PV array fraction:	1	FA	[ ]
Energy consumption:		Econ sum	[kWh]
System Performance Indices:			
Reference yield:	6.23	Yr avr	[h/d]
Final yield:	3.58	Yf avr	[h/d]
Array capture losses:	1.49	Lc avr	[h/d]
System losses:	1.16	Ls avr	[h/d]
Performance Ratio:	0.57	PR	[ ]
Array efficiency:	7.7	eta A	[%]
Inverter efficiency:	75.5	eta inv	[%]
Overall plant efficiency:	5.8	eta tot	[%]
Utility Grid:			
Energy to utility grid:	3768	ETU sum	[kWh]
Energy from utility grid:	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

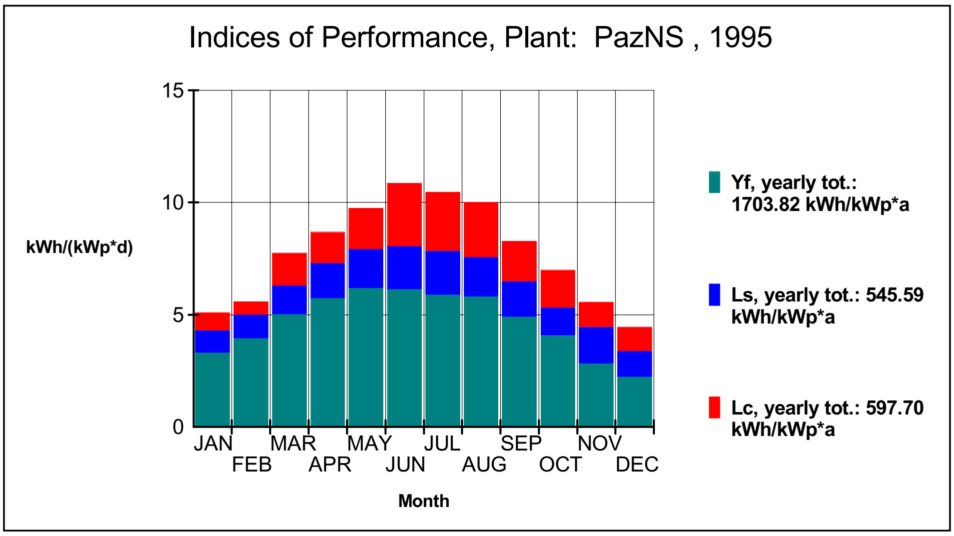
Photovoltaic Database Report

Plant Name:	**PazNS**		
Country:	Israel		
Type of plant:	Grid connected	Mounting:	One-axis tracking
Nominal Power:	2.88 kW_p	Array area:	28.49 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**PazNS**		
Country:	Israel		
Type of plant:	Grid connected	Mounting:	One-axis tracking
Nominal Power:	2.88 kW_p	Array area:	28.49 m²



Year:	1995	1996		
Availab. of monitored data:	1	0.92	AMD	[ ]
Calculated Month:	12	11		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	2847	2411	HI sum	[kWh/m^2]
Ambient air temperature:			Tam avr	[˚C]
System Energies:				
Energy output from inverter:	4909	3744	EIO sum	[kWh]
Useful energy:	4909	3744	Euse sum	[kWh]
PV array fraction:	1	1	FA	[ ]
Energy consumption:			Econ sum	[kWh]
System Performance Indices:				
Reference yield:	7.79	7.18	Yr avr	[h/d]
Final yield:	4.66	3.88	Yf avr	[h/d]
Array capture losses:	1.63	1.79	Lc avr	[h/d]
System losses:	1.49	1.51	Ls avr	[h/d]
Performance Ratio:	0.60	0.54	PR	[ ]
Array efficiency:	8	7.6	eta A	[%]
Inverter efficiency:	75.8	72	eta inv	[%]
Overall plant efficiency:	6.1	5.5	eta tot	[%]
Utility Grid:				
Energy to utility grid:	4909	3744	ETU sum	[kWh]
Energy from utility grid:	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

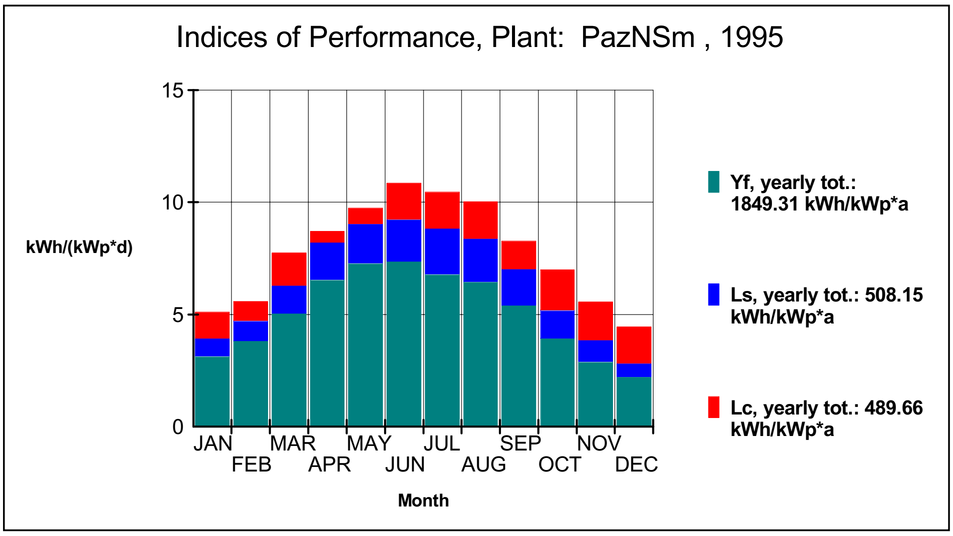
Photovoltaic Database Report

Plant Name:	**PazNSm**		
Country:	Israel		
Type of plant:	Grid connected	Mounting:	One-axis tracking + mirrors
Nominal Power:	2.88 kW_p	Array area:	28.49 m^2

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**PazNSm**		
Country:	Israel		
Type of plant:	Grid connected	Mounting:	One-axis tracking + mirrors
Nominal Power:	2.88 kW_p	Array area:	28.49 m²



Year:	1995	1996		
Availab. of monitored data:	1	0.42	AMD	[ ]
Calculated Month:	12	5		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	2847	1214	HI sum	[kWh/m^2]
Ambient air temperature:			Tam avr	[˚C]
System Energies:				
Energy output from inverter:	5326	2127	EIO sum	[kWh]
Useful energy:	5326	2127	Euse sum	[kWh]
PV array fraction:	1	1	FA	[ ]
Energy consumption:			Econ sum	[kWh]
System Performance Indices:				
Reference yield:	7.79	8	Yr avr	[h/d]
Final yield:	5.06	4.87	Yf avr	[h/d]
Array capture losses:	1.34	1.58	Lc avr	[h/d]
System losses:	1.39	1.55	Ls avr	[h/d]
Performance Ratio:	0.65	0.61	PR	[ ]
Array efficiency:	8.4	8.1	eta A	[%]
Inverter efficiency:	78.5	75.8	eta inv	[%]
Overall plant efficiency:	6.6	6.2	eta tot	[%]
Utility Grid:				
Energy to utility grid:	5326	2127	ETU sum	[kWh]
Energy from utility grid:	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

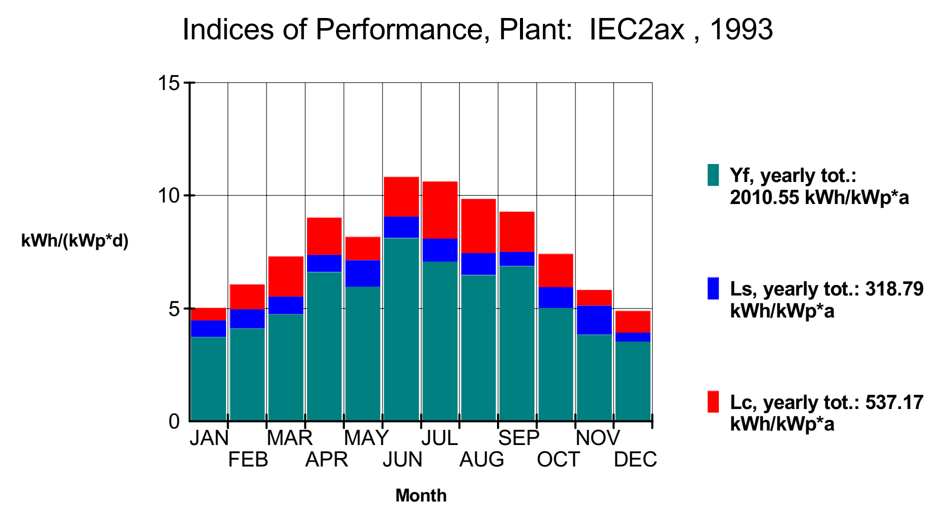
Photovoltaic Database Report

Plant Name:	**IEC2ax**		
Country:	Israel		
Type of plant:	Grid connected	Mounting:	Two-axis tracking
Nominal Power:	3.98 kW_p	Array area:	32.25 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**IEC2ax**		
Country:	Israel		
Type of plant:	Grid connected	Mounting:	Two-axis tracking
Nominal Power:	3.98 kW_p	Array area:	32.25 m²



Year:	1993	1994		
Availab. of monitored data:	1	0.64	AMD	[ ]
Calculated Month:	12	8		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	2867	2133	HI sum	[kWh/m^2]
Ambient air temperature:			Tam avr	[˚C]
System Energies:				
Energy output from inverter:	8002	5465	EIO sum	[kWh]
Useful energy:	8002	5465	Euse sum	[kWh]
PV array fraction:	1	1	FA	[ ]
Energy consumption:			Econ sum	[kWh]
System Performance Indices:				
Reference yield:	7.85	8.77	Yr avr	[h/d]
Final yield:	5.51	5.64	Yf avr	[h/d]
Array capture losses:	1.47	2.41	Lc avr	[h/d]
System losses:	0.87	0.71	Ls avr	[h/d]
Performance Ratio:	0.70	0.64	PR	[ ]
Array efficiency:	10	9	eta A	[%]
Inverter efficiency:	86.3	88.7	eta inv	[%]
Overall plant efficiency:	8.7	7.9	eta tot	[%]
Utility Grid:				
Energy to utility grid:	8002	5465	ETU sum	[kWh]
Energy from utility grid:	0	0	EFU sum	[kWh]

D - 6 Italy

IEA PVPS TASK 2 REPORT PROGRAMME

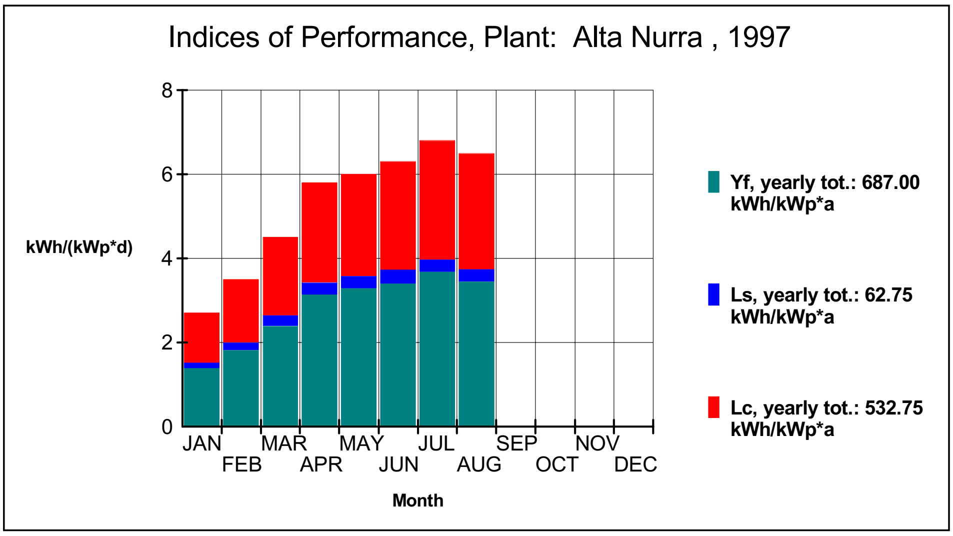
Photovoltaic Database Report

Plant Name:	**Alta Nurra**		
Country:	Italy		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	100.00 kW_p	Array area:	865.00 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Alta Nurra**		
Country:	Italy		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	100.00 kW_p	Array area:	865.00 m²



Year:	1997		
Availab. of monitored data:	0.67	AMD	[ ]
Calculated Month:	8		
Meteorology:			
Glob. Irradiation, horizontal:		H sum	[kWh/m^2]
Irradiation, in array plane:	1283	HI sum	[kWh/m^2]
Ambient air temperature:		Tam avr	[˚C]
System Energies:			
Energy output from inverter:	68700	EIO sum	[kWh]
Useful energy:	0	Euse sum	[kWh]
PV array fraction:	1	FA	[ ]
Energy consumption:		Econ sum	[kWh]
System Performance Indices:			
Reference yield:	5.26	Yr avr	[h/d]
Final yield:	2.82	Yf avr	[h/d]
Array capture losses:	2.19	Lc avr	[h/d]
System losses:	0.26	Ls avr	[h/d]
Performance Ratio:	0.54	PR	[ ]
Array efficiency:	6.8	eta A	[%]
Inverter efficiency:	91.6	eta inv	[%]
Overall plant efficiency:	6.2	eta tot	[%]
Utility Grid:			
Energy to utility grid:	0	ETU sum	[kWh]
Energy from utility grid:	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

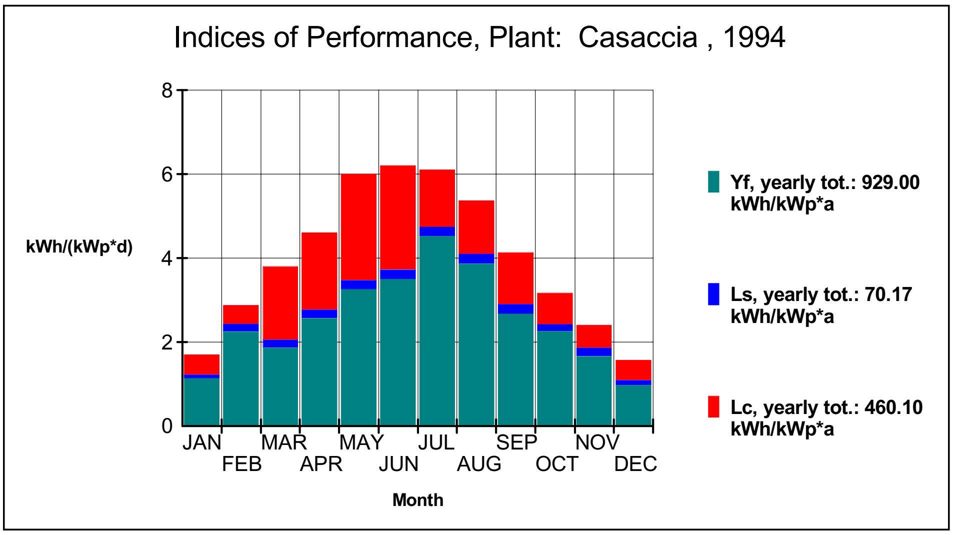
Photovoltaic Database Report

Plant Name:	**Casaccia**		
Country:	Italy		
Type of plant:	Grid connected	Mounting:	Flat roof
Nominal Power:	100.00 kW_p	Array area:	865.00 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Casaccia**		
Country:	Italy		
Type of plant:	Grid connected	Mounting:	Flat roof
Nominal Power:	100.00 kW_p	Array area:	865.00 m²



Year:	1992	1993	1994		
Availab. of monitored data:	1.00	1.00	1.00	AMD	[ ]
Calculated Month:	12	12	12		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	1350	1508	1459	HI sum	[kWh/m^2]
Ambient air temperature:				Tam avr	[˚C]
System Energies:					
Energy output from inverter:	92300	100700	92900	EIO sum	[kWh]
Useful energy:	0	0	0	Euse sum	[kWh]
PV array fraction:	1	1	1	FA	[ ]
Energy consumption:				Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.69	4.12	3.99	Yr avr	[h/d]
Final yield:	2.53	2.76	2.54	Yf avr	[h/d]
Array capture losses:	0.93	1.13	1.26	Lc avr	[h/d]
System losses:	0.23	0.24	0.19	Ls avr	[h/d]
Performance Ratio:	0.68	0.67	0.64	PR	[ ]
Array efficiency:	8.6	8.4	7.9	eta A	[%]
Inverter efficiency:	91.7	92.1	93	eta inv	[%]
Overall plant efficiency:	7.9	7.7	7.4	eta tot	[%]
Utility Grid:					
Energy to utility grid:	-	-	-	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Casaccia**		
Country:	Italy		
Type of plant:	Grid connected	Mounting:	Flat roof
Nominal Power:	100.00 kW_p	Array area:	865.00 m²

Year:	1995	1996		
Availab. of monitored data:	0.92	1.00	AMD	[ ]
Calculated Month:	11	12		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	1153	1326	HI sum	[kWh/m^2]
Ambient air temperature:			Tam avr	[˚C]
System Energies:				
Energy output from inverter:	71500	80100	EIO sum	[kWh]
Useful energy:	0	0	Euse sum	[kWh]
PV array fraction:	1	1	FA	[ ]
Energy consumption:			Econ sum	[kWh]
System Performance Indices:				
Reference yield:	3.43	3.62	Yr avr	[h/d]
Final yield:	2.13	2.19	Yf avr	[h/d]
Array capture losses:	1.1	1.24	Lc avr	[h/d]
System losses:	0.19	0.2	Ls avr	[h/d]
Performance Ratio:	0.62	0.60	PR	[ ]
Array efficiency:	7.8	7.6	eta A	[%]
Inverter efficiency:	91.7	91.8	eta inv	[%]
Overall plant efficiency:	7.2	7	eta tot	[%]
Utility Grid:				
Energy to utility grid:	0	0	ETU sum	[kWh]
Energy from utility grid:	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

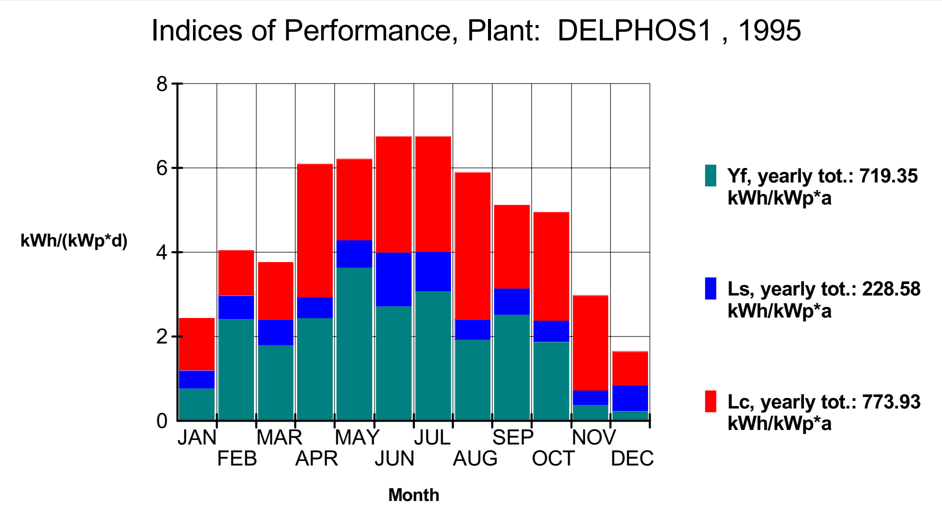
Photovoltaic Database Report

Plant Name:	**DELPHOS1**		
Country:	Italy		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	308.00 kW_p	Array area:	3,819.00 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**DELPHOS1**		
Country:	Italy		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	308.00 kW_p	Array area:	3,819.00 m²



Year:	1994	1995	1996		
Availab. of monitored data:	0.73	0.67	0.48	AMD	[ ]
Calculated Month:	12	12	9		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	1593	1722	1312	HI sum	[kWh/m^2]
Ambient air temperature:				Tam avr	[˚C]
System Energies:					
Energy output from inverter:	228050	221560	183050	EIO sum	[kWh]
Useful energy:	228050	221560	182050	Euse sum	[kWh]
PV array fraction:	1	1	1	FA	[ ]
Energy consumption:				Econ sum	[kWh]
System Performance Indices:					
Reference yield:	4.35	4.72	4.77	Yr avr	[h/d]
Final yield:	2.02	1.97	2.16	Yf avr	[h/d]
Array capture losses:	1.78	2.12	2.15	Lc avr	[h/d]
System losses:	0.55	0.63	0.45	Ls avr	[h/d]
Performance Ratio:	0.46	0.42	0.45	PR	[ ]
Array efficiency:	4.8	4.4	4.4	eta A	[%]
Inverter efficiency:	78.7	75.9	82.6	eta inv	[%]
Overall plant efficiency:	3.8	3.4	3.7	eta tot	[%]
Utility Grid:					
Energy to utility grid:	0	0	0	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

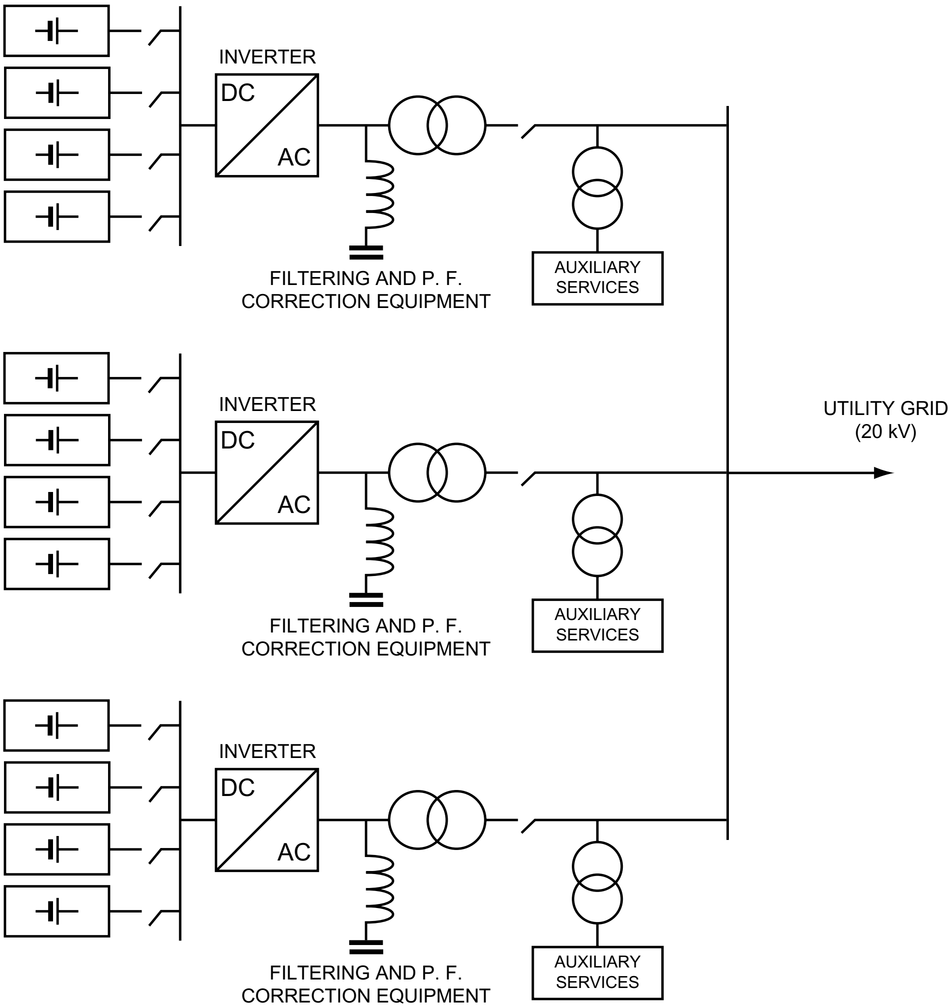
Photovoltaic Database Report

Plant Name:	**DELPHOS2**		
Country:	Italy		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	300.00 kW_p	Array area:	2,600.00 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**DELPHOS2**		
Country:	Italy		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	300.00 kW_p	Array area:	2,600.00 m²



IEA PVPS TASK 2 REPORT PROGRAMME

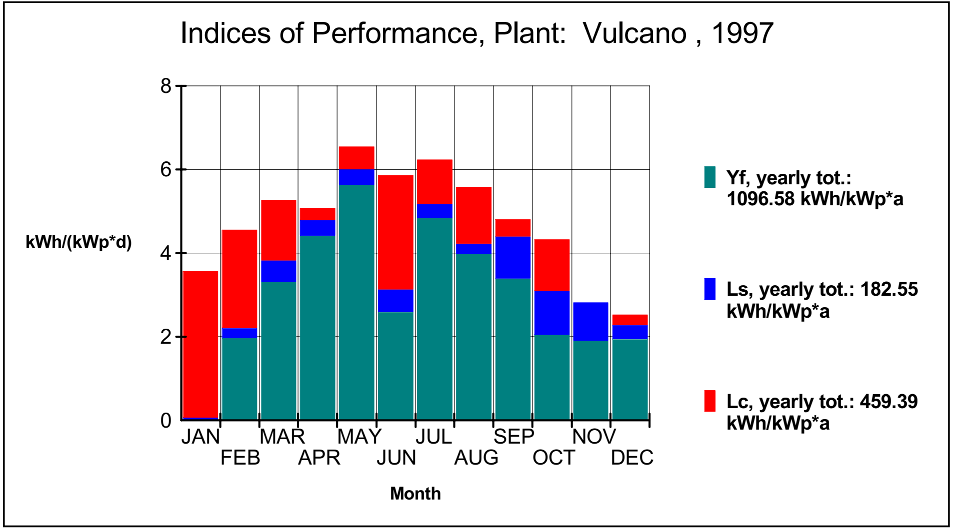
Photovoltaic Database Report

Plant Name:	**Vulcano**		
Country:	Italy		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	80.00 kW_p	Array area:	1,174.00 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Vulcano**		
Country:	Italy		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	80.00 kW_p	Array area:	1,174.00 m²



Year:	1997		
Availab. of monitored data:	1	AMD	[ ]
Calculated Month:	12		
Meteorology:			
Glob. Irradiation, horizontal:		H sum	[kWh/m^2]
Irradiation, in array plane:	1739	HI sum	[kWh/m^2]
Ambient air temperature:		Tam avr	[˚C]
System Energies:			
Energy output from inverter:	87726	EIO sum	[kWh]
Useful energy:	87726	Euse sum	[kWh]
PV array fraction:	1	FA	[ ]
Energy consumption:		Econ sum	[kWh]
System Performance Indices:			
Reference yield:	4.76	Yr avr	[h/d]
Final yield:	3	Yf avr	[h/d]
Array capture losses:	1.26	Lc avr	[h/d]
System losses:	0.5	Ls avr	[h/d]
Performance Ratio:	0.63	PR	[ ]
Array efficiency:	5	eta A	[%]
Inverter efficiency:	85.7	eta inv	[%]
Overall plant efficiency:	4.3	eta tot	[%]
Utility Grid:			
Energy to utility grid:	0	ETU sum	[kWh]
Energy from utility grid:	0	EFU sum	[kWh]

D - 7 Japan

IEA PVPS TASK 2 REPORT PROGRAMME

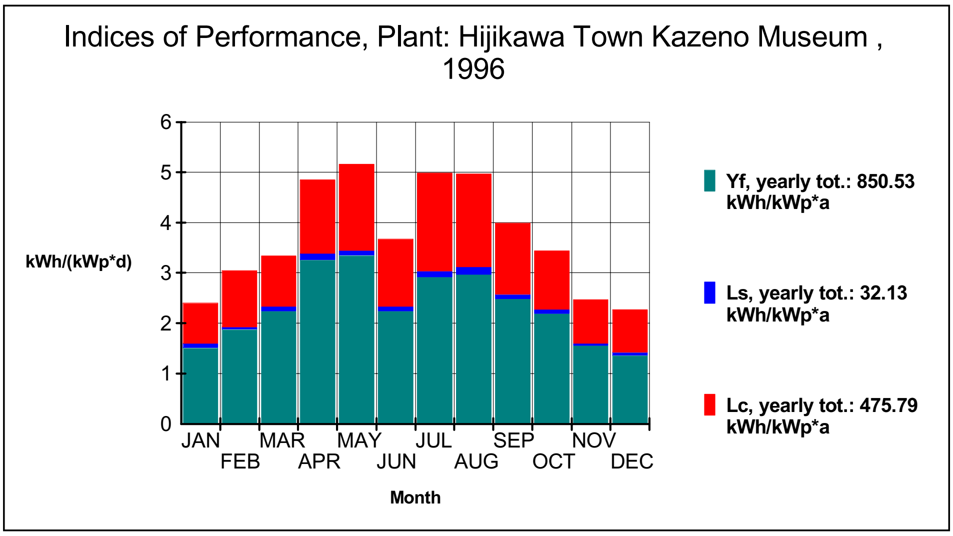
Photovoltaic Database Report

Plant Name:	**Hijikawa Town Kazeno Museum**		
Country:	Japan		
Type of plant:	Grid connected	Mounting:	Flat roof
Nominal Power:	20.58 kW_p	Array area:	128.30 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Hijikawa Town Kazeno Museum**		
Country:	Japan		
Type of plant:	Grid connected	Mounting:	Flat roof
Nominal Power:	20.58 kW_p	Array area:	128.30 m²



Year:	1996		
Availab. of monitored data:	1	AMD	[ ]
Calculated Month:	12		
Meteorology:			
Glob. Irradiation, horizontal:		H sum	[kWh/m^2]
Irradiation, in array plane:	1358	HI sum	[kWh/m^2]
Ambient air temperature:		Tam avr	[˚C]
System Energies:			
Energy output from inverter:	17504	EIO sum	[kWh]
Useful energy:	142495	Euse sum	[kWh]
PV array fraction:	0.11	FA	[ ]
Energy consumption:		Econ sum	[kWh]
System Performance Indices:			
Reference yield:	3.72	Yr avr	[h/d]
Final yield:	2.33	Yf avr	[h/d]
Array capture losses:	1.3	Lc avr	[h/d]
System losses:	0.09	Ls avr	[h/d]
Performance Ratio:	0.63	PR	[ ]
Array efficiency:	10.4	eta A	[%]
Inverter efficiency:	96.4	eta inv	[%]
Overall plant efficiency:	10	eta tot	[%]
Utility Grid:			
Energy to utility grid:	0	ETU sum	[kWh]
Energy from utility grid:	139808	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

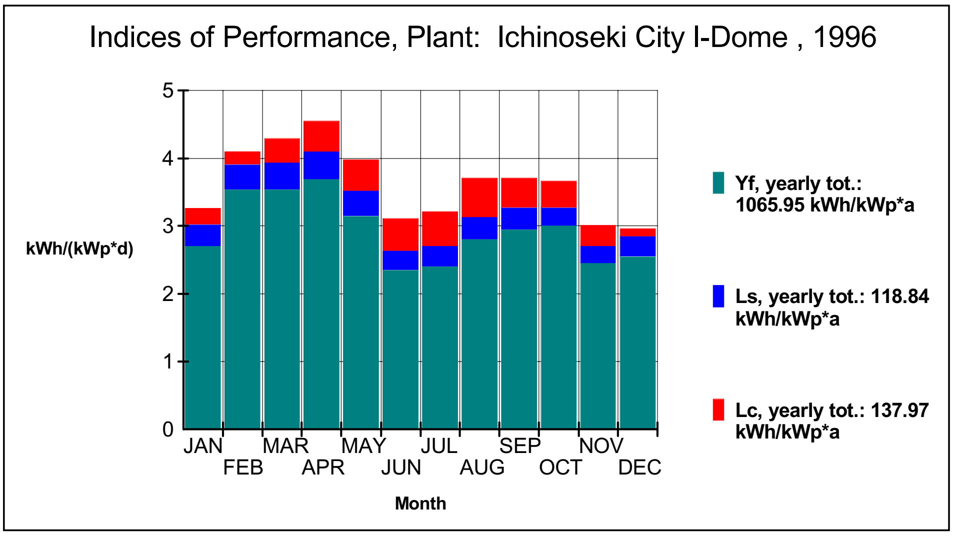
Photovoltaic Database Report

Plant Name:	**Ichinoseki City I-Dome**		
Country:	Japan		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	20.03 kW_p	Array area:	138.10 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Ichinoseki City I-Dome**		
Country:	Japan		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	20.03 kW_p	Array area:	138.10 m²



Year:	1996		
Availab. of monitored data:	1	AMD	[ ]
Calculated Month:	12		
Meteorology:			
Glob. Irradiation, horizontal:		H sum	[kWh/m^2]
Irradiation, in array plane:	1323	HI sum	[kWh/m^2]
Ambient air temperature:		Tam avr	[˚C]
System Energies:			
Energy output from inverter:	21351	EIO sum	[kWh]
Useful energy:	99146	Euse sum	[kWh]
PV array fraction:	0.21	FA	[ ]
Energy consumption:		Econ sum	[kWh]
System Performance Indices:			
Reference yield:	3.63	Yr avr	[h/d]
Final yield:	2.92	Yf avr	[h/d]
Array capture losses:	0.38	Lc avr	[h/d]
System losses:	0.33	Ls avr	[h/d]
Performance Ratio:	0.81	PR	[ ]
Array efficiency:	13	eta A	[%]
Inverter efficiency:	90	eta inv	[%]
Overall plant efficiency:	11.7	eta tot	[%]
Utility Grid:			
Energy to utility grid:	0	ETU sum	[kWh]
Energy from utility grid:	90692	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

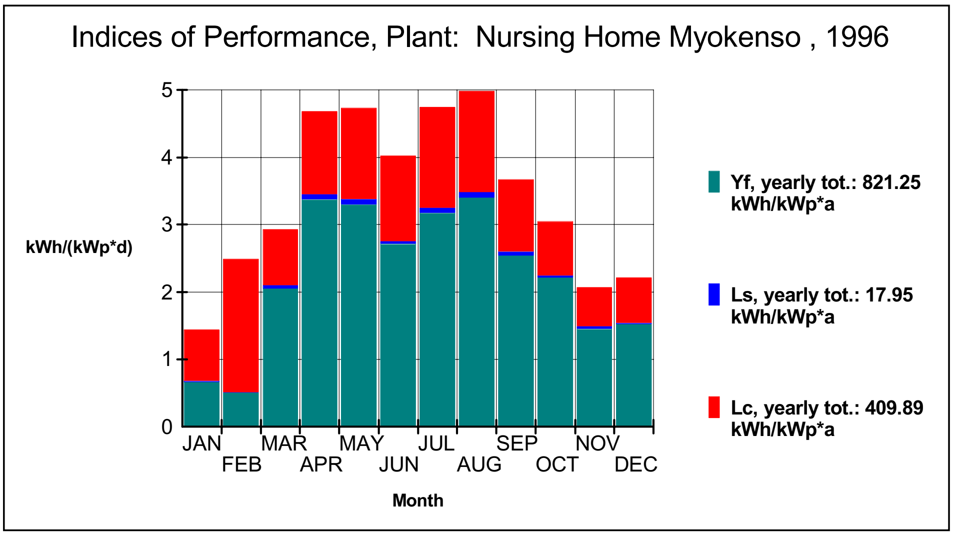
Photovoltaic Database Report

Plant Name:	**Nursing Home Myokenso**		
Country:	Japan		
Type of plant:	Grid connected	Mounting:	Flat roof
Nominal Power:	30.30 kW_p	Array area:	195.30 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Nursing Home Myokenso**		
Country:	Japan		
Type of plant:	Grid connected	Mounting:	Flat roof
Nominal Power:	30.30 kW_p	Array area:	195.30 m²



Year:	1996		
Availab. of monitored data:	1	AMD	[ ]
Calculated Month:	12		
Meteorology:			
Glob. Irradiation, horizontal:		H sum	[kWh/m^2]
Irradiation, in array plane:	1249	HI sum	[kWh/m^2]
Ambient air temperature:		Tam avr	[˚C]
System Energies:			
Energy output from inverter:	24884	EIO sum	[kWh]
Useful energy:	270970	Euse sum	[kWh]
PV array fraction:	0.06	FA	[ ]
Energy consumption:		Econ sum	[kWh]
System Performance Indices:			
Reference yield:	3.42	Yr avr	[h/d]
Final yield:	2.24	Yf avr	[h/d]
Array capture losses:	1.13	Lc avr	[h/d]
System losses:	0.05	Ls avr	[h/d]
Performance Ratio:	0.66	PR	[ ]
Array efficiency:	10.4	eta A	[%]
Inverter efficiency:	97.9	eta inv	[%]
Overall plant efficiency:	10.2	eta tot	[%]
Utility Grid:			
Energy to utility grid:	0	ETU sum	[kWh]
Energy from utility grid:	412489	EFU sum	[kWh]

D - 8 Netherlands

IEA PVPS TASK 2 REPORT PROGRAMME

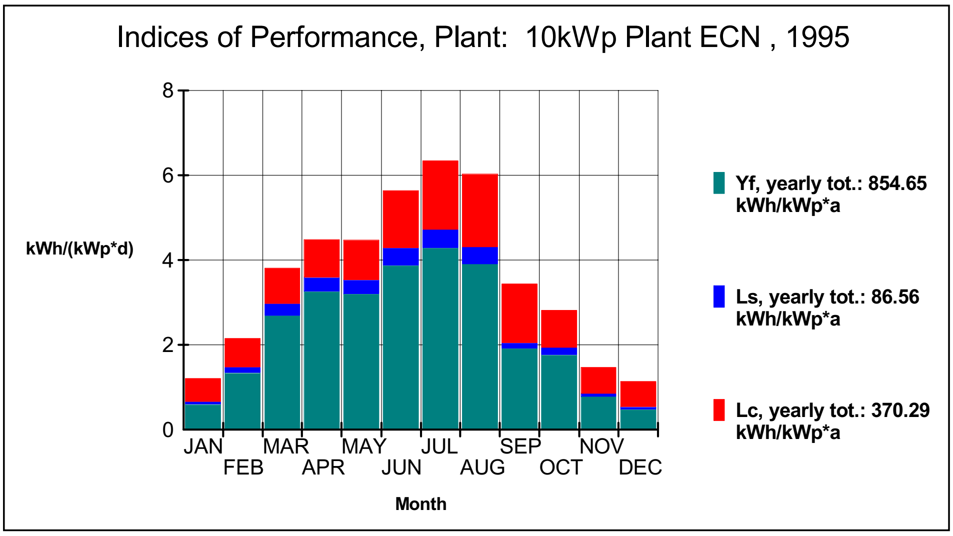
Photovoltaic Database Report

Plant Name:	**10kWp Plant ECN**		
Country:	Netherlands		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	9.90 kW_p	Array area:	79.20 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**10kWp Plant ECN**		
Country:	Netherlands		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	9.90 kW_p	Array area:	79.20 m²



Year:	1994	1995	1996		
Availab. of monitored data:	0.42	1	0.58	AMD	[ ]
Calculated Month:	5	12	7		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	380	1312	835	HI sum	[kWh/m^2]
Ambient air temperature:	11	15.38		Tam avr	[˚C]
System Energies:					
Energy output from inverter:	2363	8463	5333	EIO sum	[kWh]
Useful energy:	2363	8463	5333	Euse sum	[kWh]
PV array fraction:	1	1	1	FA	[ ]
Energy consumption:				Econ sum	[kWh]
System Performance Indices:					
Reference yield:	2.48	3.58	3.93	Yr avr	[h/d]
Final yield:	1.55	2.33	2.53	Yf avr	[h/d]
Array capture losses:	0.76	1.01	1.13	Lc avr	[h/d]
System losses:	0.16	0.24	0.27	Ls avr	[h/d]
Performance Ratio:	0.63	0.65	0.64	PR	[ ]
Array efficiency:	8.7	9	8.9	eta A	[%]
Inverter efficiency:	90.7	90.8	90.5	eta inv	[%]
Overall plant efficiency:	7.8	8.1	8.1	eta tot	[%]
Utility Grid:					
Energy to utility grid:	2363	8463	5333	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

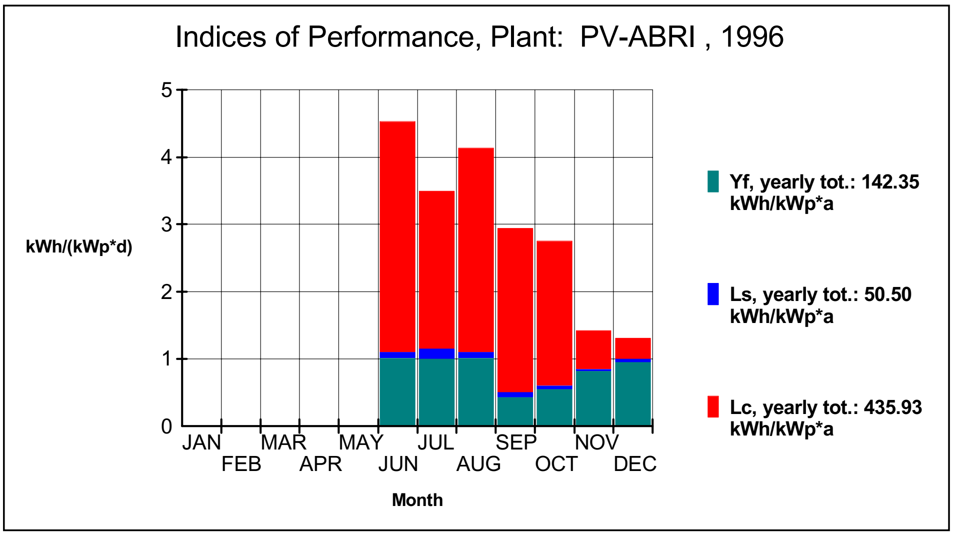
Photovoltaic Database Report

Plant Name:	**PV-ABRI**		
Country:	Netherlands		
Type of plant:	Stand-alone	Mounting:	Freestanding
Nominal Power:	0.20 kW_p	Array area:	1.44 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**PV-ABRI**		
Country:	Netherlands		
Type of plant:	Stand-alone	Mounting:	Freestanding
Nominal Power:	0.20 kW_p	Array area:	1.44 m²

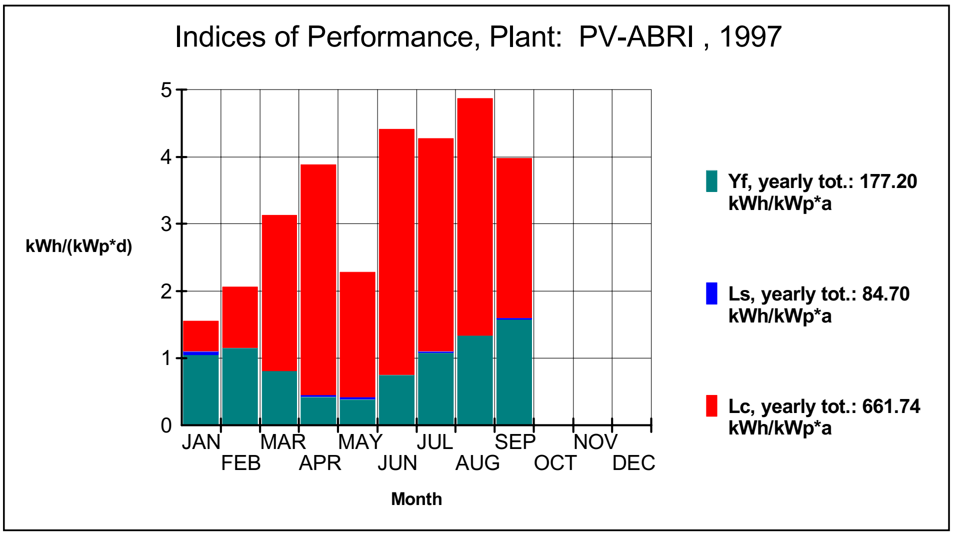


Year:	1996	1997		
Availab. of monitored data:	0.97	0.93	AMD	[ ]
Calculated Month:	7	9		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	629	924	HI sum	[kWh/m^2]
Ambient air temperature:			Tam avr	[˚C]
System Energies:				
Energy output from inverter:	0	0	EIO sum	[kWh]
Useful energy:	28	35	Euse sum	[kWh]
PV array fraction:	1	1	FA	[ ]
Energy consumption:	28	35	Econ sum	[kWh]
System Performance Indices:				
Reference yield:	2.94	3.38	Yr avr	[h/d]
Final yield:	0.66	0.65	Yf avr	[h/d]
Array capture losses:	2.04	2.42	Lc avr	[h/d]
System losses:	0.24	0.31	Ls avr	[h/d]
Performance Ratio:	0.23	0.19	PR	[ ]
Array efficiency:	4.3	3.9	eta A	[%]
Inverter efficiency:			eta inv	[%]
Overall plant efficiency:	3.1	2.7	eta tot	[%]
Utility Grid:				
Energy to utility grid:	0	0	ETU sum	[kWh]
Energy from utility grid:	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**PV-ABRI**		
Country:	Netherlands		
Type of plant:	Stand-alone	Mounting:	Freestanding
Nominal Power:	0.20 kW_p	Array area:	1.44 m²



Year:	1996	1997		
Availab. of monitored data:	0.97	0.93	AMD	[ ]
Calculated Month:	7	9		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	629	924	HI sum	[kWh/m^2]
Ambient air temperature:			Tam avr	[˚C]
System Energies:				
Energy output from inverter:	0	0	EIO sum	[kWh]
Useful energy:	28	35	Euse sum	[kWh]
PV array fraction:	1	1	FA	[ ]
Energy consumption:	28	35	Econ sum	[kWh]
System Performance Indices:				
Reference yield:	2.94	3.38	Yr avr	[h/d]
Final yield:	0.66	0.65	Yf avr	[h/d]
Array capture losses:	2.04	2.42	Lc avr	[h/d]
System losses:	0.24	0.31	Ls avr	[h/d]
Performance Ratio:	0.23	0.19	PR	[ ]
Array efficiency:	4.3	3.9	eta A	[%]
Inverter efficiency:			eta inv	[%]
Overall plant efficiency:	3.1	2.7	eta tot	[%]
Utility Grid:				
Energy to utility grid:	0	0	ETU sum	[kWh]
Energy from utility grid:	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

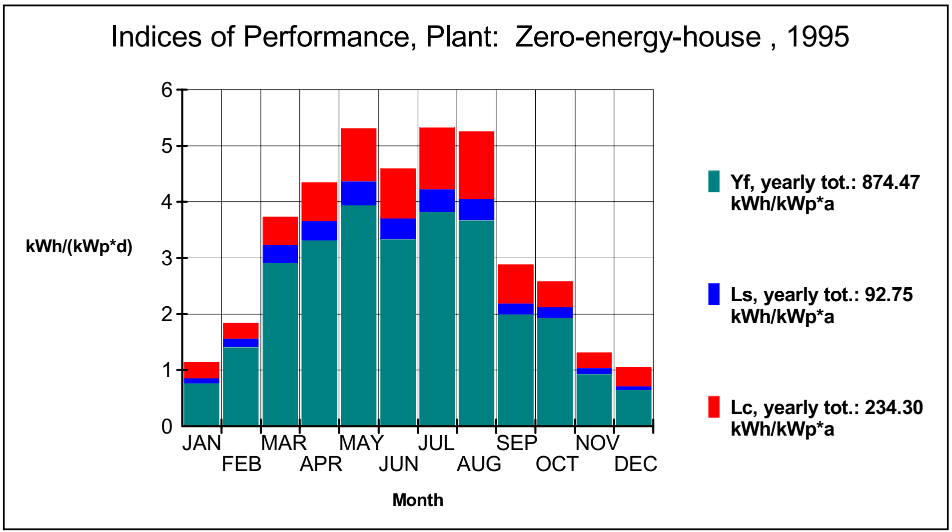
Photovoltaic Database Report

Plant Name:	**Zero-energy-house**		
Country:	Netherlands		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	3.29 kW_p	Array area:	23.04 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**Zero-energy-house**		
Country:	Netherlands		
Type of plant:	Grid connected	Mounting:	Sloped roof
Nominal Power:	3.29 kW_p	Array area:	23.04 m²



Year:	1994	1995		
Availab. of monitored data:	0.50	1.00	AMD	[ ]
Calculated Month:	6	12		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	498	1202	HI sum	[kWh/m^2]
Ambient air temperature:			Tam avr	[˚C]
System Energies:				
Energy output from inverter:	1173	2877	EIO sum	[kWh]
Useful energy:	1173	2877	Euse sum	[kWh]
PV array fraction:	0.38	0.27	FA	[ ]
Energy consumption:			Econ sum	[kWh]
System Performance Indices:				
Reference yield:	2.7	3.28	Yr avr	[h/d]
Final yield:	1.93	2.39	Yf avr	[h/d]
Array capture losses:	0.56	0.64	Lc avr	[h/d]
System losses:	0.21	0.25	Ls avr	[h/d]
Performance Ratio:	0.72	0.73	PR	[ ]
Array efficiency:	11.3	11.5	eta A	[%]
Inverter efficiency:	90.2	90.4	eta inv	[%]
Overall plant efficiency:	10.2	10.4	eta tot	[%]
Utility Grid:				
Energy to utility grid:	729	2087	ETU sum	[kWh]
Energy from utility grid:	2405	2178	EFU sum	[kWh]

D - 9 Switzerland

IEA PVPS TASK 2 REPORT PROGRAMME

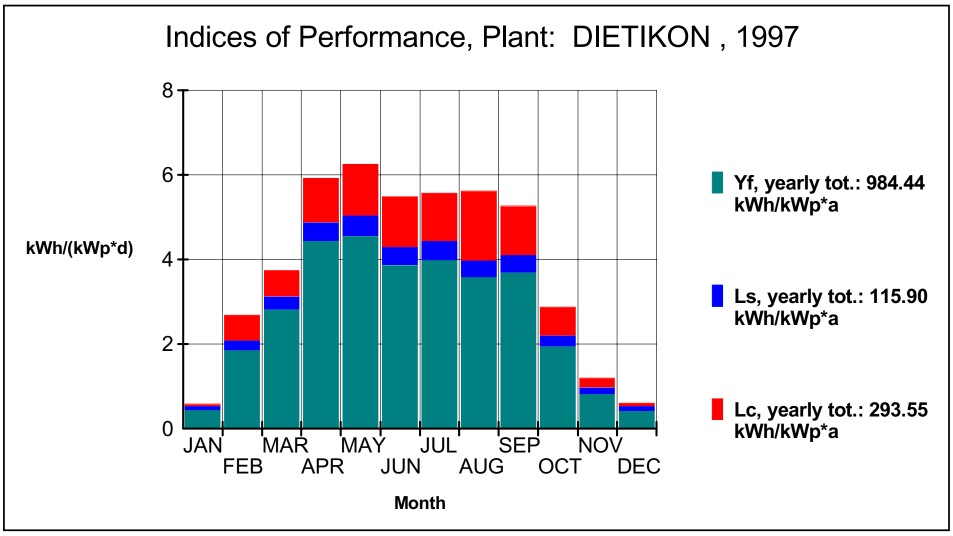
Photovoltaic Database Report

Plant Name:	**DIETIKON**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	1.80 kW_p	Array area:	15.14 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**DIETIKON**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	1.80 kW_p	Array area:	15.14 m²



Year:	1997		
Availab. of monitored data:	1.00	AMD	[ ]
Calculated Month:	12		
Meteorology:			
Glob. Irradiation, horizontal:		H sum	[kWh/m^2]
Irradiation, in array plane:	1394	HI sum	[kWh/m^2]
Ambient air temperature:		Tam avr	[˚C]
System Energies:			
Energy output from inverter:	1776	EIO sum	[kWh]
Useful energy:	1776	Euse sum	[kWh]
PV array fraction:	1	FA	[ ]
Energy consumption:		Econ sum	[kWh]
System Performance Indices:			
Reference yield:	3.82	Yr avr	[h/d]
Final yield:	2.7	Yf avr	[h/d]
Array capture losses:	0.8	Lc avr	[h/d]
System losses:	0.32	Ls avr	[h/d]
Performance Ratio:	0.71	PR	[ ]
Array efficiency:	9.4	eta A	[%]
Inverter efficiency:	89.5	eta inv	[%]
Overall plant efficiency:	8.4	eta tot	[%]
Utility Grid:			
Energy to utility grid:	1776	ETU sum	[kWh]
Energy from utility grid:	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

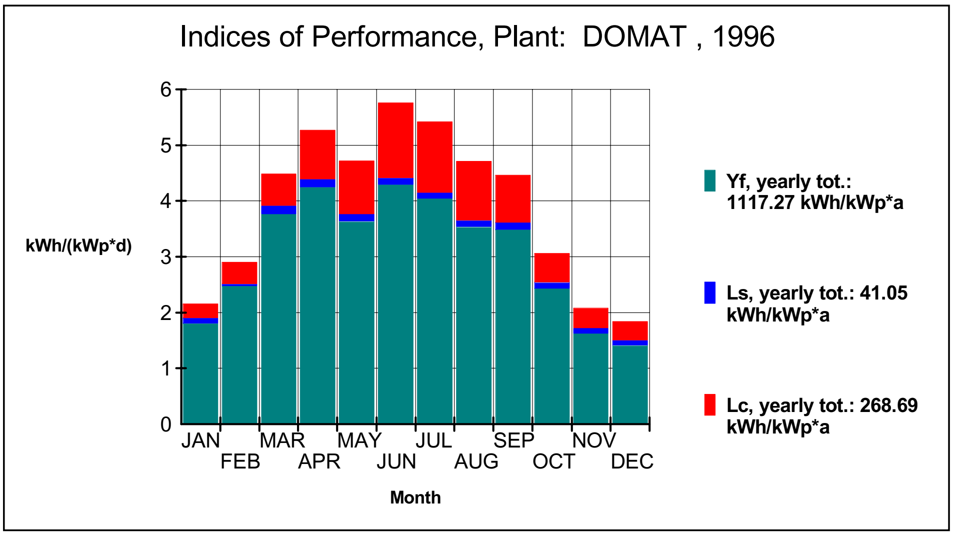
Photovoltaic Database Report

Plant Name:	**DOMAT**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Sound barrier
Nominal Power:	103.99 kW_p	Array area:	967.82 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**DOMAT**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Sound barrier
Nominal Power:	103.99 kW_p	Array area:	967.82 m²



Year:	1990	1991	1992		
Availab. of monitored data:	1.00	1.00	1.00	AMD	[ ]
Calculated Month:	12	12	12		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	1436	1422	1353	HI sum	[kWh/m^2]
Ambient air temperature:	9.69	9.03	9.55	Tam avr	[˚C]
System Energies:					
Energy output from inverter:	84151	114785	107697	EIO sum	[kWh]
Useful energy:	84151	114785	107697	Euse sum	[kWh]
PV array fraction:	1	1	1	FA	[ ]
Energy consumption:				Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.93	3.9	3.71	Yr avr	[h/d]
Final yield:	2.21	3.03	2.84	Yf avr	[h/d]
Array capture losses:	1.48	0.73	0.75	Lc avr	[h/d]
System losses:	0.24	0.14	0.12	Ls avr	[h/d]
Performance Ratio:	0.56	0.78	0.77	PR	[ ]
Array efficiency:	6.7	8.7	8.6	eta A	[%]
Inverter efficiency:	90.3	95.6	96	eta inv	[%]
Overall plant efficiency:	6.1	8.3	8.2	eta tot	[%]
Utility Grid:					
Energy to utility grid:	84151	114785	107697	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**DOMAT**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Sound barrier
Nominal Power:	103.99 kW_p	Array area:	967.82 m²

Year:	1993	1994	1995		
Availab. of monitored data:	1.00	1.00	1.00	AMD	[ ]
Calculated Month:	12	12	12		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	1361	1372	1383	HI sum	[kWh/m^2]
Ambient air temperature:	9.25	10.6	9.33	Tam avr	[˚C]
System Energies:					
Energy output from inverter:	112133	104602	106262	EIO sum	[kWh]
Useful energy:	112133	104602	106262	Euse sum	[kWh]
PV array fraction:	1	1	1	FA	[ ]
Energy consumption:				Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.73	3.75	3.8	Yr avr	[h/d]
Final yield:	2.95	2.75	2.79	Yf avr	[h/d]
Array capture losses:	0.66	0.89	0.88	Lc avr	[h/d]
System losses:	0.12	0.11	0.13	Ls avr	[h/d]
Performance Ratio:	0.79	0.73	0.73	PR	[ ]
Array efficiency:	8.9	8.2	8.3	eta A	[%]
Inverter efficiency:	96.2	96.1	95.5	eta inv	[%]
Overall plant efficiency:	8.5	7.9	7.9	eta tot	[%]
Utility Grid:					
Energy to utility grid:	112133	104602	106262	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**DOMAT**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Sound barrier
Nominal Power:	103.99 kW_p	Array area:	967.82 m²

Year:	1996	1997		
Availab. of monitored data:	1.00	1.00	AMD	[ ]
Calculated Month:	12	12		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	1427	1522	HI sum	[kWh/m^2]
Ambient air temperature:	9.08	10.0	Tam avr	[˚C]
System Energies:				
Energy output from inverter:	116189	127318	EIO sum	[kWh]
Useful energy:	116189	127318	Euse sum	[kWh]
PV array fraction:	1	1	FA	[ ]
Energy consumption:			Econ sum	[kWh]
System Performance Indices:				
Reference yield:	3.91	4.17	Yr avr	[h/d]
Final yield:	3.06	3.36	Yf avr	[h/d]
Array capture losses:	0.73	0.70	Lc avr	[h/d]
System losses:	0.11	0.12	Ls avr	[h/d]
Performance Ratio:	0.78	0.81	PR	[ ]
Array efficiency:	8.7	9.0	eta A	[%]
Inverter efficiency:	96.5	96.6	eta inv	[%]
Overall plant efficiency:	8.4	8.6	eta tot	[%]
Utility Grid:				
Energy to utility grid:	116189	127318	ETU sum	[kWh]
Energy from utility grid:	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

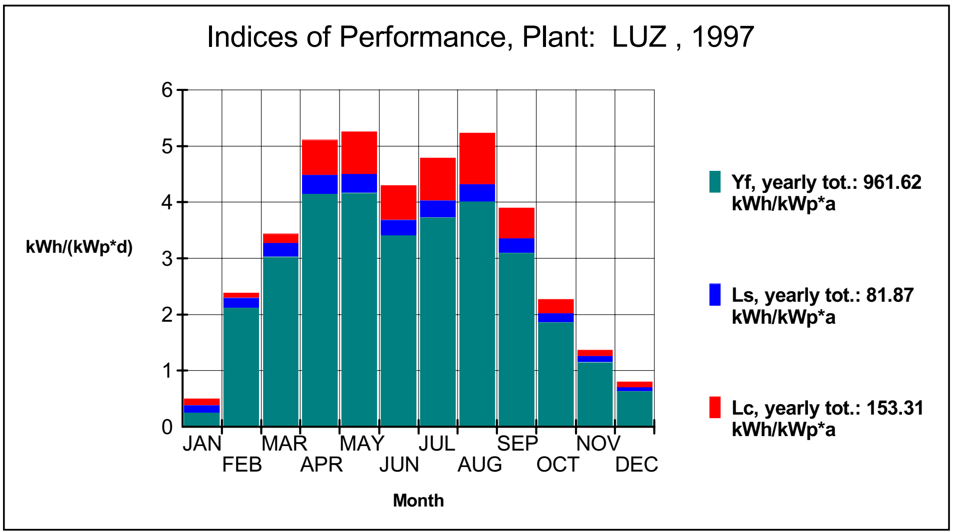
Photovoltaic Database Report

Plant Name:	**LUZ**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	49.50 kW_p	Array area:	396.37 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**LUZ**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	49.50 kW_p	Array area:	396.37 m²



Year:	1997		
Availab. of monitored data:	1.00	AMD	[ ]
Calculated Month:	12		
Meteorology:			
Glob. Irradiation, horizontal:		H sum	[kWh/m^2]
Irradiation, in array plane:	1197	HI sum	[kWh/m^2]
Ambient air temperature:		Tam avr	[˚C]
System Energies:			
Energy output from inverter:	47606	EIO sum	[kWh]
Useful energy:	47606	Euse sum	[kWh]
PV array fraction:	1	FA	[ ]
Energy consumption:		Econ sum	[kWh]
System Performance Indices:			
Reference yield:	3.28	Yr avr	[h/d]
Final yield:	2.63	Yf avr	[h/d]
Array capture losses:	0.42	Lc avr	[h/d]
System losses:	0.22	Ls avr	[h/d]
Performance Ratio:	0.80	PR	[ ]
Array efficiency:	10.9	eta A	[%]
Inverter efficiency:	92.2	eta inv	[%]
Overall plant efficiency:	10	eta tot	[%]
Utility Grid:			
Energy to utility grid:	47606	ETU sum	[kWh]
Energy from utility grid:	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

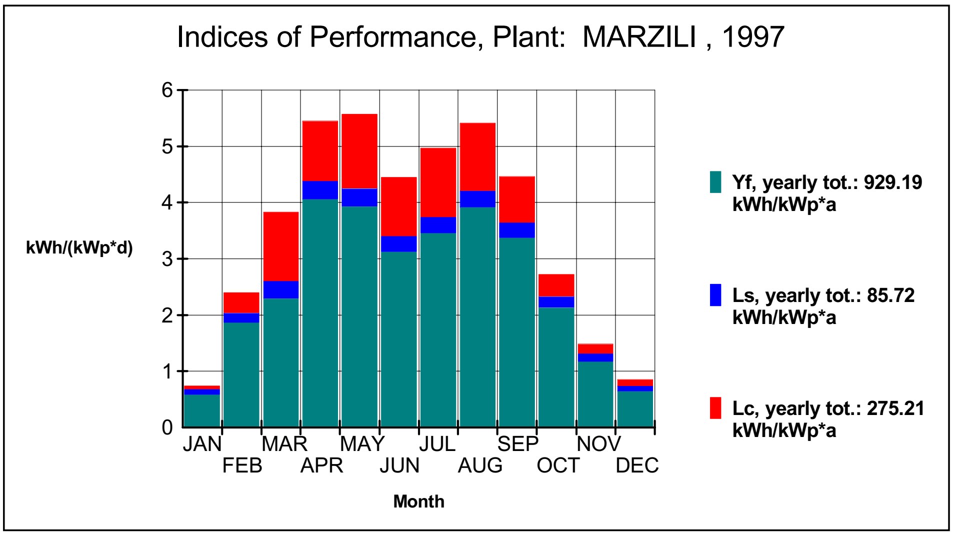
Photovoltaic Database Report

Plant Name:	**MARZILI**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Flat roof
Nominal Power:	22.71 kW_p	Array area:	170.10 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**MARZILI**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Flat roof
Nominal Power:	22.71 kW_p	Array area:	170.10 m²



Year:	1993	1994	1995		
Availab. of monitored data:	1.00	1.00	1.00	AMD	[ ]
Calculated Month:	12	12	12		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	1167	1112	1233	HI sum	[kWh/m^2]
Ambient air temperature:	9.23	10.61	9.5	Tam avr	[˚C]
System Energies:					
Energy output from inverter:	20938	19132	20052	EIO sum	[kWh]
Useful energy:	20938	19132	20052	Euse sum	[kWh]
PV array fraction:	1	1	1	FA	[ ]
Energy consumption:				Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.19	3.04	3.37	Yr avr	[h/d]
Final yield:	2.52	2.3	2.41	Yf avr	[h/d]
Array capture losses:	0.42	0.49	0.72	Lc avr	[h/d]
System losses:	0.25	0.25	0.24	Ls avr	[h/d]
Performance Ratio:	0.79	0.76	0.72	PR	[ ]
Array efficiency:	11.6	11.2	10.5	eta A	[%]
Inverter efficiency:	90.9	90.4	91	eta inv	[%]
Overall plant efficiency:	10.5	10.1	9.6	eta tot	[%]
Utility Grid:					
Energy to utility grid:	20938	19132	20052	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**MARZILI**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Flat roof
Nominal Power:	22.71 kW_p	Array area:	170.10 m²

Year:	1996	1997		
Availab. of monitored data:	1.00	1.00	AMD	[ ]
Calculated Month:	12	12		
Meteorology:				
Glob. Irradiation, horizontal:			H sum	[kWh/m^2]
Irradiation, in array plane:	1179	1290	HI sum	[kWh/m^2]
Ambient air temperature:	8.7	9.8	Tam avr	[˚C]
System Energies:				
Energy output from inverter:	19885	21107	EIO sum	[kWh]
Useful energy:	19885	21107	Euse sum	[kWh]
PV array fraction:	1	1	FA	[ ]
Energy consumption:			Econ sum	[kWh]
System Performance Indices:				
Reference yield:	3.23	3.53	Yr avr	[h/d]
Final yield:	2.39	2.54	Yf avr	[h/d]
Array capture losses:	0.61	0.75	Lc avr	[h/d]
System losses:	0.23	0.23	Ls avr	[h/d]
Performance Ratio:	0.74	0.72	PR	[ ]
Array efficiency:	10.9	10.5	eta A	[%]
Inverter efficiency:	91.4	91.6	eta inv	[%]
Overall plant efficiency:	9.9	9.6	eta tot	[%]
Utility Grid:				
Energy to utility grid:	19885	21107	ETU sum	[kWh]
Energy from utility grid:	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

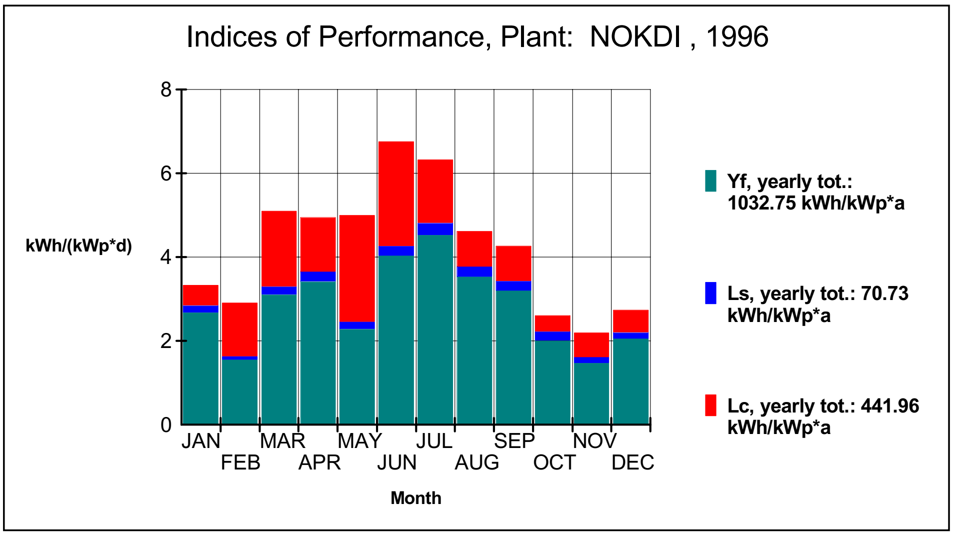
Photovoltaic Database Report

Plant Name:	**NOKDI**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	97.78 kW_p	Array area:	805.20 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**NOKDI**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	97.78 kW_p	Array area:	805.20 m²



Year:	1994	1995	1996		
Availab. of monitored data:	1.00	1.00	1.00	AMD	[ ]
Calculated Month:	12	12	12		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	1487	1615	1545	HI sum	[kWh/m^2]
Ambient air temperature:				Tam avr	[˚C]
System Energies:					
Energy output from inverter:	110603	119667	101010	EIO sum	[kWh]
Useful energy:	110603	119667	101010	Euse sum	[kWh]
PV array fraction:	1	1	1	FA	[ ]
Energy consumption:				Econ sum	[kWh]
System Performance Indices:					
Reference yield:	4.06	4.43	4.23	Yr avr	[h/d]
Final yield:	3.09	3.35	2.82	Yf avr	[h/d]
Array capture losses:	0.74	0.83	1.21	Lc avr	[h/d]
System losses:	0.24	0.25	0.19	Ls avr	[h/d]
Performance Ratio:	0.76	0.76	0.67	PR	[ ]
Array efficiency:	9.9	9.9	8.7	eta A	[%]
Inverter efficiency:	92.9	93.2	93.6	eta inv	[%]
Overall plant efficiency:	9.2	9.2	8.1	eta tot	[%]
Utility Grid:					
Energy to utility grid:	110603	119667	101010	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

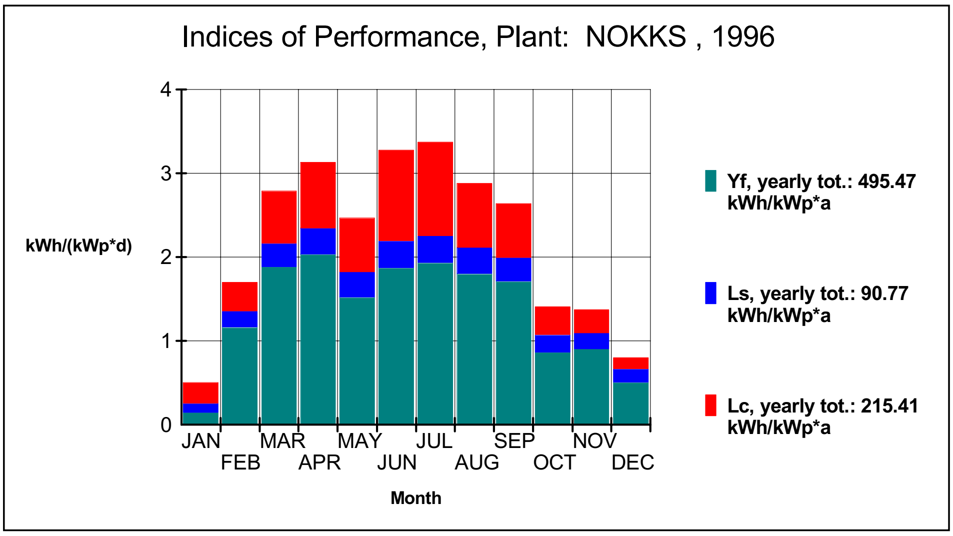
Photovoltaic Database Report

Plant Name:	**NOKKS**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Facade
Nominal Power:	19.42 kW_p	Array area:	149.90 m²

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**NOKKS**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Facade
Nominal Power:	19.42 kW_p	Array area:	149.90 m²



Year:	1994	1995	1996		
Availab. of monitored data:	1.00	1.00	1.00	AMD	[ ]
Calculated Month:	12	12	12		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	821	851	802	HI sum	[kWh/m^2]
Ambient air temperature:	11.24	10.02	9.13	Tam avr	[˚C]
System Energies:					
Energy output from inverter:	8961	9726	9627	EIO sum	[kWh]
Useful energy:	8961	9726	9627	Euse sum	[kWh]
PV array fraction:	1	1	1	FA	[ ]
Energy consumption:				Econ sum	[kWh]
System Performance Indices:					
Reference yield:	2.24	2.33	2.2	Yr avr	[h/d]
Final yield:	1.26	1.37	1.36	Yf avr	[h/d]
Array capture losses:	0.74	0.71	0.59	Lc avr	[h/d]
System losses:	0.25	0.25	0.25	Ls avr	[h/d]
Performance Ratio:	0.56	0.59	0.62	PR	[ ]
Array efficiency:	8.7	9	9.5	eta A	[%]
Inverter efficiency:	83.6	84.5	84.5	eta inv	[%]
Overall plant efficiency:	7.3	7.6	8	eta tot	[%]
Utility Grid:					
Energy to utility grid:	8961	9726	9627	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]

IEA PVPS TASK 2 REPORT PROGRAMME

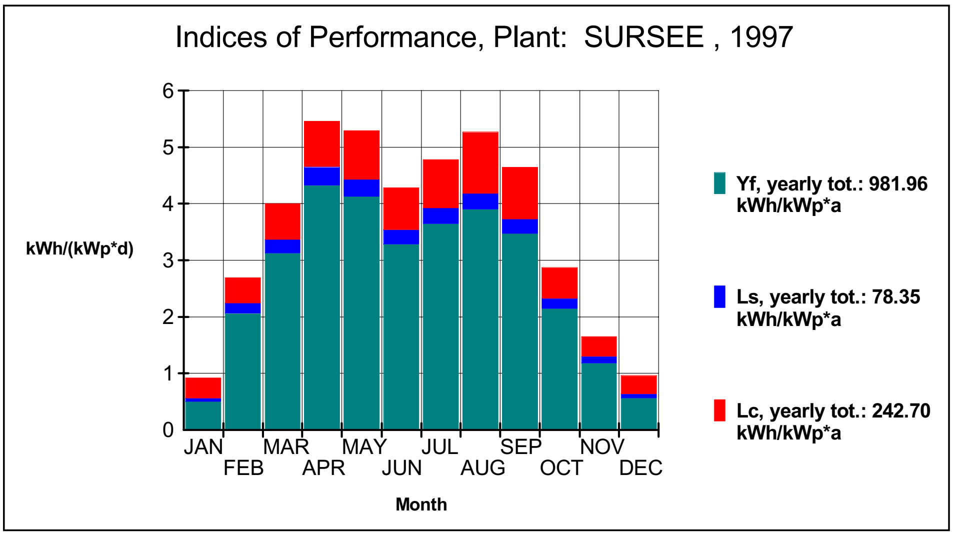
Photovoltaic Database Report

Plant Name:	**SURSEE**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	10.09 kW_p	Array area:	85.60 m^2

IEA PVPS TASK 2 REPORT PROGRAMME

Photovoltaic Database Report

Plant Name:	**SURSEE**		
Country:	Switzerland		
Type of plant:	Grid connected	Mounting:	Freestanding
Nominal Power:	10.09 kW_p	Array area:	85.60 m²



Year:	1995	1996	1997		
Availab. of monitored data:	1.00	1.00	1.00	AMD	[ ]
Calculated Month:	12	12	12		
Meteorology:					
Glob. Irradiation, horizontal:				H sum	[kWh/m^2]
Irradiation, in array plane:	1217	1186	1303	HI sum	[kWh/m^2]
Ambient air temperature:	9.79	8.4	9.65	Tam avr	[˚C]
System Energies:					
Energy output from inverter:	8886	9026	9916	EIO sum	[kWh]
Useful energy:	8886	9026	9916	Euse sum	[kWh]
PV array fraction:	1	1	1	FA	[ ]
Energy consumption:				Econ sum	[kWh]
System Performance Indices:					
Reference yield:	3.33	3.25	3.57	Yr avr	[h/d]
Final yield:	2.41	2.45	2.69	Yf avr	[h/d]
Array capture losses:	0.66	0.6	0.66	Lc avr	[h/d]
System losses:	0.26	0.2	0.21	Ls avr	[h/d]
Performance Ratio:	0.72	0.75	0.75	PR	[ ]
Array efficiency:	9.5	9.6	9.6	eta A	[%]
Inverter efficiency:	90.2	92.4	92.6	eta inv	[%]
Overall plant efficiency:	8.5	8.9	8.9	eta tot	[%]
Utility Grid:					
Energy to utility grid:	8886	9026	9916	ETU sum	[kWh]
Energy from utility grid:	0	0	0	EFU sum	[kWh]