IEA INTERNATIONAL ENERGY AGENCY

COST AND PERFORMANCE TRENDS IN GRID-CONNECTED PHOTOVOLTAIC SYSTEMS AND CASE STUDIES

PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

Report IEA-PVPS T2-06:2007

INTERNATIONAL ENERGY AGENCY
PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

COST AND PERFORMANCE TRENDS IN GRID-CONNECTED PHOTOVOLTAIC SYSTEMS AND CASE STUDIES

IEA PVPS Task 2

Report IEA PVPS T2-06:2007

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This technical report has been prepared under the supervision of
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in co-operation with Task 2 experts from:
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Contents

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 member countries. The European Union (EU) and the European Photovoltaic Industry Association (EPIA) also participate in the work of the IEA.

The IEA Photovoltaic Power Systems Programme (PVPS) is one of the collaborative R & D Agreements established within the IEA, and since its establishment in 1993, the PVPS participants have been conducting a variety of joint projects in the application of photovoltaic conversion of solar energy into electricity.

The mission of the IEA PVPS programme is: To enhance the international collaboration efforts which accelerate the development and deployment of photovoltaic solar energy as a significant and sustainable renewable energy option. The underlying assumption is that the market for PV systems is continuously expanding from the earlier niche markets of remote applications and consumer products, to the rapidly growing markets for building integrated and other diffused and centralised grid-connected PV generation systems. This market expansion requires the availability of and access to reliable information on the performance of PV systems, technical and design guidelines, planning methods, financing, etc. to be shared with the various actors.

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. By mid 2007, twelve Tasks were established within the PVPS programme.

The overall objective of Task 2 is to improve the operation and sizing, electrical and economic output of photovoltaic power systems and sub-systems by collecting, analysing and dissemination information on their technical performance and reliability, providing a basis for their assessment, and developing practical recommendations. The current members of the IEA PVPS Task 2 include:

Austria, Canada, European Commission, European Photovoltaic Industry Association, France, Germany, Italy, Japan, Sweden, Switzerland, United Kingdom, United States of America and Poland as an observer.

This report contains the analysis of an on-line survey on performance and cost of PV systems over time, as well as case studies from six countries.

This technical report has been prepared with the support of:

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

Further information on the activities and results of the Task can be found at:
http://www.iea-pvps-task2.org and http://www.iea-pvps.org.

Introduction

In past phases of the Task 2 activities, the IEA PVPS Performance Database [1] was set up, containing monthly operational performance data of PV systems from all the member countries and also from non-members. Part of the on-going work of Task 2 is to provide information on system performance to the target groups. In 2004, an overview of the data was published in Country Reports on PV System Performance [3]. Due to the lack of sufficient data on plant cost, failures and maintenance in the IEA PVPS Performance Database, a sub-task was set up in 2005 with the purpose of collecting and analysing data on these topics. In June 2005, a worldwide interactive on-line economic survey database was established on the internet. This database was active until the end of 2006 to enable plant owners and operators to enter technical, economic and operational data on their PV systems.

This report is divided into three parts. In the first part, the economic data from 527 grid-connected PV systems collected as part of the economic survey are analysed. In part two, the performance data from 461 grid-connected PV systems with a total of 1 544 operational years in the IEA PVPS Database [1] are examined. Part three presents case studies on PV system cost, yield, performance and maintenance provided by Task 2 members on PV systems of their country.

Executive summary

This report gives an overview of the system costs of PV systems, based on data collected as part of the IEA PVPS Task 2 Economic Survey and of the operational performance, based on data from the IEA PVPS Performance Database [1]. The report shows the development of the actual PV system cost and the performance over time for grid-connected PV systems built between 1991 and 2005. The results for the grid-connected PV systems investigated show a trend towards lower system cost and increased performance over this period.

System cost

In total, 774 datasets were collected in the economic survey, of which 527 contained useful economic data from grid-connected PV systems built between 1992 and 2006. The overall trend is a reduction in the average system cost from 16 USD per watt to 8 USD per watt over the 15 year period.

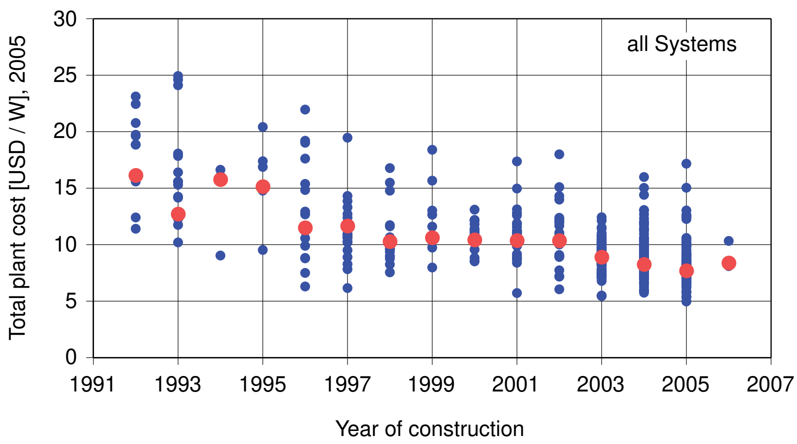


Figure I, System cost in USD per watt over time, showing the values of each of the 527 grid-connected PV systems and the average value for each year from 1992 to 2006.

The location, size, type of project, typical use as well as the mounting of these PV systems varies greatly. This is reflected in the wide spread of the values for each year. The annual mean values do not follow a linear trend, specially for the earlier years and from 1999 to 2002 there is almost no change in the average system cost. There is, however a steady decrease from 2002 to 2005. For the year 2006, the sample may be too small for the findings to be significant (4 systems only).

As shown in the report the reduction in cost of all the components of a grid-connected system, modules costs, inverter cost and BOS cost (Balance of systems), contributes to the reduction of the system cost over time.

Executive summary (cont.)

Performance ratio

The 2007 edition of the IEA PVPS Performance Database [1] contains performance data from 505 PV systems with a total of 1 648 years of operational data. For this report 461 grid-connected PV systems built between 1991 and 2005 with a total of 1 544 operational years are analysed.

The report shows a trend towards higher inverter efficiency and a higher performance ratio over time.

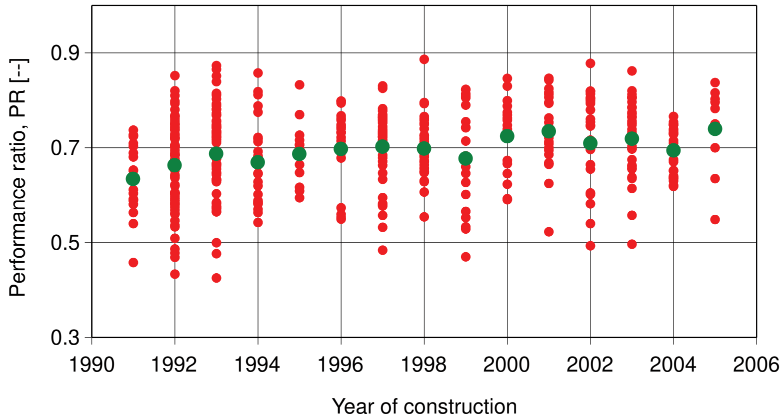


Figure II, Performance ratio over time of the 461 grid-connected PV systems built between 1991 and 2005. Showing the values for each system as well as the annual mean value.

Many of the systems are domestic systems smaller than 10 kW nominal power and 63% of the systems are located in Germany, Japan or Switzerland. A contributing factor to the improved performance ration is the rise in the inverter efficiency over time and also, as shown in this report, the less frequent downtime of the system.

Case studies

The report contains case studies from: Canada, Germany, Japan, Sweden, Switzerland and the United Kingdom on one or more chosen subject:

A - System cost, B - Annual yield over time, C - Performance over time, D - Statistic on maintenance.

The contribution from Japan reports on failure and maintenance of 725 small domestic PV systems built in Japan between 1995 and 2003.

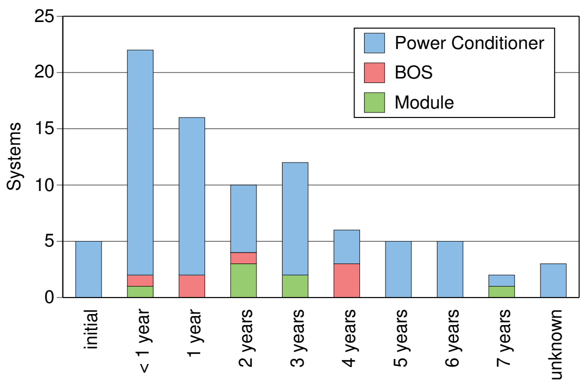


Figure III, Distribution of the operational year of first failure after installation from a survey of 725 small domestic PV systems in Japan.

This detailed survey shows that the residential systems in Japan are operating well – failures occurred in only 12% of the systems (86 out of 725). An interesting point evident in this unique contribution is that 50% of the 86 reported first time failures occurred within the first year of operation and 84% of the failures are failures of the power conditioner (Inverter).

1. IEA PVPS Task 2 Economic Survey

The interactive database was active from June 2005 to December 2006, enabling the PV community to enter systemic, economic and operational data on PV systems. The data were entered mainly by PV plant owners/operators. Some data were also supplied in bulk by Task 2 members.

The survey included the sections on the following topics:

- Plant information
- Technical data
- Economic data
- Operational data
- Report on failures
- Report on maintenance.

In total, data on 774 PV systems were collected over an eighteen-month period. Of the 774 datasets collected, 527 sets from PV systems in 11 countries contained valid economic data on grid-connected PV systems built in the period 1992 to 2006. The remaining data consisted of eight stand-alone PV systems, ten systems that were built prior to 1992, and some datasets contained yield or performance data only; these datasets were excluded from the analysis.

1.1 The PV systems analysed

The 527 datasets analysed are mainly from small domestic grid-connected PV systems and also from some larger grid-connected PV systems in 11 countries. They include freestanding, roof top and façade systems as well as one sound-barrier system. The PV plants investigated were built between 1992 and 2006. In Table 1, the number of entries and total and average nominal power per country are shown. The number of systems per country ranges from 1 in Belgium to 292 in the United States. The total nominal power of all the 527 systems is 11 063 kW.

Table 1, Overview of all the data used in the economic report.

Country	ISO country code	Total systems	Total nominal power [kW]	Average nominal power [kW]
United States	USA	292	1 528.8	5.2
Switzerland	CHE	88	3 026.4	34.4
Japan	JPN	74	1 295.0	17.5
Italy	ITA	24	4 508.8	187.9
Austria	AUT	14	111.1	7.9
Sweden	SWE	11	287.5	26.1
Germany	DEU	9	101.6	11.3
United Kingdom	GBR	9	183.3	20.4
Mexico	MEX	3	5.2	1.7
Spain	ESP	2	10.8	5.4
Belgium	BEL	1	5.2	5.2
	11	527	11 063	21.0

1.1 The PV systems analysed (cont.)

In Figure 1, all 527 systems are grouped by country. The 292 entries from USA are dominant. Most systems were constructed between 2003 and 2005 (Figure 2).

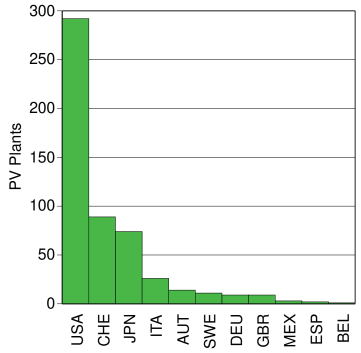


Figure 1, Datasets by country.

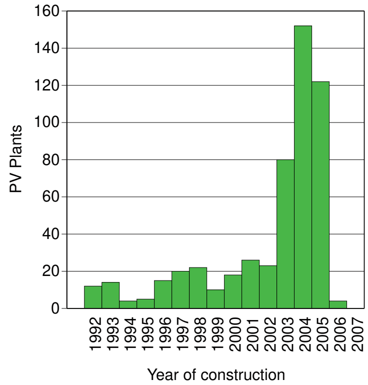


Figure 2, Datasets by year of construction.

Typical use and mounting

As can be seen from Table 2, 262 of the 527 systems are domestic systems. Roof mounted systems (158) are most frequent. The type of mounting was not reported in 322 cases.

Table 2, List for the type of plant, typical use and mounting with number of systems for each section.

Typical use	Systems
Domestic	262
Power station	95
Other	64
Office	39
Appartments	24
Housing-Other	20
NA	10
Factory	9
Other Professional	2
Other Rural	1
Vacation house	1
	527

Mounting	Systems
NA	322
Rooftop	158
Free-standing	25
Facade	14
Other	7
Soundbarrier	1
	527

Nominal power

About 363 (69%) of the 527 systems are smaller than 10 kW (Figure 3) and the remaining 164 PV systems have a nominal power ranging from 10 to 2 970 kW.

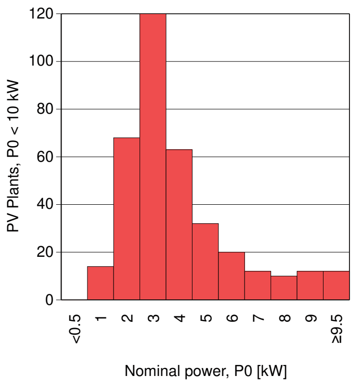


Figure 3, Datasets by nominal power, P0 < 10 kW.

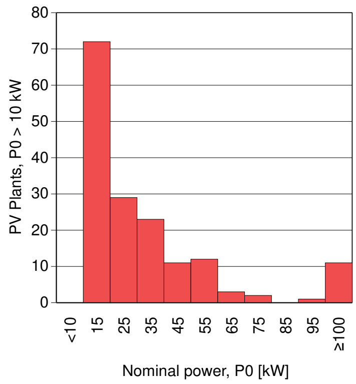
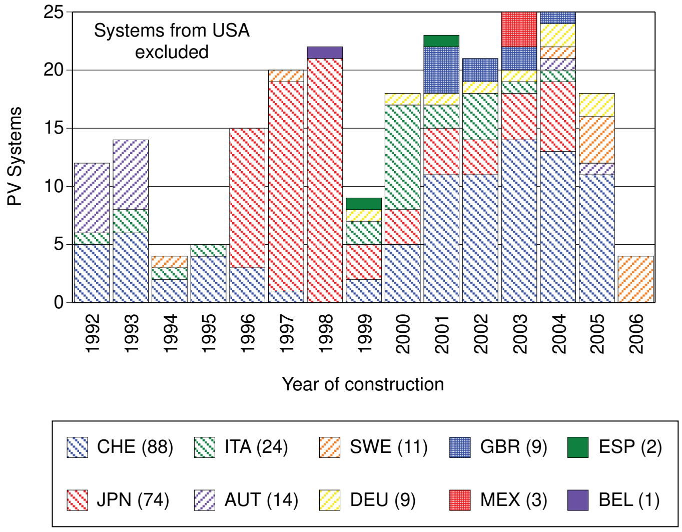


Figure 4, Datasets by nominal power, P0 > 10 kW.

1.1 The PV systems analysed (cont.)

As can be seen from Table 1 and Figure 1, a large number of entries concerned PV systems located in the United States. Most of the PV systems in the USA were built in the years 2003 to 2005. Because of the dominance of the US systems in the data collected, the data from these systems are represented in separate graphs for some of the following evaluations. Figure 6 shows all the 292 US systems grouped by year of construction and Figure 5 shows the 235 systems in the remaining 10 countries.



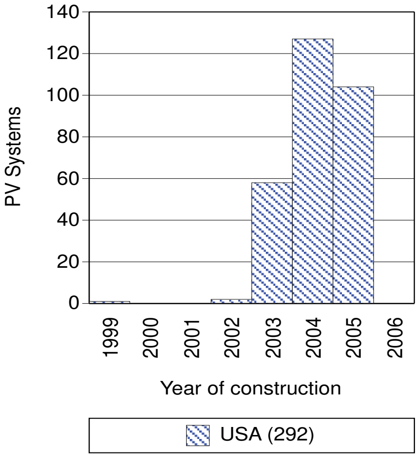


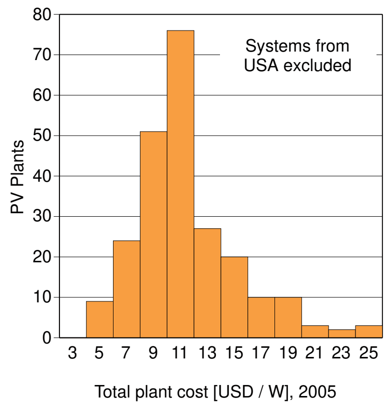
Figure 5, PV systems by country and year of construction.

Figure 6, PV systems from the USA by year of construction.

1.2 Findings

The economic data were entered online by survey participants in local currency and the base year for the costs was also requested. The cost data were converted into 2005 prices in USD. The tables used for this conversion were the OECD consumer price index (CPI), 2007 and the historical exchange rates (HExR), 2007.

In total, 527 datasets containing valid economic data from 11 countries were used for this section of the report. Figure 4 shows the number of systems in each country. The year of construction of the PV plants ranges from 1992 to 2006. Over half of the systems (292) are located in the United States. Figure 7 shows a histogram of the plant cost of systems, excluding systems in the USA; 54% of the plants are in the 8 to 12 USD/W range. In Figure 8, the US plants are shown; 84% of these plants are in the 6 to 10 USD/W range.



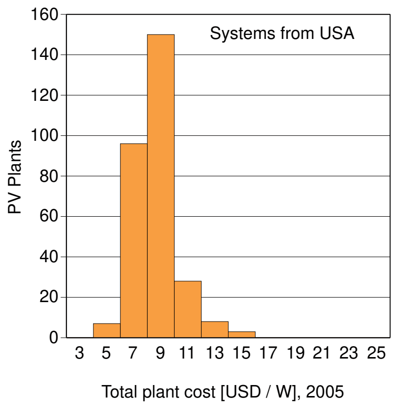


Figure 7, Plant cost, excluding USA.

Figure 8, Plant cost, USA.

1.2. Findings (cont.)

Figures 9 and 10 show the ratio of unit cost to the installed PV power (P0). The PV systems in this sample are too diverse in location, type of mounting and the year of construction to enable conclusions to be drawn about a downward trend in plant cost for the larger systems. In some of the case studies with closer matching systems (section 3), a reduction was evident in the specific costs for larger systems.

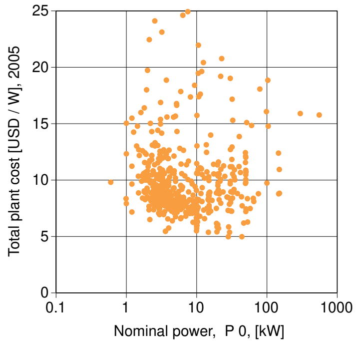


Figure 9, Plant cost to nominal power, logarithmic scale.

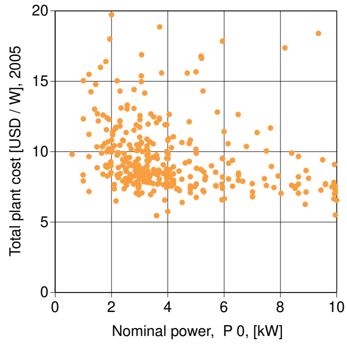


Figure 10, Plant cost to nominal power, P0 < 10 kW.

Cost over time

In Figure 11, the plant cost over time is shown for all systems, including all the values and the mean value for each year from 1992 to 2006. In Figure 12, plant costs are shown, omitting the values for the United States. Both sets of figures show a clear downward trend in plant cost over time, from 16 USD/W in 1992 to 8 USD/W in 2006. The cost values for the systems in the USA are shown in Figure 13.

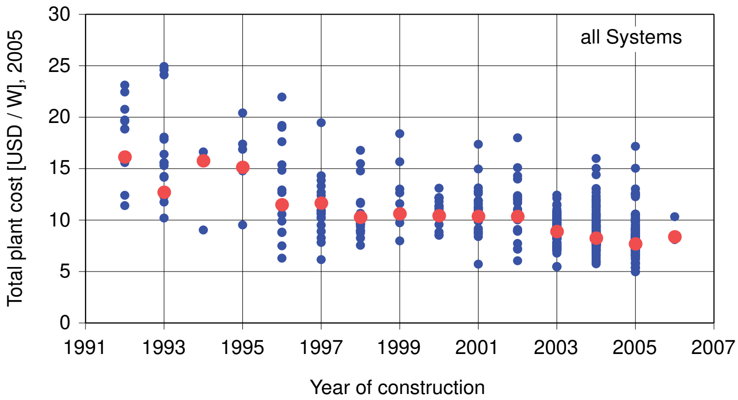


Figure 11, System cost in USD per watt over time.

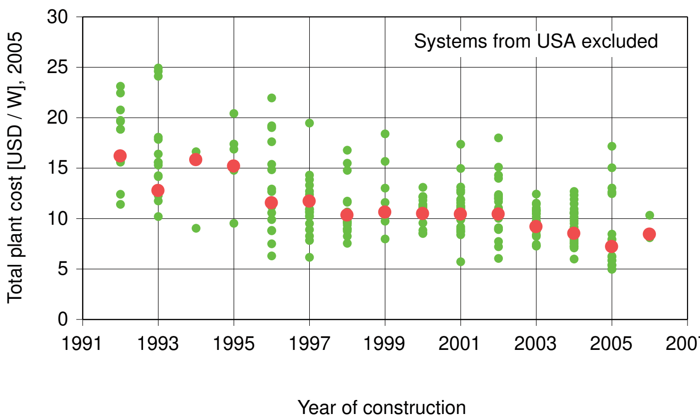


Figure 12, Cost over time, excluding data from USA.

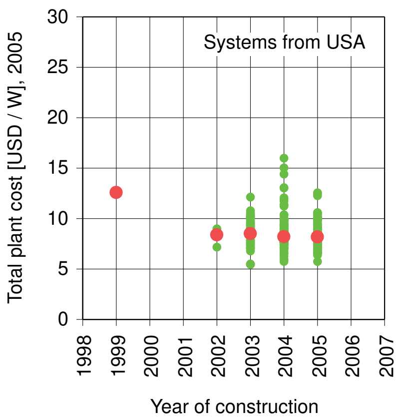


Figure 13, Cost over time, data from USA.

1.2. Findings (cont.)

Sub-systems

387 of the 527 datasets also contain cost data for the sub-systems (modules and inverter). Figure 14 shows the cost for the sub-systems over time of all the systems and Figures 15 and 16 show the cost of the sub-systems grouped by selected years in USD/W and in % of the total. The 267 US systems are presented as a separate group.

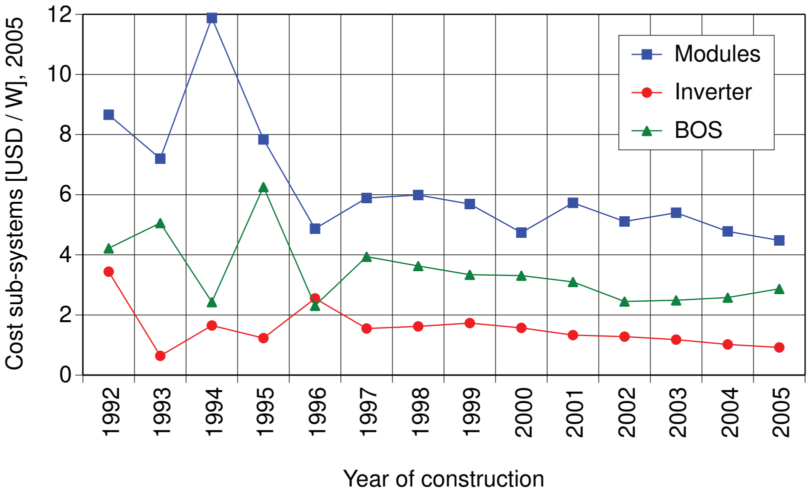
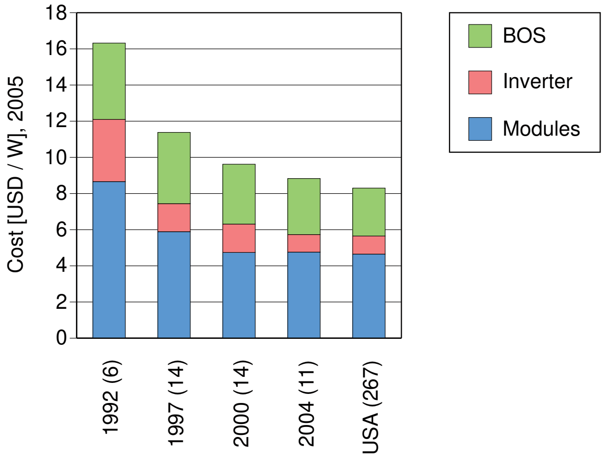


Figure 14, Cost sub-systems over time, 387 of 527 including 267 systems in the USA.

There is a clear downward trend in the cost reduction of the sub-systems over time, especially from 1997 to 2005 (Figure 14). For the years prior to 1997 the sample is small and some of the early systems are R&D projects.



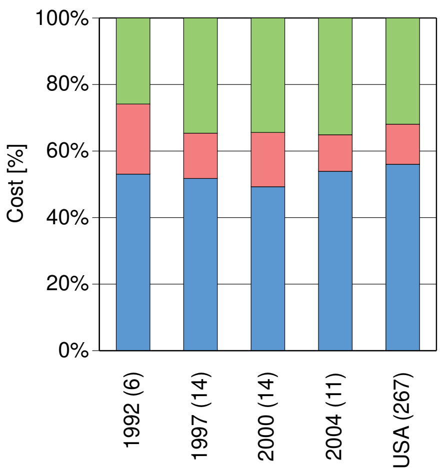


Figure 15, Cost sub-systems. *Figure 16, Cost sub-systems [%].*

The years chosen for the sample are the years with the most entries for the sub-system cost data. The number of systems is indicated in brackets. Figure 14 shows that the price reduction for all components contributes to the reduction of the total system cost over time. Overall, the cost of the modules is 55% of the total cost, the cost of the Inverter 10% and the balance of systems (BOS) 35%. The balance of systems cost consists of all the cost components other than modules and inverter for a turnkey PV system (including engineering, mounting structures, wiring and labour costs).

1.3. Summary

A significant finding of this report is a clear trend towards lower system cost over time from 16 USD/W in 1992 to 8 USD/W in 2005.

The sample in this section of the report comprises 527 grid-connected PV systems from 11 countries built between 1992 and 2006. The sample also includes 292 systems in the USA. Most of the systems are domestic systems with a nominal power smaller than 10 kW.

Grid-connected PV systems in the United States of America

Most of the 292 PV systems in the USA were built between 2003 to 2005 and are domestic and apartment systems with a nominal power ranging from 1 to 20 kW. Most systems are also located in New York. For all these reasons this sample is not considered representative for the purposes of this survey.

Other grid-connected PV systems

The other 235 grid-connected PV systems are more diverse and located mainly in central Europe and in Japan. On average there are 15.6 systems per year of construction with a nominal power range from 1 to 3 000 kW and a large number of small residential systems. The cost data for these systems is representative of mainly roof-top mounted residential systems with a nominal power smaller than 10 kW located in Japan and central Europe.

Sub-systems

The sample for the cost data of the non US systems includes only 120 systems but gives a good indication of the costs of sub-systems from 1997 onwards.

Failure and maintenance

Failure, maintenance and maintenance cost would be an important component of the real cost of a PV system over time. The reporting on these topics in the economic survey was minimal and the data was therefore not used for this report.

2. IEA PVPS Performance Database

Task 2 set up the IEA PVPS Performance Database in 2000 and has maintained it up to now (October 2007). The latest edition of the database (2007) contains data from 505 PV systems with 1 648 years of operational data. Of the 505 PV systems built between 1983 to 2005, 445 systems or 88% are grid-connected. The plant and operational data were supplied by the Task 2 members for their respective countries. Data from past Task 2 members, Israel and the Netherlands, are also available in the database. Some non-members also supplied data.

2.1. The PV systems analysed

An additional 39 grid-connected PV systems with valid performance data from the economic survey were added to the 445 selected grid-connected PV systems from the IEA PVPS Database. After filtering out some datasets with out-of-range data, a total of 473 grid-connected PV systems were selected (Figure 17).

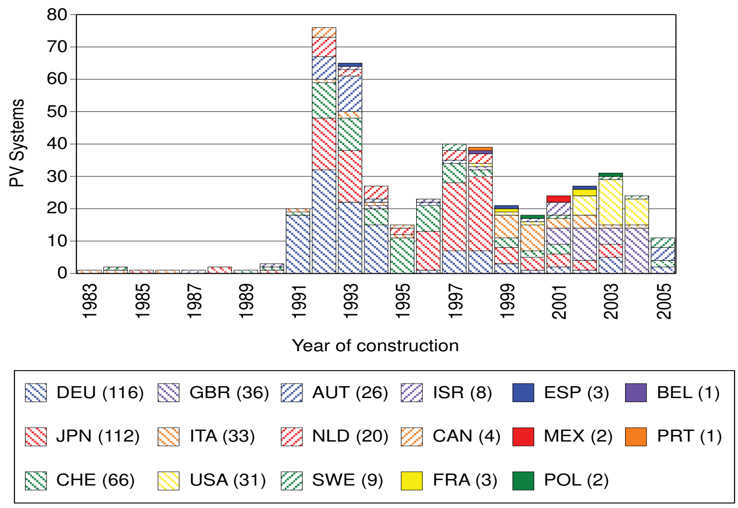


Figure 17, All 473 available grid-connected PV systems grouped by country and year of construction.

In this section of the report, only 461 grid-connected PV systems built between 1991 and 2006 with a total of 1 544 operational years are analysed (Table 3).

Table 3 All 461 grid-connected PV systems used, for this section of the report, grouped by country.

Country	ISO country code	Total systems	Years of Data	Average years	Total nominal power [kW]	Average nominal power [kW]
Germany	DEU	116	442	3.8	1 618.0	13.9
Japan	JPN	108	355	3.3	2 095.4	19.4
Switzerland	CHE	64	341	5.3	2 848.1	44.5
United Kingdom	GBR	36	73	2.0	158.6	4.4
United States	USA	31	55	1.8	120.0	3.9
Italy	ITA	30	86	2.9	4 624.1	154.1
Austria	AUT	26	48	1.8	86.4	3.3
Netherlands	NLD	20	52	2.6	535.7	26.8
Sweden	SWE	8	29	3.6	107.2	13.4
Israel	ISR	6	9	1.5	6.2	1.0
Canada	CAN	4	26	6.5	20.9	5.2
France	FRA	3	6	2.0	32.9	11.0
Spain	ESP	3	6	2.0	52.8	17.6
Mexico	MEX	2	4	2.0	3.5	1.8
Poland	POL	2	6	3.0	1.8	0.9
Belgium	BEL	1	4	4.0	5.2	5.2
Portugal	PRT	1	2	2.0	5.0	5.0
	17	461	1 544	3.3	12 322	26.7

The entries for PV systems in Germany, Japan and Switzerland make up 63% of the systems, 74% of the operational years and 53% of the total nominal power (Table 3).

2.1. The PV systems analysed (cont.)

Typical use and mounting

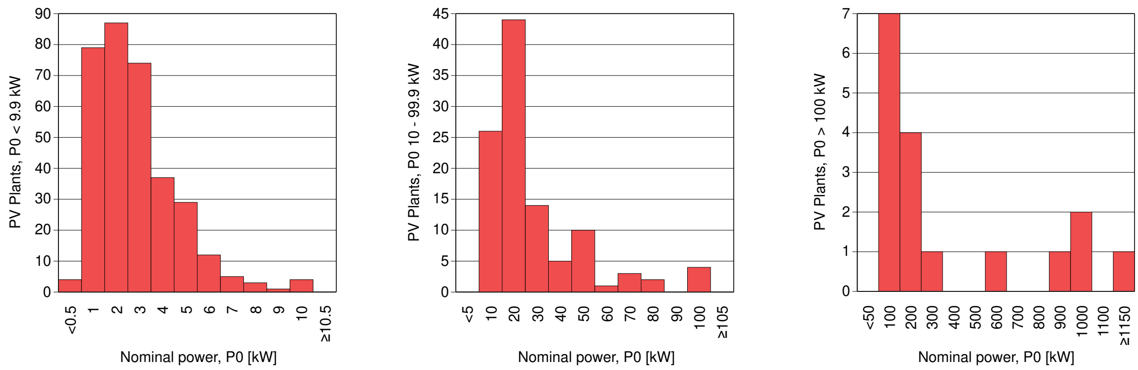
Table 4 shows the PV systems by typical use and type of mounting. Of the 461 systems 39% are domestic systems and 20% are power stations. 73% are roof top systems and 15% are free-standing.

Table 4, Typical use and mounting.

Typical use	Systems	Average P0 [kW]	Mounting	Systems	Average P0 [kW]
Domestic	179	3.98	Rooftop	338	14.14
Power station	91	96.92	Free-standing	70	86.91
Other	56	7.19	Façade	28	15.56
Office	42	32.30	Other	18	27.75
Housing-Other	21	17.84	Soundbarrier	7	74.83
School	18	3.98			
Apartments	14	4.26			
Factory	12	25.40			
NA	11	2.44			
University	11	1.25			
Other Professional	2	52.30			
Vacation house	2	22.05			
Hotel	1	20.20			
Water pumping	1	10.37			
	461	26.73		461	26.73

Nominal power

Figures 18 to 20 show the distribution of the nominal power. Of the 461 PV systems 73% are smaller than 9.9 kW, 24% are in the range of 10 to 99 kW and 4% are larger than 100 kW.



Figures 18, 19, 20, Distribution of the nominal power (P0) of the 461 grid-connected PV systems.

2.2 Findings

The 461 PV systems from the IEA PVPS Performance Database were analysed in respect to the annual yield (Yf a), the nominal module efficiency (ηA0), the operational array efficiency (ηA,mean), the operational inverter efficiency (ηI), the performance (PR) and the outage (O). The average values over the whole monitoring period were calculated for each system. The monitoring period for each system varies from 1 to 14 years.

Yield

The final yield (Yf) is the ratio of the energy produced by the PV plant to the nominal power (P0). This is a representative figure that enables comparison of similar PV systems in a specific geographic region. The yield (Yf) is dependent on the type of mounting, vertical on a façade (Figure 21) or inclined on a roof (Figure 22) and also on the location, as shown in Figure 23. In this figure the final yield is shown relative to the geographical latitude of the northern hemisphere, ranging from locations in the south of Japan to Israel, and from Mexico and the south of the United States to central Europe and Sweden.

2.2. Findings (cont.)

In Figure 23, yield values from 31 façade and other vertically mounted systems are highlighted. Figures 21 to 23 give an indication of the possible energy yields for the locations and the mounting of the systems analysed.

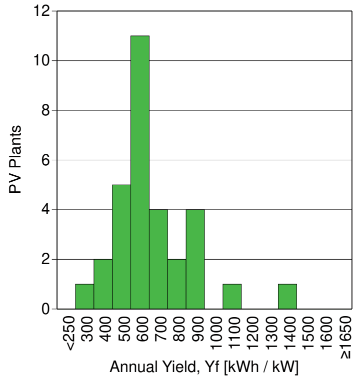


Figure 21, Annual yield, (Yf) façade systems.

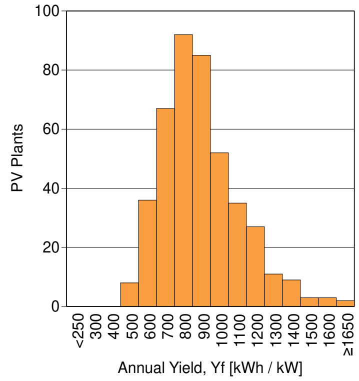


Figure 22, Annual yield (Yf), other systems.

About 30% of the façade systems have an annual yield of around 600 kWh/kW (Figure 21) and about 60% of the remaining systems show a yield of 800 to 900 kWh/kW (Figure 22).

Some of the façade systems shown in Figure 21 and highlighted in Figure 23 demonstrate a higher than expected annual yield. These façade systems are located in the alpine region of Switzerland and benefit from clear sky conditions and from the effect of the albedo from the snow cover.

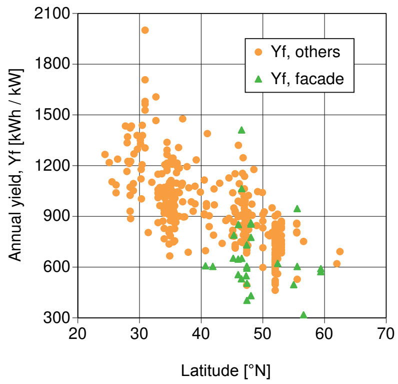


Figure 23, Annual final yield (Yf) vs. northern latitude.

Module efficiency

In Figure 24, the nominal module efficiency is shown relative to year of construction of the PV systems built from 1991 to 2005. PV plants with amorphous modules that have a lower efficiency are highlighted The mean value for each year is the mean efficiency value of the plants with crystalline cell modules. The overall trend is an increase from 11.6% to 12.9% in the installed nominal module efficiency for the 15-year-period from 1991 to 2005. Figure 25 shows the distribution of the nominal module efficiency of the 461 PV systems. The efficiency value for about 30% of the systems is between 11.5% to 12.5%.

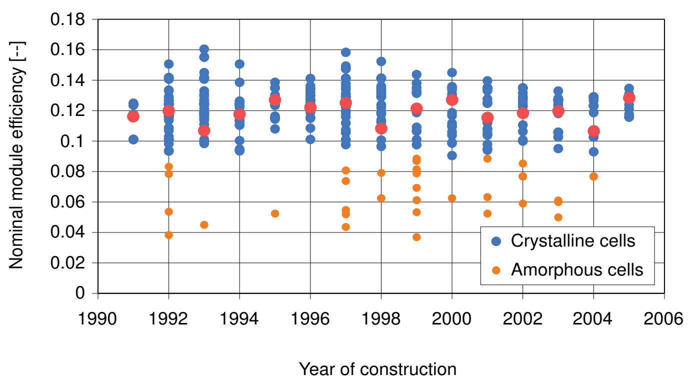


Figure 24, Nominal module efficiency over time.

2.2 Findings (cont.)

Figure 26 shows the module efficiency against the operational array efficiency. The operational array efficiency also takes into account any shading, mismatch or cable losses as well as non-availability of the system. The operational efficiency is on average about 20% below the nominal module efficiency. This value seems high and may have to do with the fact that the nominal power rating of the modules is higher than the actual power of the module, especially for the older systems. 91% of the systems have a nominal module efficiency of more than 9%, these were classified as having crystalline cells.

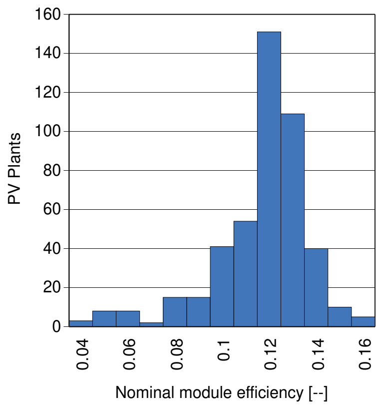


Figure 25, Nominal module efficiency.

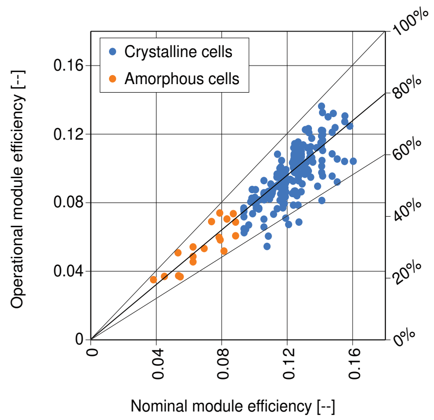


Figure 26, Nominal efficiency to the operational efficiency.

Inverter efficiency

Figure 27 shows the operational inverter efficiency over time. Of the 527 systems used for this section of the report, 331 systems have monitored data for the inverter efficiency. The figure shows a rising mean efficiency over time.

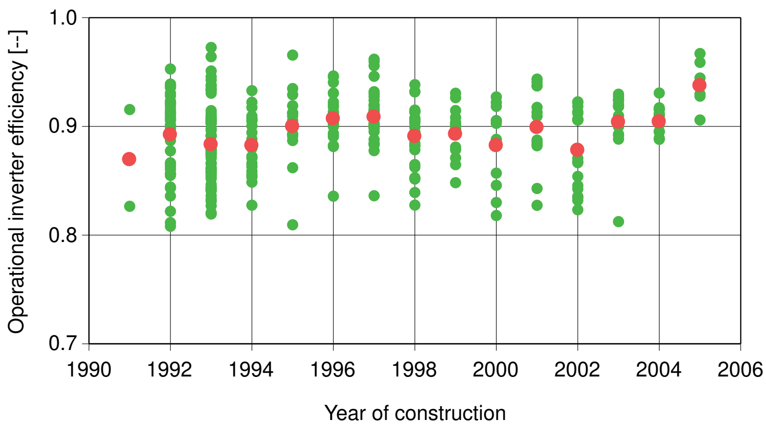


Figure 27, Annual operational inverter efficiency over time.

Figure 28 shows the distribution of the operational inverter efficiency. About 30% of the systems show an annual operational inverter efficiency between 89% and 91%.

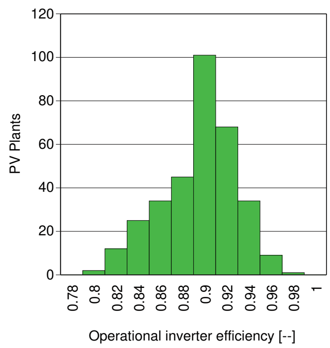


Figure 28, Annual operational inverter efficiency.

2.2. Findings (cont.)

Performance ratio

The performance ratio (PR) is the ratio of the final yield (Yf) to the reference yield (Yr) for a given period. The value of the reference yield is identical to that of the irradiation on the PV array plane (Hi). The performance ratio can be used to compare PV systems, independent of size, mounting and location. It expresses how much of the available solar energy is converted into electrical energy actually used.

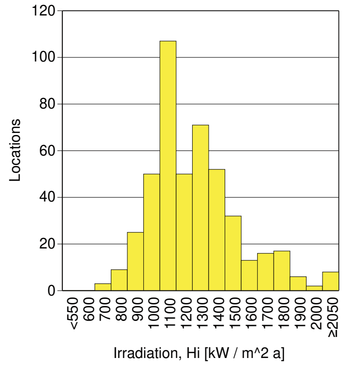


Figure 29, Distribution of in-plane irradiation.

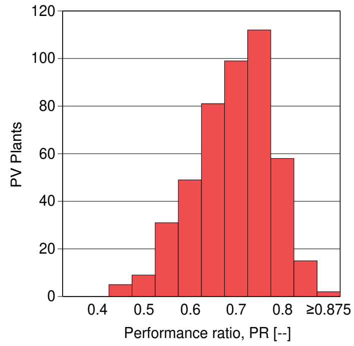


Figure 30, Distribution of the annual performance ratio.

Figure 29 shows the distribution of values for annual irradiation. Figure 30 shows the distribution of the performance ratio (PR).

Figure 31 shows the final yield (Yf) to the reference yield (Yr) for all the systems.

In Figure 32 the performance over time for the 461 PV systems from 1991 to 2005 is shown. This shows an upward trend of the mean annual PR from 0.64 in 1991 to 0.74 in 2005. The values shown in Figure 32 are the mean values for the whole monitoring period of the system, varying from 1 to 14 operational years.

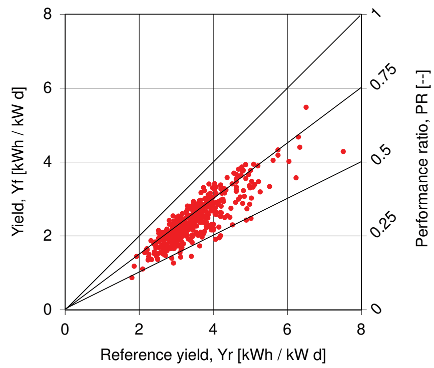


Figure 31, Final yield (Yf) vs. reference yield (Yr), all data.

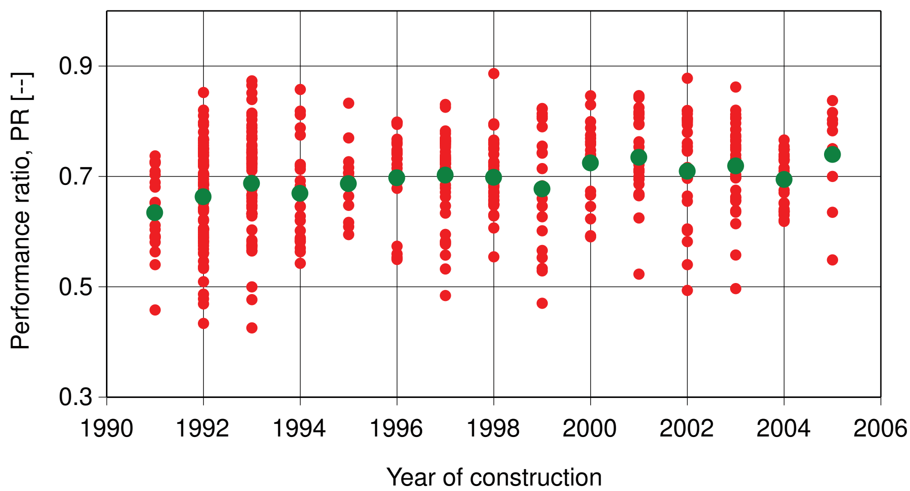


Figure 32, Performance ratio (PR) over time, all data.

2.2. Findings (cont.)

The three parts of Figure 33 show the performance over time of the 116 systems in Germany, 108 systems in Japan and 64 systems in Switzerland. Here also, a tendency of higher performance ratio of the newer PV plants is evident. The remaining systems are represented in Figure 34.

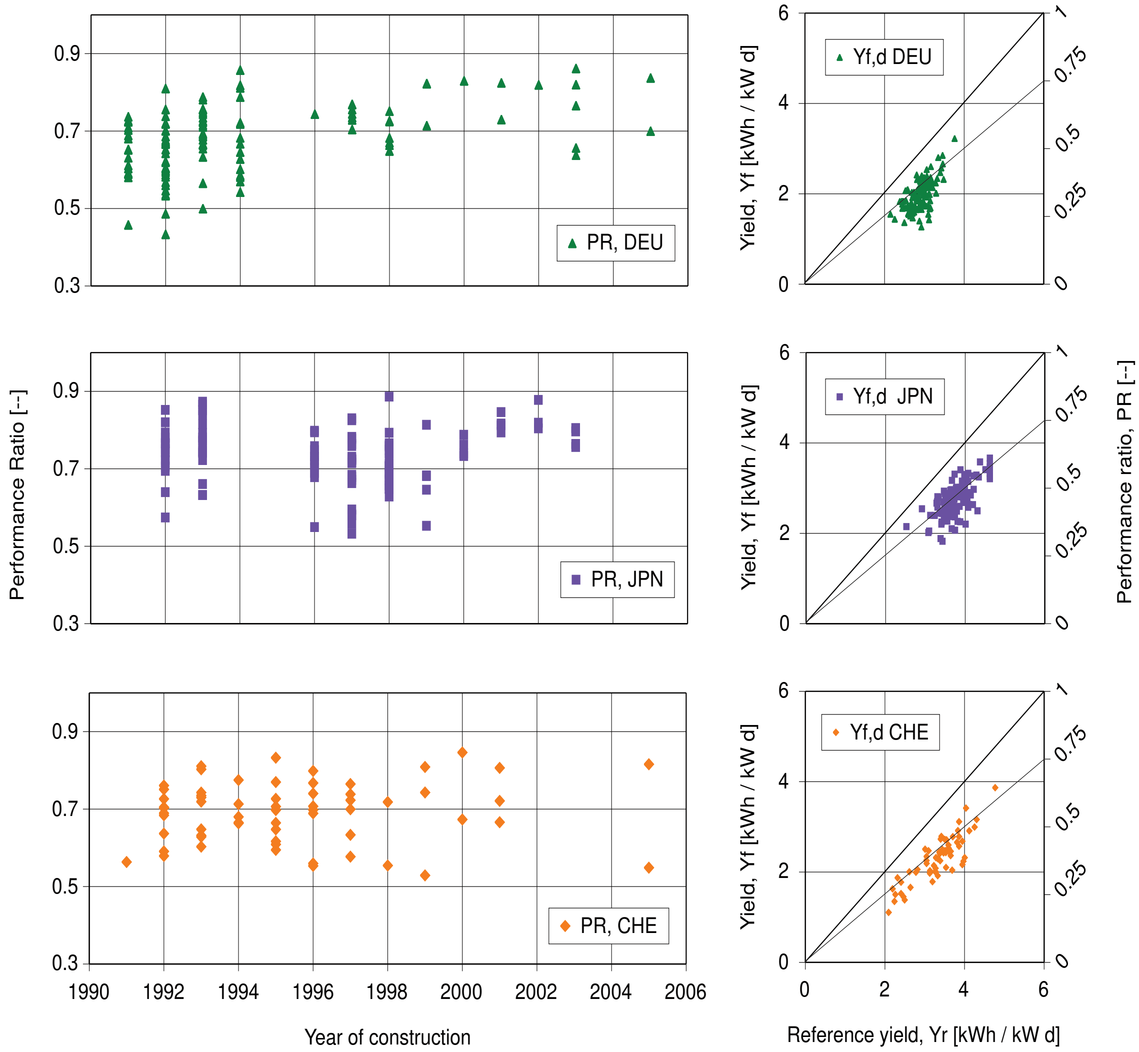


Figure 33, Performance ratio (PR) over time and final yield (Yf) vs. reference yield (Yr) for Germany, Japan and Switzerland.

Figure 34, Performance ratio (PR) over time and final yield (Yf) vs. reference yield (Yr) all other countries.

2.2. Findings (cont.)

Outage

The outage O is the downtime of a PV system. In Figure 35, the reported outage is shown for each system (left scale) and as an average value for each year (right scale). Failures occur less often over time and for 10 out of 15 annual values, a decrease in the annual outage over time is apparent. The highest annual value is in 1995. The value of 0.045 means that the systems built in 1995 were not operating for 4.5% of the time.

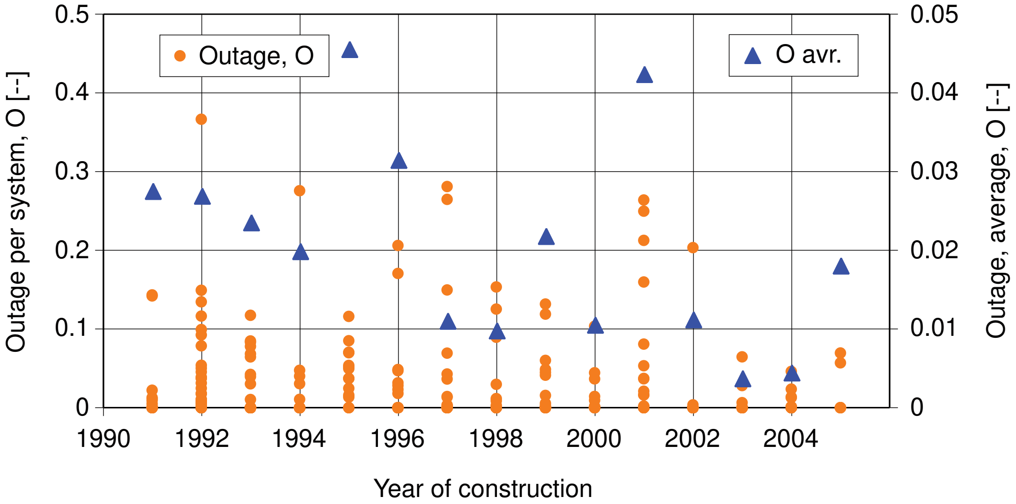


Figure 35, Reported outage (O) over time for all the systems and as an average value per year.

For quite number of systems, there is no reporting of any failures, even when the system has a lower than average performance ratio. Some of the datasets do not contain any outage data because the data are from globally monitored systems where the energy values are recorded manually on a monthly bases and the outage is not recorded.

2.3. Summary

Systems

All 461 datasets selected for this part of the report are from grid-connected PV built between 1991 and 2005 from 17 countries. They are mainly domestic roof-top systems with a nominal power smaller than 10 kW.

Annual yield

There are three main groups of locations for the systems analysed: Israel and southern Japan with a Yf of about 1 400 kWh/kW; Florida, USA, with a Yf of 1 000 kWh/kW and central Europe with a Yf of 900 kWh/kW.

Module efficiency

There is an increase in the module efficiency over time. The operational array efficiency is on average about 20% below the nominal module efficiency.

Inverter efficiency

The average annual operational inverter efficiency rises over time from 87% in 1991 to 94% in 2005.

Outage

In 30 % of the systems the outage is larger than zero. There is a decrease in the occurrences over time.

Performance ratio

The mean annual performance ratio shows an upward trend from 0.64 in 1991 to 0.74 in 2005. The rise in the operational inverter efficiency, the decrease in the frequency and duration of outage and a more accurate module rating are contributing factors to the rise in the performance ratio over time.

A typical grid-connected PV system

A typical grid-connected PV system for the year 2005 shows an improvement of the overall plant efficiency of 29% compared to a system built in 1991. The overall plant efficiency in Table 5 is the product of the nominal module efficiency and the performance ratio.

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

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

3. Case Studies

To supplement this Cost and Performance Trend Report Task 2 Members from:

Canada, Germany, Japan, Sweden, Switzerland and the United Kingdom have contributed a case study on one or more subjects with information and data from PV projects from their country.

- A - System cost
- B - Annual yield over time
- C - Performance over time
- D - Statistics on maintenance.

The data presented in the case studies are usually from specific national PV projects where the systems have a common denominator. In the case studied the system costs and the maintenance costs are shown in local currency.

Case studies

The two PV systems from **Canada** are diverse in size and system cost, location and yield. The performance (PR) for both systems is between 70% and 75%.

33 systems built in **Germany** between 2005 and 2007 having nominal powers between 1.5 and 12 kW show a mean reduction rate for the system cost of 0.046 EUR/W with increased size.

Japan reported on system failures and maintenance. Of 725 replies to a questionnaire survey, only 86 (12%) contain a report on failure. About 50% of the failures occurred during the first year of operation.

Sweden presented detailed costs for eight **Swedish** PV systems and long-term performance data from six systems.

Of the seven systems from **Switzerland** with yield data, three show a lower than average yield in the second year of operation.

The study from the **United Kingdom** gives a detailed description of three projects of a total of 54 residential PV systems.

3.1. Canada

Case study - System cost - Yield data - Performance data

PV in Canada

Growth in Canadian capacity has averaged 25% per year since 1995, and in 2006, the installed solar PV capacity amounted to 20.50 MW. Whereas the worldwide trend has been moving towards grid-connected application supported by market stimulation measures, in Canada the market is mainly for off-grid applications which represent 93% of the total installed PV power capacity. However, with barriers to interconnection of decentralized systems being addressed and the recent implementation of a feed-in tariff program in Ontario, a shift towards grid-connected installations is expected to happen in the coming years.

Plants

More than half the Canadian capacity has been installed in the last five years and few plants have been monitored extensively for a time period of more than six years.

Nunavut Arctic College

This example is a PV system demonstration monitored by the Canadian PV R&D programme. The Nunavut Arctic College PV system was installed in 1995 to document the long-term performance of a grid-tied PV system in the north of Canada. This façade system is connected to the local community grid, which is powered by large diesel generators. The material and installation costs amounted to USD 70,000 at the time of installation (monitoring system costs not included).

Nunavut Arctic College, Iqaluit, Nunavut, Canada [-68.5°E, 63.8°N]

Monitoring data

The nominal power of the system is 3.2 kW. Tests performed after installation under standard testing conditions on sample modules have however shown that some of the modules under perform their nominal rating by as much as 13%.

The plant is monitored in real time on an hourly basis. Amongst the monitored parameters are AC and DC power, array and ambient temperatures, global irradiance and irradiance in the plane of the array as well as operation time. These results were compiled on an annual basis for the needs of this report.

The annual yield, the performance and the operation of the system are shown in Figure 36. The constant yield is a reflection of the high operation time of the system. The façade installation of the array as well as a lower annual insolation in the arctic explain the relatively lower yield of this system when compared to systems installed in more southern latitudes in Canada.

3.1. Canada (cont.)

The performance of the system is depicted on Figure 36. The low operating temperature of the array counterbalanced the negative impact of low light conditions on the array and inverter performance and thus yielded a fair performance ratio oscillating between 70% and 80%.

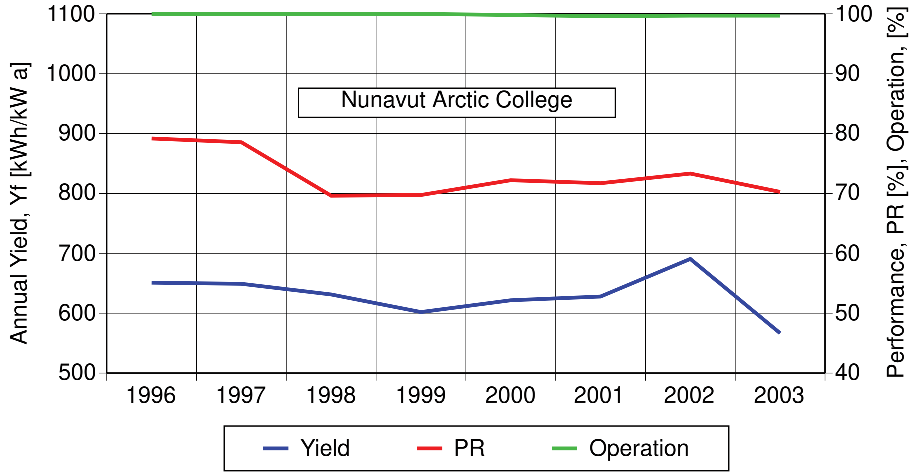


Figure 36, Annual yield, Performance and Operation of the Nunavut Arctic College PV system from 1996 to 2003.

Queen's University

This example is a PV system demonstration installed on the façade of the Goodwin Hall, home to Queen's Departments of Mining Engineering, Electrical and Computer Engineering, and Computing and Information Science. The system was installed in 2003 and resulted in a visible, attractive demonstration of the University's commitment to new energy technologies and sustainability. The material and installation costs amounted to USD 13.35 per W at the time of installation (4.80 USD/W for modules and 8.55 USD/W for installation and BOS).

Goodwin Hall, Queen's University, Kingston, Ontario, Canada

Monitoring data

The nominal power of the system is 19.8 kW. The plant is monitored in real time on a minute basis. Amongst the monitored parameters are AC and DC power, array and ambient temperatures, global irradiance and irradiance in the plane of the array as well as operation time. These results were compiled by Queen's University on an annual basis for the needs of this report.

3.1. Canada (cont.)

The annual yield, the performance and the operation of the system is shown in Figure 37. The constant yield in the first two years is a reflection of the high operation time of the system. String failures in 2006 resulted in a lower annual yield for that year.

The system yielded a fair performance ratio oscillating between 69% and 75% and had a nearly 100% operation time.

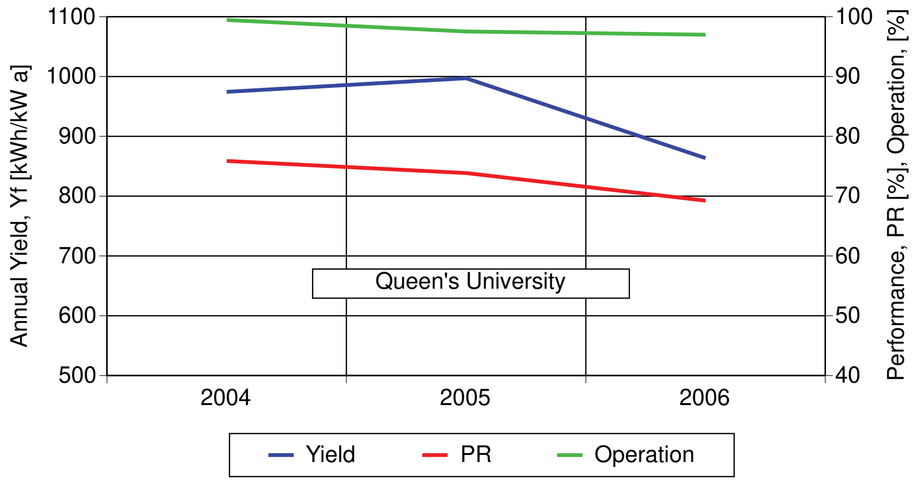


Figure 37, Annual yield, Performance and Operation of the Queen's University PV *system from 2004 to 2006.*

Cost data

The difference of the two systems is also reflected in the specific cost. The older PV system is located in a remote location and is about six times smaller than the newer system in Ontario.

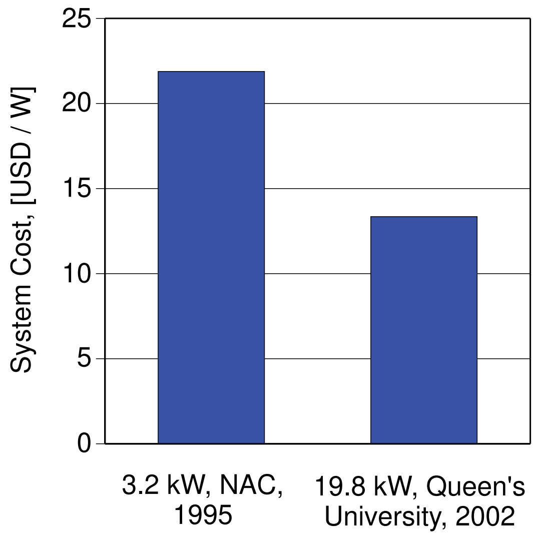


Figure 38, Comparison of the specific cost of the two Canadian PV systems.

3.2. Germany

Case study - System cost - Yield data - Performance data

A, Cost data - 33 systems

Cost data of 33 grid-connected PV plants have been obtained from www.sonnenertrag.eu. The PV plants were selected according to the following criteria:

- PV plants installed in different regions of Germany
- PV roof-top plants installed on residential houses
- Installed PV power between 1 and 12 kW

The installation years vary between 2005 and 2007 (plant no. 94554 was installed in 2000).

The locations of the plants are between 48.75°N and 51.33°N latitude.

The module technology mainly consists of mono- and poly- crystalline solar cells. Five of the 33 systems have thin film PV modules (amorphous and CIS technology).

Results

Figures 39 and 40 show the turn-key costs of 33 residential PV plants installed in Germany between 2005 and 2007. The average PV system cost is 5.2 EUR per W installed.

The specific PV system investment cost vary between 2.93 EUR and 7.24 EUR per W. The lowest PV system cost is attributed to a 7 kW system having amorphous PV modules from a Japanese manufacturer. The PV plant with the highest cost has thin film modules of CIS technology from a German PV module producer.

Residential PV system

Fig. 40 shows the system costs as a function of the installed peak power varying from 1.5 kW to 11.9 kW. The spread of system costs is rather high (more than a factor of two). There is a clear correlation between system costs and installed power. As expected, the PV plant costs decrease with increasing nominal power. For the 33 plants of the investigation, the mean reduction rate is 0.046 EUR/W for the given range of 1.5 kW to 12 kW.

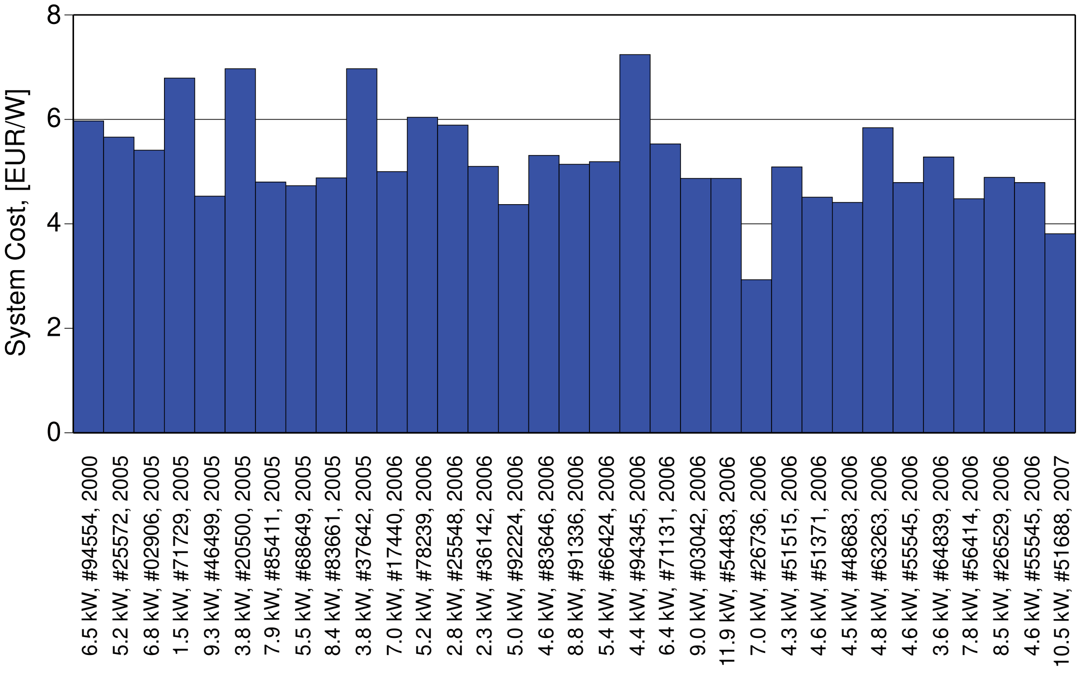


Figure 39, Specific plant cost of 33 grid-connected German residential PV systems, sorted by year of construction.

3.2. Germany (cont.)

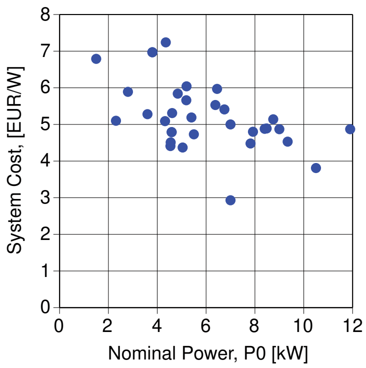


Figure 40, Specific plant cost as a function of installed power, German systems.

B, Annual yield - 8 systems

PV at School

Two successful PV promotion programmes for schools have been carried out in Germany. “Sun at School” sponsored by the utility Bayernwerk (now E.ON Energie) and “SONNEonline” sponsored by utility Preussen Elektra (now E.ON Energie).

Within the project **Sun at School** it was possible to combine innovative technology with an innovative idea and to take an important step towards spreading PV technology among students and teachers. Between 1994 and 1997, 544 schools in Bavaria received a highly subsidised PV construction kit for a grid-connected PV system with an electrical output of about 1 kW. Teachers and students, together with support from regional and local power supply utilities, were responsible for assembling the PV system. The monitoring and evaluation work has been carried out by the Solar Lab Munich University of Applied Sciences on behalf of the Solarenergieförderverein Bayern (SeV= Bavarian Association for the Promotion of Solar Energy) in conjunction with E.ON Energie.

Students learn about PV, Photo Courtesy of Solarenergieförderverein

Within the project **SONNEonline**, about 400 schools in the region of Northern Germany were provided with grid-connected PV systems of about 1 kW installed power in 1996. SONNEonline was based on a profound educational concept, which aims to introduce PV technology to a target group of students and teachers, which is expected to multiply in the years to come.

More than 900 schools spreading from the North to the South of Germany received and installed the 1 kW PV systems. The PV systems show good performances, their annual energy yields are in a wide range from below 500 kWh/kW to above 1000 kWh/kW. For these 900 systems, monthly operational results are provided at: www.sev-bayern.de.

3.2. Germany (cont.)

Selected Systems

Eight plants located in the state of Bavaria were chosen from the Sun at School project. The plants are identical with respect to components (modules Siemens M55, Siemens inverter) and size (1.1 kW). The location and irradiation level is in the same region and the tilt angle is about 30° for all systems under investigation.

Figure 41 shows the annual yields of eight grid-connected school systems of 1 kW installed peak power, which were commissioned between 1995 and 1997.

These eight plants show a rather consistent performance behaviour having their highest PV output in 2003, when the irradiation was about 25% higher than the 10-year-mean. During 2003, the final yields (Y_f) of the 8 systems investigated vary between 850 kWh/kW and 1 130 kWh/kW due to the different irradiation sums and array's orientations at the systems sites. One relevant plant malfunctioning is observed for plant Altötting in 2006, when the system delivers only 2/3 of the expected output due to an inverter failure, which lasted from August to December 2006 before it was repaired.

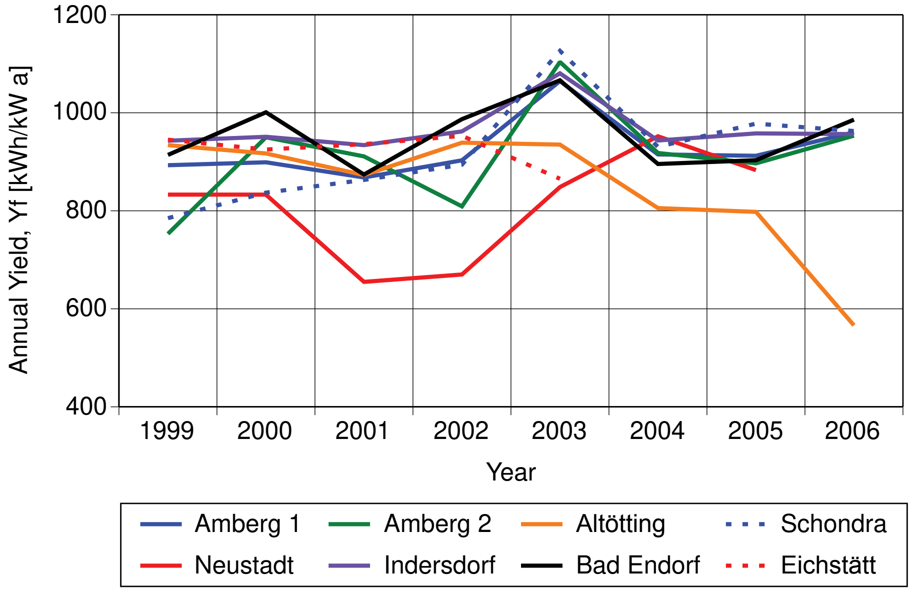


Figure 41, Annual yields of eight German grid-connected PV school plants over eight years of operation (1999 – 2006).

C, Performance data, 6 systems

Twelve PV installations were equipped with analytical monitoring systems and six of them are still monitored until the end of 2006. The annual performance ratio (PR) was calculated for each plant.

Residential PV system

For all the given plants the module technology is mono- and polycrystalline silicon (Siemens M55, Kyocera KC 120 and Kyocera 110) using different inverters (SMA SWR 850 and Siemens SPN 1000). Plant performance and irradiation data are available for at least four to nine years (1998 – 2006). All plants are located in Germany, between the longitude 48.22 N and 54.21 N.

For some of the systems the availability of the monitoring data were too low for the data analysis due to problems with the irradiance sensor (Samtens system).

3.2. Germany (cont.)

Figure 42 shows the annual PR values of six grid-connected PV plants between 1998 and 2006. They show rather constant annual performance (PR) in the typical range of 0.70 to 0.80, which represent PV systems with good performance. For one system (Beelitz) the annual PR values are reduced to lower PR between 0.66 (1998) and 0.59 (2006) due to a systematic shading of the system by trees. As the shading cannot be avoided, a lower PV output than expected is accepted. The six monitored, small PV systems installed on public buildings in different parts of Germany demonstrate a high overall performance during the nine years of operation.

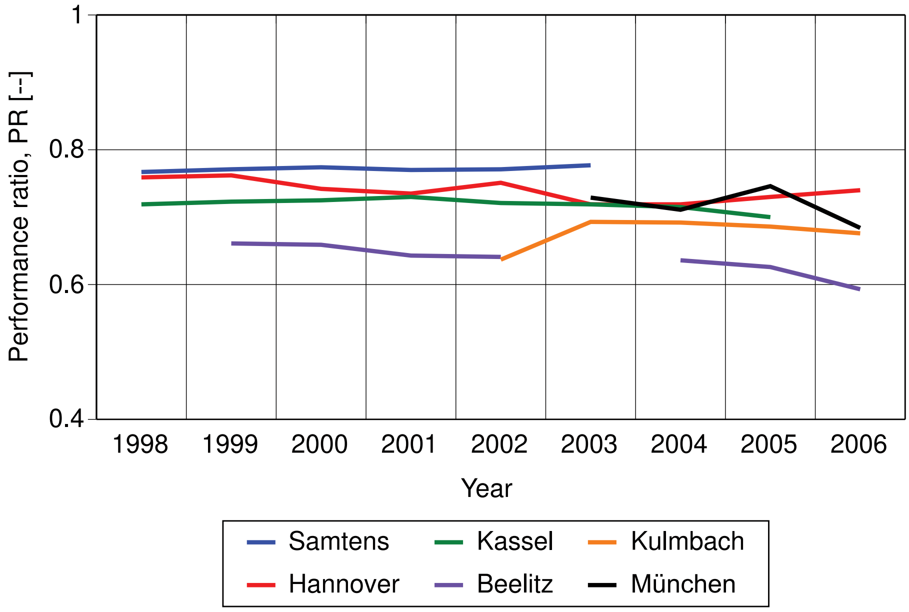


Figure 42, Annual performance ratio over time for six German PV systems (1998 – 2006).

3.3. Japan

Case study - Statistical data on maintenance

D, Maintenance - 725 systems

Under the auspices of the New Sunshine Program and continuous R&D programmes by the New Energy Development and Industrial Technology Organization (NEDO), JET and AIST (JET-AIST) have been implementing a measurement and evaluation programme for photovoltaic (PV) systems since the 1997 fiscal year. In this program, a total of 100 residential grid-connected PV systems (GCS), equipped with data acquisition systems, have been monitored for ten years. The purpose of this study was to clarify the operating performance of the grid-connected PV systems on the rooftops of residential houses in Japan and to develop a simulation methodology in order to estimate the electricity generation and costs in the actual housing environment.

JET-AIST have also carried out a questionnaire survey of Japanese users on the awareness of failures and performance of GCS between FY 2002 and 2004. This survey aims to study various troubles (failures) of the grid-connected PV systems (GCS) in the real environment, and to understand the user's awareness of the troubles of the GCS. Also the survey aims to utilize these results as useful data for evaluating the operational performance and providing technical support for design and operation, and for the development of the supporting technology for performance improvement. The number of replies to our three-year-questionnaire-survey was 725 (362 in 2002, 259 in 2003, and 104 in 2004.)

In this case study, maintenance records and costs of repairs are described.

Repair cost

In the 725 replies to our questionnaire survey, 86 cases were classified as actual failure events of the components of PV systems after follow-up surveys by JET-AIST. Another 639 replies except for these 86 cases implied that the owners did not experience any significant failures. This means that 88% of the PV systems were operating well without any problems or failures. There were seven cases of PV module failures, seventy-two cases of power conditioner failures, and seven cases of BOS (balance of system) failures. These events and the repair costs sorted by the operating period are listed in Tables 6, 7 and 8.

The number of cases that cost the owners a certain amount for repair were few. The repair costs for PV modules, power conditioners and BOS averaged 57 000 JPY, 10 000 JPY and 0 JPY (no charge) respectively. The reason why almost all cases were repaired without any charge to the owners seems to be that many failures occurred in the early stage of operation, mainly in the warranty period. There were six exceptions where the owners had to pay a certain amount for replacing the failed power conditioners. The replacement cost of the power conditioners ranged between 58 000 JPY and 244 000 JPY. There were a few cases in which the loss of energy yield during failure was compensated for by manufactures.

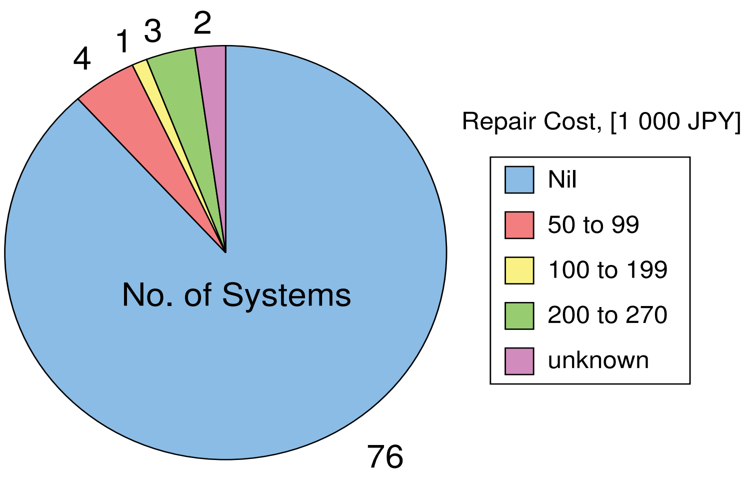


Figure 43, Distribution of the actual repair costs (in 1 000 JPY) from 86 reported cases of 725 Japanese PV systems.

3.3. Japan (cont.)

Failure over time

The time of the first failure after installation of the residential PV systems is indicated in Figure 44. The failure rate decreased year by year after the installation. The failure events obtained by the questionnaire survey are the early failures in the bath-tub curve. Continuous surveys of the failures are necessary to reveal the long-term reliability of PV systems.

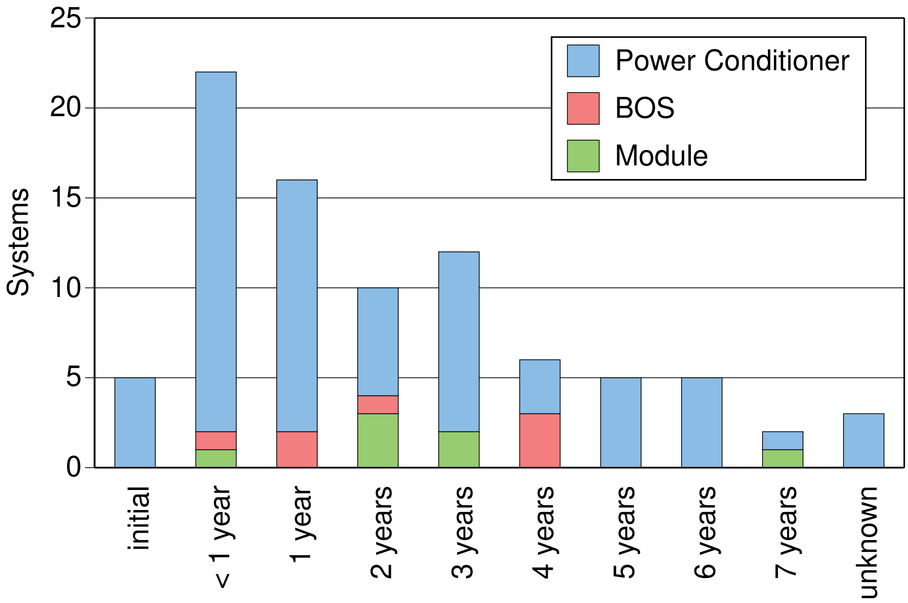


Figure 44, Distribution of operational year of the first failure after installation.

Tables 6, 7 and 8 list the type of failure of the 86 reported failures from a total of 725 Japanese residential PV systems.

Table 6, PV module failures and repair costs, 7 systems

Module Failure event	Repair action	Period	Cost
The breakage of PV module glass by roof tiles of a neighboring house during a typhoon	PV module replacement	> 1 year	130 000 JPY
The breakage of PV module glass of unknown cause	PV module replacement	2 years	0
Change in color (turning yellow)	PV module replacement	2 years	0
The breakage of PV module glass due to snow coverage, 1.5m high	PV module replacement	2 years	270 000 JPY
The output degradation by the soldering defects inside PV module (recall)	PV module replacement	3 years	0
The output degradation by the soldering defects inside PV module (recall)	PV module replacement	3 years	0
Change in color (white spot in cells)	PV module replacement	7 years	0

Table 7, BOS failures and repair costs, 7 systems

BOS Failure event	Repair action	Period	Cost
Breakage of breaker in the junction box (poor bolting of a mounting bolt)	Power conditioner element replacement	< 1 year	0
Wring wiring of 2 in 24 modules	Repair of wiring	1 year	0
Breakage of LCD circuit	Power conditioner element replacement	1 year	0
Electrical disconnection of the PV modules due to heavy snow	Repair of wiring	2 years	0
Disconnection of wiring	Repair of wiring	4 years	0
Breakage of LCD	Power conditioner element replacement	4 years	0
Electrical disconnection of the PV modules due to heavy snow	Repair of wiring	4 years	0

3.3. Japan (cont.)

Table 8, Power conditioner failures and repair costs, 72 systems

Power Conditioner Failure event	Repair action	Period	Cost
Improper display on LCD	Power conditioner replacement	initial	0
Interruption of operation with error sign	Power conditioner replacement	initial	0
Interruption of operation	Power conditioner replacement	initial	0
Error sign on LCD	Power conditioner element replacement (control circuit)	initial	0
Interruption of operation	Power conditioner element replacement (control circuit)	initial	0
Interruption of operation with error sign	Power conditioner replacement	< 1 year	0
Error sign on LCD	Power conditioner replacement	< 1 year	0
Interruption of operation (lightning surge?)	Power conditioner replacement	< 1 year	0
Interruption of operation	Power conditioner replacement	< 1 year	0
Interruption of operation with error sign	Power conditioner replacement	< 1 year	0
Interruption of operation with error sign	Power conditioner replacement	< 1 year	0
Error sign on LCD, and abnormal sound	Power conditioner replacement	< 1 year	0
Interruption of operation with error sign	Power conditioner replacement	< 1 year	0
Interruption of operation with error sign	Power conditioner replacement	< 1 year	0
Interruption of operation	Power conditioner replacement	< 1 year	0
Interruption of operation	Power conditioner replacement	< 1 year	0
Interruption of operation (lightning surge?)	Power conditioner replacement	< 1 year	0
Incorrect measurement of energy yield	Power conditioner replacement	< 1 year	0
Error sign on LCD, monitor	Power conditioner replacement	< 1 year	0
Intermittent operation	Power conditioner element replacement (control circuit)	< 1 year	0
Incorrect measurement of energy yield	Power conditioner element replacement (control circuit)	< 1 year	0
Intermittent operation	Power conditioner element replacement (control circuit)	< 1 year	0
Interruption of operation with error sign	Repair by manufacturer	< 1 year	0
Error sign on LCD	Power conditioner element replacement	< 1 year	0
Recall by manufacturer	Repaired by manufacturer with energy yield compensation for the repair period (20 days)	< 1 year	0
Abnormal waveform of AC output	Power conditioner element replacement (ROM exchange)	1 year	0
Error sign on LCD	Power conditioner element replacement	1 year	0
Breakage of LCD	Power conditioner element replacement	1 year	0
Power conditioner damaged by the wrong wiring	Power conditioner element replacement	1 year	0
Electronic parts are damaged by lightning surge	Power conditioner element replacement	1 year	0
Error sign on LCD (lightning surge?)	Onsite repair by manufacturer	1 year	0
Recall by manufacturer	Repaired by manufacturer with energy yield compensation for the repair period (500 JPY per day)	1 year	0
Recall by manufacturer	Repaired by manufacturer with energy yield compensation for the repair period (500 JPY per day)	1 year	0
Interruption of operation	Power conditioner replacement	1 year	0
Poor performance due to defective control circuit	Power conditioner replacement	1 year	0
Error sign on LCD	Power conditioner replacement	1 year	0
Error sign on LCD	Power conditioner element replacement ?	1 year	0
Interruption of operation	Power conditioner replacement	1 year	0
Incorrect measurement of energy yield	Power conditioner replacement	1 year	0
Recall by manufacturer	Power conditioner element replacement	2 years	0
Recall by manufacturer	Power conditioner element replacement	2 years	0
Recall by manufacturer	Power conditioner element replacement	2 years	0
Breakage of power conditioners element due to invader (gecko)	Power conditioner element replacement (control circuit)	2 years	0
Interruption of operation	Power conditioner replacement	2 years	0
Interruption of operation	Power conditioner replacement	2 years	0
Interruption of operation	Power conditioner replacement	3 years	0
Abnormal sound	Power conditioner replacement	3 years	0
Error sign on LCD	Onsite repair by manufacturer	3 years	0
Interruption of operation with error sign	Onsite repair by manufacturer	3 years	0
Interruption of operation, and abnormal sound	Power conditioner replacement	3 years	58 000 JPY
Interruption of operation with error sign (blown fuse?)	Power conditioner replacement	3 years	0
Interruption of operation with error sign	Power conditioner replacement	3 years	0
Interruption of operation	Secondhand power conditioner replacement	3 years	0
Error sign on LCD	Power conditioner replacement	3 years	0
Poor performance?	Unknown	3 years	Unknown
Interruption of operation	Power conditioner replacement	4 years	0
Breakage with explosive sound	Power conditioner replacement (after warranty period)	4 years	200 000 JPY
Error sign on LCD	Power conditioner element replacement	4 years	0
Error sign on LCD	Power conditioner replacement (different type from another manufacturer)	5 years	244 000 JPY
Interruption of operation (lightning surge?)	Power conditioner replacement	5 years	0
Error sign on LCD	Power conditioner replacement	5 years	60 000 JPY
Breakage of power conditioner	Unknown	5 years	Unknown
Interruption of operation	Power conditioner replacement (different type from another manufacturer)	5 years	0
Interruption of operation	Power conditioner replacement	6 years	0
Interruption of operation	Power conditioner replacement	6 years	0
Error sign on LCD	Power conditioner replacement (different type from another manufacturer)	6 years	75 000 JPY
Error Sign on LCD (lightning surge?)	Onsite repair by manufacturer	6 years	0
Error Sign on LCD (lightning surge?)	Onsite repair by manufacturer	6 years	0
Breakage of LCD	Power conditioner replacement (different type from another manufacturer)	7 years	90 000 JPY
Interruption of operation	Power conditioners element replacement	Unknown	0
Interruption of operation	Power conditioners element replacement	Unknown	0
Intermittent operation	Power conditioner replacement	Unknown	0

3.4. Sweden

Case study - System cost - Yield data - Performance data

A, Cost data - 12 systems

For the cost data analysis five grid-connected systems have been chosen, all from the city of Stockholm.

Huvudsta

This plant was constructed in 1984 on the façade of the attic on the roof of an eight-floor multi-dwelling residential building. The polycrystalline silicon modules, with a total peak power of 2.1 kW, are mounted on a structure made of wood and are facing south-southeast with an 80° tilt.

Ringen

The utility company Stockholm Energy built this plant in 1993 as a demonstration plant on the roof of a shopping mall. 10 kW of monocrystalline silicon modules are mounted vertically and on the 45° sloped roof of the south facing part of the building.

JM

Two identical 5.7 kW systems with semi-transparent polycrystalline modules integrated in a sloped glass roof on the top of two buildings within a high profile residential area. They were brought into operation in 2002 and 2003. The tilt of the roof is 30° with one building facing directly south and the other south-east.

Lysande

This building is located within the same high profile area as the JM buildings and it has an external structure with specially designed PV modules working as solar shading on the south façade. There are also modules on the east, south and west sides of the 16° sloping roof. Total peak power is 21.9 kW and it was brought into operation in 2004.

NCC

These twin buildings are also located within the same area as the two previous buildings. They have a total amount of 34.7 kW of brown polycrystalline silicon modules integrated in the façade, balconies and windows on the south-southwest side of the buildings. In operation since 2003 and 2004.

IKEA roof and façade

See description under Sample B, annual yield over time.

3.4. Sweden (cont.)

Göteborg Energi

The installation became more complicated than expected due to the construction of the façade. This is the reason for the very high installation costs. Further description under Sample B, annual yield over time.

ABB

Located in Västerås. ABB built this system in 2005 to study costs and the rules and regulations for connecting and selling electricity from a small PV system.

Alléskolan

Located in Hallsberg. Brought into operation in December 2005 as the first new system within the support programme. Glass-glass modules are integrated in the east, south and west façades of this school building. Aesthetics were important in this project.

Fläckebo

Located north of Västerås, built in 2006. Standard modules are mounted on the sloped roof of a barn. The cost for this system is quite low. This is because it was built by a new company that wanted to establish itself on the Swedish market as a consequence of the support programme.

Fjärås

Located south of Göteborg, built in 2006. Standard modules are mounted on four different areas of the sloping roof of this health centre.

A comparison of the costs of these plants is shown in the Figures 45, 46 and 47. The costs were recalculated according to the consumer price index for September 2006. Most of the 12 plants are demonstration systems and in some cases with a high level of building integration. No attempts were made to build PV from a low cost perspective, with the exceptions of the three systems: Fjärås, Fläckebo and IKEA roof. They were built with the focus on the energy production rather than on demonstration purposes.

In May 2005 the first support specifically directed towards installation of PV systems in Sweden was initiated - 70% investment support with 15 M€ in total to be spent from 2005 until 2008.

3.4. Sweden (cont.)

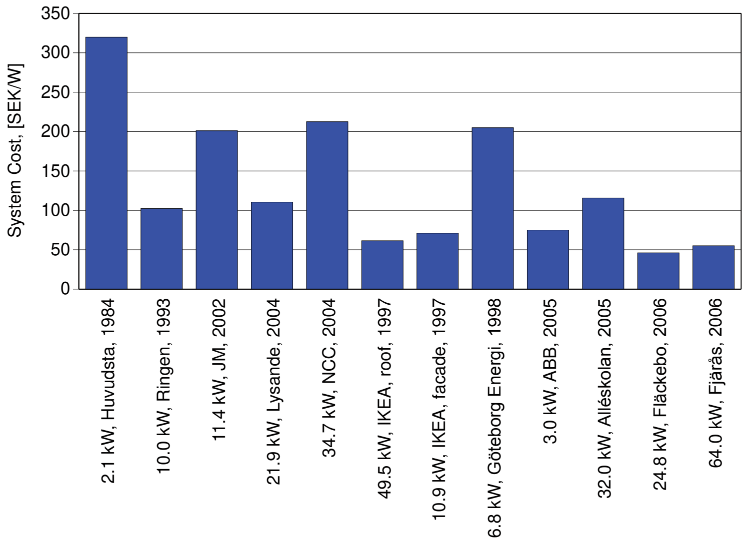


Figure 45, System cost per installed power for 12 systems in Sweden in 2006 prices, sorted by year of installation

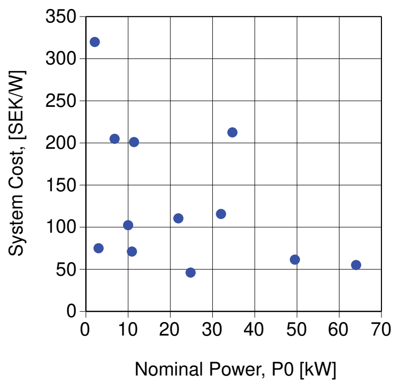


Figure 46, System cost to the installed power for the 12 Swedish PV systems

A breakdown of the cost for 8 of the 12 Swedish PV systems is shown in Figure 47.

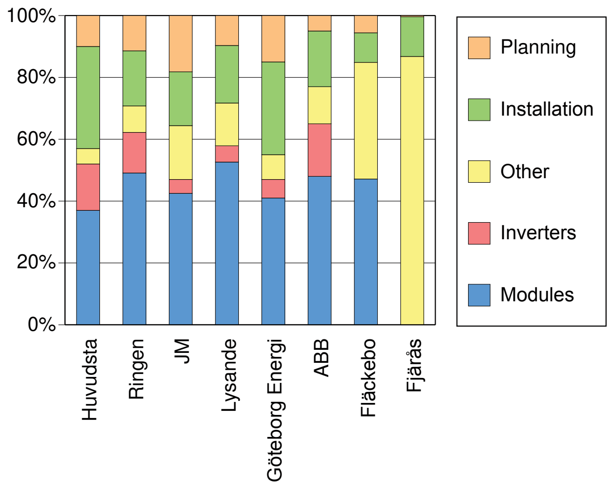


Figure 47, Breakdown of the system cost in percent for 8 Swedish PV systems.

3.4. Sweden (cont.)

B, Annual yield - 5 systems

There are not that many PV plants in Sweden with a continuous production record over six years or more. Figure 48 shows the annual yield over time from five plants.

IKEA roof and façade

IKEA build this plant in 1997 in order to gain knowledge about PV technology. The roof installation was optimized for production while the façade installation has a demonstration purpose. All modules are facing south. Until recently it was the largest PV plant in Sweden with a capacity of 60.4 kW.

Göteborg Energi

The utility company Göteborg Energi built this façade installation of amorphous silicon modules in 1998 because they wanted to attract attention to their environmental work. The modules are attached to the southwest façade of Göteborg Energi's main office. As with the façade installation on the IKEA building this was an early experiment with amorphous silicon and the peak power of 6.8 kW is overestimated.

Österängen

When these buildings were renovated in 1998 it was decided that poly-crystalline PV modules should be integrated in two of the buildings. Part of the installation is integrated in the façade and another part in the 30° sloped roof, all facing south. The peak power of the plant is 11.8 kW and it was built as a part of the housing company's plans for sustainable development.

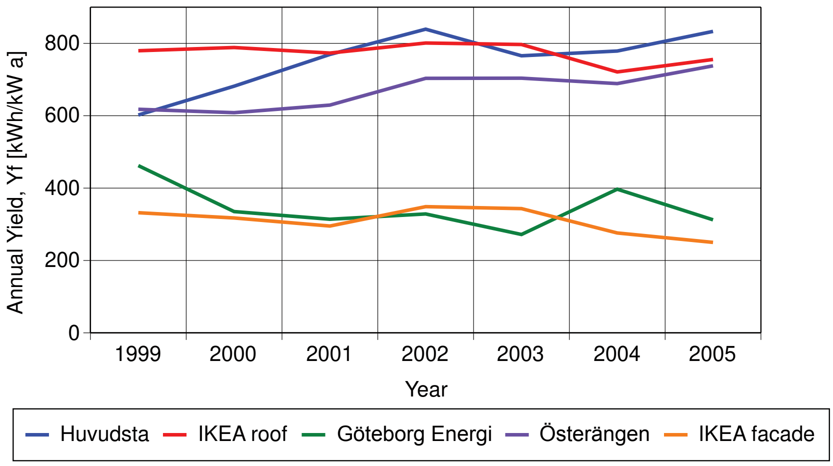


Figure 48, Annual yield of 5 Swedish systems all from 1999 to 2005. The values for Göteborg Energi and IKEA façade are considerably lower. Both these systems are façade installations using amorphous silicon. They were early experiments with this technology and the peak power is overestimated.

3.4. Sweden (cont.)

C, Performance data - 6 systems

For the cost data analysis six grid connected systems have been chosen, all for the city of Stockholm. Three of them have been presented above. The three other systems are described before a brief description of each system's performance and operation.

Borlänge

This 3 kW plant was built in 1994 on the roof of the University of Dalarna for educational purposes. The modules are mounted with a 60° tilt towards south-southeast.

Naturhistoriska Göteborg

This 1.8 kW system with mono-crystalline modules was built as a demonstration plant on Göteborg Natural History Museum. The modules are mounted with a 50° tilt, oriented almost to the south. It was brought into operation in 1999.

Nordens Ark

The utility company Vattenfall built this plant in 2000 as a demonstration of new energy techniques. 10.1 kW of polycrystalline silicon modules are mounted using a simple technique on a slightly sloping southwest roof. The tilt of the modules is 34°.

Performance and operation

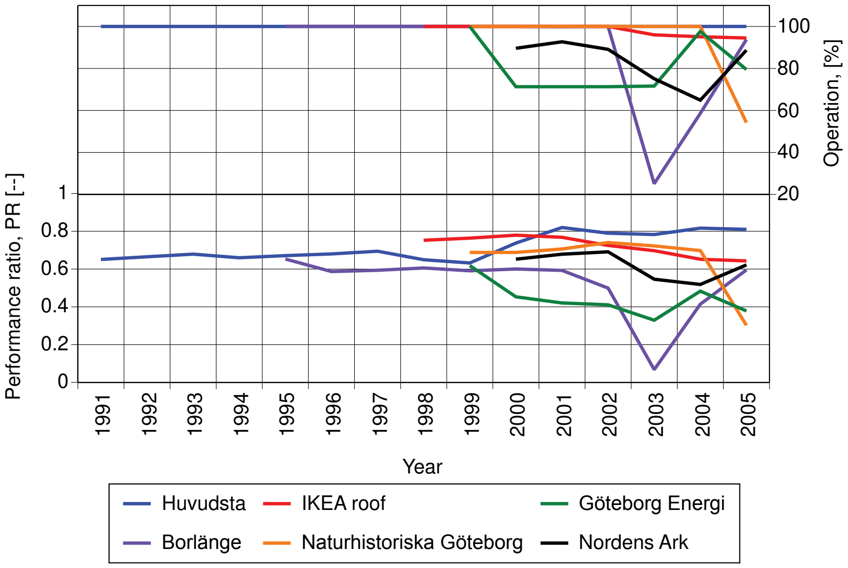


Figure 49, Performance over time for six Swedish grid-connected PV plants.

3.4. Sweden (cont.)

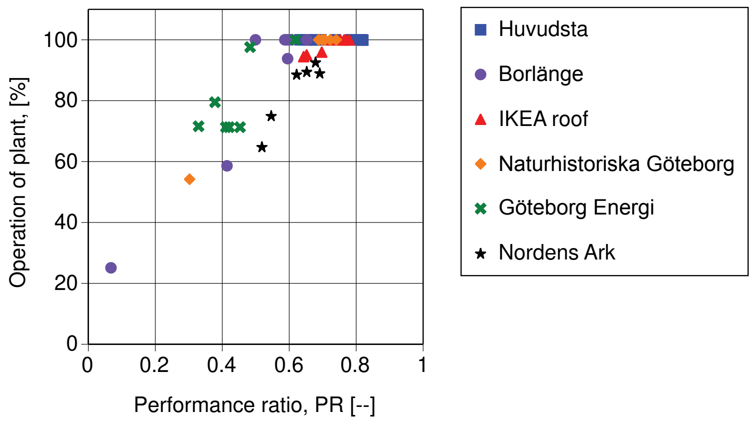


Figure 50, Comparison of the performance to the operation of the plant, six PV plants in Sweden.

In Figure 50, a low performance value in conjunction with a low operation value indicates a system failure. Otherwise a lower performance ratio indicates for example shadowing, snow cover or an overestimated value of the peak power.

Remarks to the six PV systems

Huvudsta

The original inverter was changed in July 2000. The increase in the yield can be attributed to the new inverter. The original inverter was installed 1984 and the technology at that time had an maximum efficiency of approximately 85%. The inverter was still functioning in year 2000 when it was changed to a modern transformerless inverter, resulting in a rise in of the performance ratio from 0.63 in 1999 to 0.82 in 2001 (Figure 49).

Borlänge

The Borlänge plant suffered from an inverter problem. The MPP-tracking function gradually deteriorated in 2002. The inverter was of low quality and the plant operator also had not enough knowledge to operate the system. The system was closed down in April 2003 and a new inverter was installed in June 2004. Now the performance ratio is back to the original level of 0.59 (Figure 49). The reason that the PR is relatively low is because the nominal power of 3.0 kW is most likely overestimated. The actual value of the nominal power still needs to be established.

IKEA roof

The initial performance (PR) of roughly 0.75 was maintained for the first five years. In 2003 one or two of the inverters were taken out of service without being replaced. The 49.5 kW PV plant has a total of 45 inverters and they are not serviced or repaired on a regular bases.

Naturhistoriska Göteborg

After five years one of the two inverters in the system have been out of operation since January 2005. The inverters are of an old technology and in need of replacement. Due to lack of interest from the operator the plant is not sufficiently maintained.

Göteborg Energi

All seven original inverters are working. Problems have occurred with blown fuses that have not been reset over a long period of time (several years in some cases). In the year 2004 the plant was in full operation. The nominal peak power of 6.8 kW is most likely overestimated (4.6 kW would be a better estimate). Due to lack of interest from the operator the plant is not sufficiently maintained.

Nordens Ark

The inverters selected for this system are of low quality. In order to handle the weak grid all the 14 original inverters have been rebuilt at this site. Fuses have blown several times every year for unknown reasons. The performance ratio (PR) of the system in full operation is close to 75%.

3.5. Switzerland

Case study - System cost - Yield data - Performance data

A, Cost data - 11 systems

The utility of the town of Zürich, **ewz** had already started a successful green tariff PV programme in 1995 ("Solarstrom Börse"). By the end of 2007 more than 130 grid-connected PV plants with a total capacity of about 4 500 kW will produce 4 000 MWh of electrical energy. Figure 51 shows the cost data from 11 grid-connected PV systems that were constructed in 2004 and 2005 for the utility **ewz** in Zürich as part its PV programme.

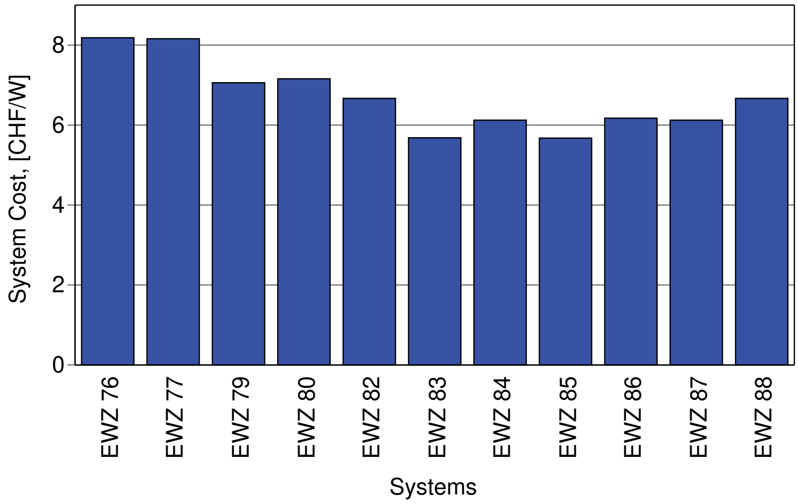


Figure 51, Cost data of 11 PV system from the ewz green tariff PV programme.

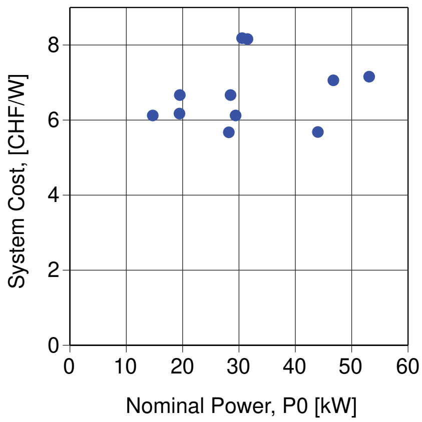


Figure 52, Specific cost in relation to the size of the plant of the 11 PV systems in Figure 51.

The owner of these PV systems are encouraged to keep the total cost as low as possible, therefore many PV systems are mounted on flat roofs. As can be seen from Figure 52 there is no significant change in the unit cost to the size of the PV system.

3.5. Switzerland (cont.)

B, Yield data - 7 systems

Figure 38 shows the annual yield (Yf) from 1999 to 2005 of seven systems in the Utility of Zürich, **ewz** PV programme. The values for the plants EWZ 3, 4, and 5 show a lower yield in the second year of operation. The problem is not known, but has been rectified in the year 2001. The overall variation over time of the annual yield reflects the variation in the irradiation.

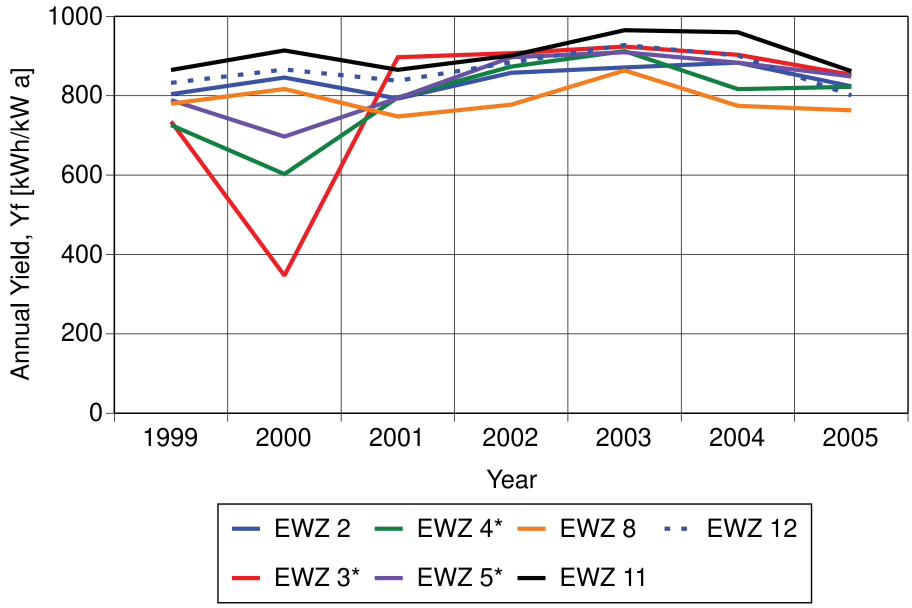


Figure 53, Annual yield (Yf) of 7 PV systems in the Utility of Zürich, ewz PV programme.

C, Performance data - 4 systems

The performance data and the data of the availability in Figure 54 and Figure 55 are from four Swiss systems of different size and in different locations over a period from 1990 to 2003. These datasets were extracted from the IEA PVPS Performance Database.

Domat

The performance data of the 100 kW plant Domat shows some malfunctioning in the first year of operation and again in the years 2000 and 2001. In 2002 the inverter was repaired, but failed again in 2003. Subsequently the inverter was replaced with two 50 kW inverters. The plant is in full operation since October 2005.

Marzili

The 22 kW plant Marzili performed well over the period monitored. The inverter was down for a short period in 1999. There is a slight degradation over time, which may be due to dirt deposits on the glass surface of the modules. In 1996 the modules were cleaned.

Herisau

The 6 kW plant Herisau had a low output for the first two years of operation. This was due to faulty wiring and not because of an inverter failure (see Figure 39). The system was down for a short period in 1999.

3.5. Switzerland (cont.)

Joch

Built in 1993 his façade plant is located at the Jungfraujoch in the Swiss Alps at 3 454 meters altitude and has, because of the high albedo, an annual yield (Yf) of more than 1 400 kWh/kW. The 1.13 kW alpine façade system Joch performed well over the time monitored. Due to snow or ice cover in 2001 there was a slight drop in the performance. The annual mean module temperature is below 24 °C and the highest yield was 1 537 kWh/kW in the year 2005.

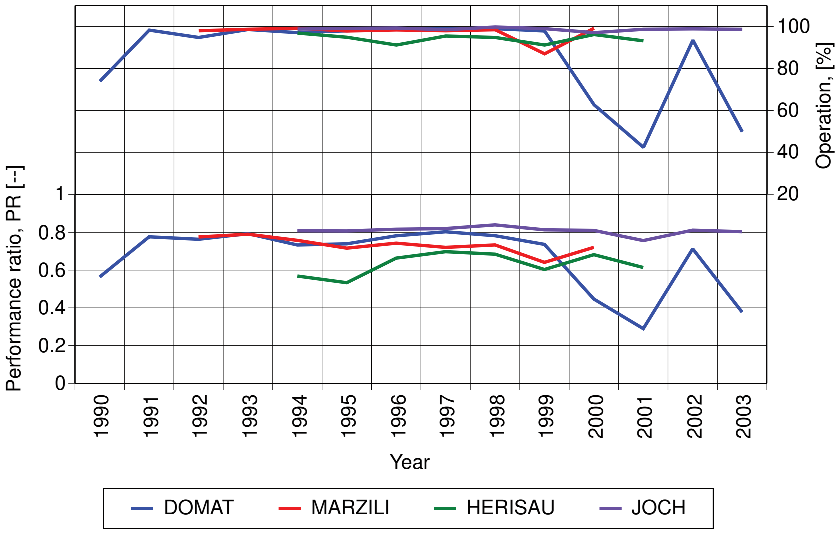


Figure 54, Operation and performance over time, four Swiss PV plants.

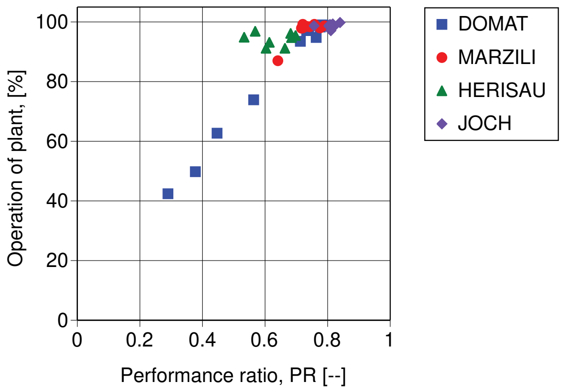


Figure 55, Comparison of the performance to the operation of the plant, four Swiss PV plants.

In Figure 55, a low performance value in conjunction with a low operation value indicates a system failure (Domat). Otherwise a lower PR only indicates a fault in the wiring, shadowing or snow cover (Herisau).

3.6. United Kingdom

Case study - System cost - Yield data - Performance data

For this case study data from three residential grid-connected PV projects have been chosen. Each project has a number of identical PV systems from the UK PV Domestic Field Trial (PVDFT). The cost data represent the specific system cost of all the systems of the project. For the yield and performance data, data from an individual system from each project was chosen.

Campkin Court

Built in 1966 Campkin Court is owned by the Cambridge Housing Society. It is a three-storey brick building with a flat roof and is divided into 23 flats. The building has been refurbished, incorporating energy saving measures such as roof resurfacing and insulation in 2004. It is hoped that these energy saving measures and individual PV systems will help to reduce fuel poverty for the low income residents. The building has a large flat roof, with few obstructions, making it suitable for PV installation.

A PV system of 184 Kyocera modules (southwest orientation) is installed on the roof (23.8 m by 14.4 m), giving a total capacity of 22.1 kW. The modules are mounted using the SolarMarkt AluStand system, which is specifically designed for supporting tilted modules on flat roofs. Detailed structural engineering calculations were carried out to simulate the worst case of wind uplift expected at the site. This resulted in the stands being screwed to specified concrete slabs as shown in the picture below. Due to the PV frame being mounted within the outline of the flat roofed building it is not visible from street level.

- 23 Apartments
- renovated in 2004
- 22.1 kW installed capacity
- Kyocera polycrystalline 120W modules
- Flat roof mounted using SolarMarkt AluStand
- Average annual yield – 744 kWh/kW
- Average annual savings – 7.1 tonnes CO_2
- Average performance (PR) – 0.69
- Average cost of PV energy - 0.298 GBP per kWh

System Costs

The average electricity cost (excluding management costs for the project team and monitoring costs specific to the Domestic Field Trial) over a predicted 25 year lifetime is estimated to be 0.298 GBP per kWh.

It has been calculated that over the first year of operation 58% of the electricity consumed was generated by the PV systems.

Lessons Learnt

Overall the project team thought the installation went much smother than expected. Due to the Domestic Field Trial project requirements, it was necessary to install inverters within each flat. It was felt that installing three larger ones for the whole site instead would have been a neater solution. This would have enabled them to incorporate the Balance of System (BOS) components (i.e. isolator switches, displays) into the existing plant room, rather than having to build dedicated cupboards within the already small entrance halls. It is clear that the cramped working conditions were not ideal and this resulted in increased labour costs.

3.6. United Kingdom (cont.)

The AluStand system is specifically designed for supporting tilted modules on flat roofs. Essentially the system uses horizontal rails of AluVer 41 secured to 150mm concrete slabs, each 600mm square that form ballast on the flat roof. The PV array is arranged into three banks approximately 2.5m apart. The slabs had to be produced on site and lifted onto the roof. At a rate of moulding 15 slabs a day, this turned out to be a quite time consuming task.

It was noted that there were alternative module frame systems available that may, in hindsight, have been even simpler to install. However, the installation was completed in such a way as to cause little disruption to the tenants.

For safety reasons a guard rail had to be fitted around the edge of the roof, which means that a number of modules along the front edge are shaded, reducing overall output by approximately 5%.

Conclusion

Overall the project team thought the installation went much smother than expected. Occupants were surveyed and found to be pleased with their system, even if their knowledge of the electricity and carbon savings was patchy. The installation had no impact on the aesthetics of the building as the array was not visible at street level.

Pinehurst, Liverpool

This housing estate in Liverpool has undergone refurbishment as part of a regeneration process within the area. Plus Housing Group therefore decided to install roof integrated PV on the new build properties benefiting low income families.

Within the estate's renovation programme, nine of the 55 houses were deemed to be beyond economic repair. Hence the decision was taken to build nine new properties incorporating photovoltaics in 2002. The Redland PV700 tile system was chosen because the rest of the estate uses conventional Redland tiles. There are 40 PV tiles (1.4 kW orientated 55° W of S) on five smaller houses and 48 tiles (1.68 kW orientated 24° W of S) on four larger ones. One PV tile displaces four conventional tiles.

All roofs are at an angle of 35°. The PV tiles are designed to fit in with the conventional tiles' horizontal lines resulting in flushness with the roof. Also the contrast in colour between the red tiles and blue PV modules was deliberate. The overall result is an uncluttered roof with an eye-catching PV system.

- 9 new build single family houses
- built in 2002
- 14 kW installed capacity
- Redland PV700 tile system (BP Solar SRT 35 laminates), roof integrated
- Average annual yield 777 kWh/kW (best 845 kWh/kW)
- Average annual savings 4.7 tonnes CO_2
- Average performance (PR) – 0.72 (best 0.80)
- Average cost of PV energy - 0.318 GBP per kWh

3.6. United Kingdom (cont.)

System Costs

The average electricity cost (excluding management costs for the project team and monitoring costs specific to the Domestic Field Trial) over a predicted 25 year lifetime is estimated to be 0.318 GBP per kWh.

Lessons Learnt

The PV installation was completed by conventional roofing contractors who received initial training by the PV contractor in the handling and inter-connecting of the modules.

Installing the mounting system was generally straightforward. Once the battening was completed the PV tiles were installed in a two stage process. First, the proprietary mounting system was attached to the battens allowing the plastic trays to be fitted. These mesh with the conventional tiles, ensuring weather tightness of the assembly and also ventilation behind the modules. In the second stage, the modules were connected together electrically and clipped into place. One concern with this system, was that access to failed panels or to connectors for testing was only possible by removing a column of panels above the panel in question, from the top down. This could result in some onerous maintenance work if lower panels were to require checking or replacement.

There were some minor problems with the PV-roof integration. For example, on the first completed roof, the roofer placed the felt between the counter battens and battens instead of underneath both, thus reducing the ventilation air gap. Emphasising the correct sequence of the counter battening here is crucial as this will be unusual practice to roofers.

Visual integration of the roof lights (roof windows) was also less straight forward than anticipated. The conventional tiles had to be cut to fill-in the gap between the roof lights and the PV modules, which are of fixed length. On overall visual inspection, it was clear that the lengths of the short tiles were slightly unequal and all that could be done was to make the shapes around the roof lights look as balanced as possible.

The roofers made the electrical connections between the modules as they progressed, using Multi-Contact (MC) connectors, which are touch-safe. The connections were made as straightforward as possible by installing the modules in columns to form a string from bottom to top. The strings comprised ten or twelve modules depending on the site. The PV contractor returned to test the continuity of the strings after the modules were installed and before the scaffolding came down.

The PV systems on this site show good and reliable performance, but analysis showed that the smaller systems gave a reduced output in the winter months compared to the larger systems. This was traced to the operation of the inverter, where low irradiance levels caused the voltage of the strings on the small systems to fall below the input range for the inverter. In turn, this led to a problem with tracking of the maximum power point of the PV array and hence reduced system output. This behaviour is also related to a relatively high grid voltage at this site, which affects the input voltage range of the inverter.

The ability to compare two different system sizes on this site has allowed the identification of this issue and will be addressed in the system design recommendations arising from the Field Trial, which will suggest an additional allowance on the inverter string voltage within the system design.

Conclusion

Overall the Project Team is very positive about the PV installation and pleased that it has provided the Plus Housing Group with its first portfolio of PV properties. The housing group felt that the key to its success has been good teamwork and a positive approach from every team member including the main building contractor. This was very important especially in regards to problem solving and being able to deal with the few that did occur effectively and efficiently.

3.6. United Kingdom (cont.)

Corncroft, Nottingham

This is an example of PV installations in a large social housing scheme in Nottingham. The buildings were designed to be low energy, with features such as low 'e' glass and very high levels of insulation. The development consists of new build bungalows for elderly and disabled occupants.

This development uses PV laminates integrated into the roof with the PV installers' bespoke RIS (roof integrated system) mounting system. There is a total of 22 systems, comprising 34 kW (400 laminates), 20 units were fitted with 1.53 kW with two slightly larger systems at 1.7 kW. The array tilt is 60 degrees and orientation is SSW.

- 22 new build bungalows
- built 2001
- 34 kW installed capacity
- BP Solar BP 585 laminates, roof integrated
- Average annual yield - 753kWh/kW
- Average annual savings - 11.1 tonnes CO_2
- Average performance (PR) – 0.725
- Average cost of PV energy - 0.262 GBP per kWh

System Costs

The average electricity cost (excluding management costs for the project team and monitoring costs specific to the Domestic Field Trial) over a predicted 25 year lifetime is estimated to be 0.262 GBP per kWh.

Lessons Learnt

During installation one PV module broke but otherwise no other technical problems occurred on site. There were, however, some financial issues as additional scaffolding costs were incurred due to building site delays, as well as some extra costs for monitoring equipment.

Overall, it was felt that good communication between the various parties was essential for the success of a project, and the benefits of completing the installation before tenants arrive in a new build building were seen.

It was noticed while analysing some initial data that part of one array had a reduced output. A visit revealed that a television aerial on one roof was ideally positioned for birds to perch on allowing them to soil the PV system underneath. The aerial was moved and consequently the array output returned to expected levels.

Analysis of tenant surveys shows that half of the tenants said that their electricity bills were lower, associating this with PV systems. However when questioned about how much money and carbon dioxide the systems are saving, many residents were unsure. Although they were not at the time on a green tariff, i.e. being paid for any export, many tenants have started to run appliances during times when the PV system is likely to be operating. This change in daily routine is an interesting observation and is most probably the result of good dissemination of information to the tenants.

Initial discussions with electricity suppliers about an export tariff for the surplus PV electricity turned out to be fruitless. However, discussions resumed at a later date, and with pressure from the electricity regulator, it is expected that a reasonable agreement should be possible. This problem does not affect countries with a feed-in tariff, where a rate for exported electricity is guaranteed.

3.6. United Kingdom (cont.)

Conclusion

The project team felt that their installation has been very successful. It has provided comfortable, energy efficient and affordable homes for the elderly. The majority of tenants were very positive about the PV system, realising savings with their electricity bills. Despite the problems that were encountered through the project, there is a high level of tenant satisfaction with the systems. This is accredited to the smooth and swift way in which the problems were resolved. The Housing Association is very pleased with the project, and as a result is working on a tile integrated PV system on another site.

A, Cost data - 3 projects

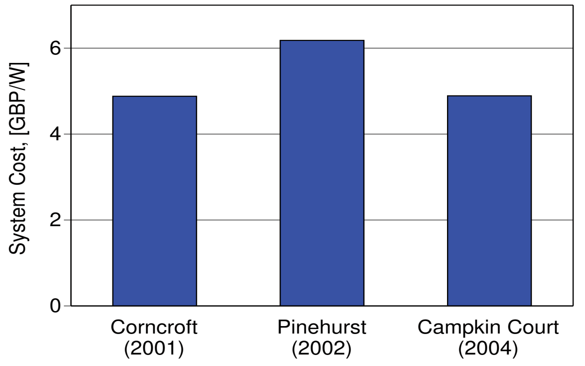


Figure 56, Overall specific cost data from 3 projects.

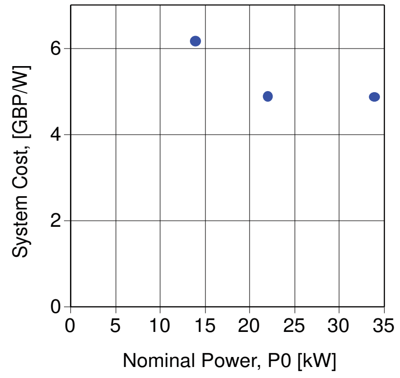


Figure 57, Overall specific cost data vs. nominal power.

For the cost analysis data three grid-connected systems have been chosen from the UK PV Domestic Field Trial (PVDFT).

B, Annual yield

The average annual yield for each of the projects is:

Campkin Court	744 kWh/kW
Pinehurst	777 kWh/kW
Corncroft	753 kWh/kW

C, Performance over time

Figure 58 shows the Performance over time of five PV system from each project.

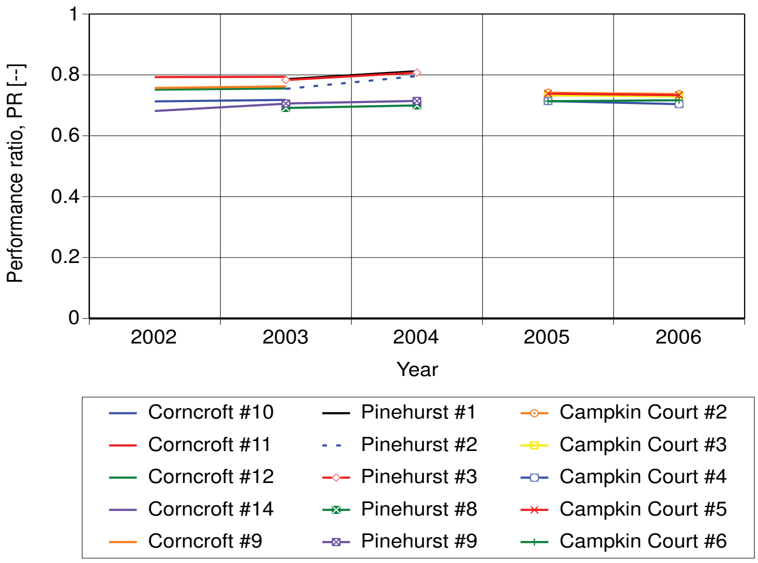


Figure 58, Performance over Time.

4. Conclusions

As it is within the scope of Task 2 to disseminate results of PV system performance to the target groups, part one of this report is an addition to the IEA PVPS Country Report [3] and gives a more detailed view of system cost over time. In part two the grid-connected PV systems from the 2007 edition of the IEA PVPS Database [1] are analysed. The PV systems analysed are mainly located in central Europe, Japan and the United States. This report is therefore only representative with respect to these locations. In part three some members of Task 2 contributed a case study from PV systems in their country.

The sample analysed shows a trend towards lower system costs and higher performance (PR) for newer PV systems.

System costs

There is a wide variation in the costs for a grid-connected PV system. The system costs depend on the location, size, type of components available, type of mounting and level of integration among other factors. As shown in Table 9 a modern grid-connected PV system of today would cost 62.5% less than an average PV system built in 1992.

Table 9, 2005 “Best Case” grid-connected PV system compared to an average system built in 1991 or 1992.

Typical system	1991	1992	2005 best case	
Nominal module efficiency (ηA0)	11.6		14	%
Operational inverter efficiency (ηI)	89		94	%
Outage (O)	0.03		0	
Performance ratio (PR)	0.64		0.84	
Overall PV plant efficiency (ηtot)	7.4		11.8	%
Improvement	100		158	%
System cost		16	6	USD/W
Cost		100	62.5	%

Performance

The variation of the performance ratio for each year is the result of the variation in the inverter efficiency and the availability of the PV system. A state of the art grid-connected PV has an improved annual plant efficiency of plus 58% compared to an average PV system built in 1991(Table 9). A modern roof top mounted grid-connected PV system in central Europe produces 1 000 kWh/kW per year or 1800 kWh/kW in Israel or Mexico.

Reliability

The Japanese study shows that half of the reported failures occur in the early stages of the operational time of a PV plant. This is also reflected in the case study from Switzerland, where three out of seven systems showed some failures in the second year of operation (Annual yield over time). On the other hand another Swiss system, after ten years of successful operation the inverter came to the end of its life span and had to be replaced (Domat). This is also shown in an example from Sweden, where the inverter had to be replaced after seven years of operation (Borlänge). These are some examples from older systems. As shown in this report newer systems tend to be more reliable and specially since the introduction of feed in tariffs in some countries, better maintained. The Japanese study also shows that early failures are covered by a warranty and the repairs and the loss of energy are usually compensated for by the manufacturer.

5. Recommendations

An important finding of this survey is that the performance ratio of PV systems has increased over time, partly because of an increase in the operational inverter efficiency. In the survey carried out, however, the reporting on outages and the type of failure is minimal. Accurate reporting on failures of PV systems as part of the monitoring would greatly contribute to the understanding of long term behaviour of PV systems. Without such reporting one can only guess that the performance ratio has also increased because of an increased reliability of PV systems over time.

Performance, reliability and cost data of PV systems are most important for a broad PV implementation and dissemination strategy in future. While the number of installed PV systems grows very rapidly in several countries (e.g. in Germany due to the feed-in tariff), the number of available PV systems, which are well monitored, seems to decrease at the same time. It is due to this lack of sufficient sample size that the results given in this report may not always be representative for the relevant country. There is an essential need for reliable and long-term information on the economic and technical performance of PV systems.

The authors wish to thank the colleagues of IEA PVPS Task 2 for providing the case study of their countries including the data for the diagrams and the photographs for this report.

6. References and Task 2 publications

Database

[1] IEA PVPS Task 2,
Performance Database, Version 1.19, Edition: May 2007.
For download and interactive web-application: http://www.iea-pvps-task2.org/database/

Reports

[2] IEA PVPS Task 1,
TRENDS IN PHOTOVOLTAIC APPLICATIONS
in selected IEA countries between 1992 and 2005,
Report IEA-PVPS T1-15:2006.

[3] IEA PVPS Task 2,
Country Reports on PV System Performance,
Report IEA-PVPS T2-05:2004.

[4] IEA PVPS Task 2,
The Availability of Irradiation Data,
Report IEA-PVPS T2-04:2004

[5] IEA PVPS Task 2,
Operational Performance, Reliability and Promotion of Photovoltaic Systems,
Report IEA-PVPS T2-03:2002

[6] IEA PVPS Task 2,
Analysis of Photovoltaic Systems,
Report IEA-PVPS T2-01:2000.

Publications

[7] S. Castello,
Training experience in Italy,
21st European Photovoltaic Solar Energy Conference and Exhibition,
September 2006, Dresden, Germany.

[8] S. Mau, U. Jahn,
PERFORMANCE ANALYSIS OF GRID-CONNECTED PV SYSTEMS,
21st European Photovoltaic Solar Energy Conference and Exhibition,
September 2006, Dresden, Germany.

[9] U. Jahn, Th. Nordmann, L. Clavadetscher,
PERFORMANCE OF GRID-CONNECTED PHOTOVOLTAIC SYSTEMS: OVERVIEW OF PVPS TASK 2 RESULTS,
20th European Photovoltaic Solar Energy Conference and Exhibition,
June 2005, Barcelona, Spain.

[10] Th. Nordmann,
FEED-IN TARIFFS AND BIPV - CAN WE MAKE A WINNING TEAM?
20th European Photovoltaic Solar Energy Conference and Exhibition,
June 2005, Barcelona, Spain.

[11] U. Jahn, W. Nasse, Th. Nordmann, L. Clavadetscher, D. Mayer,
ACHIEVEMENTS OF TASK 2 OF IEA PV POWER SYSTEMS PROGRAMME: FINAL RESULTS ON PV SYSTEM PERFORMANCE,
19th European Photovoltaic Solar Energy Conference and Exhibition,
June 2004, Paris, France.

[12] Thomas Nordmann, Ulrike Jahn, Wolfgang Nasse,
Performance of PV systems under real conditions at the European Workshop on Life Cycle Analysis and Recycling of Solar Modules,
The Waste Challenge,
March 2004, Brussels.

[13] D. Mayer, M. Heidenreich,
PERFORMANCE ANALYSIS OF STAND ALONE PV SYSTEMS FROM A RATIONAL USE OF ENERGY POINT OF VIEW,
3rd World Conference on Photovoltaic Energy Conversion,
May 2003, Osaka, Japan.

[14] T. Nordmann,
SUBSIDIES VERSUS RATE BASED INCENTIVES; FOR TECHNOLOGY-, ECONOMICAL- AND MARKET-DEVELOPMENT OF PV. THE EUROPEAN EXPERIENCE,
3rd World Conference on Photovoltaic Energy Conversion,
May 2003, Osaka, Japan.

[15] T. Nordmann, L. Clavadetscher,
UNDERSTANDING TEMPERATURE EFFECTS ON PV SYSTEM PERFORMANCE,
3rd World Conference on Photovoltaic Energy Conversion,
May 2003, Osaka, Japan.

[16] U. Jahn, W. Nasse;
PERFORMANCE ANALYSIS AND RELIABILITY OF GRID-CONNECTED PV SYSTEMS IN IEA COUNTRIES,
3rd World Conference on Photovoltaic Energy Conversion,
May 2003, Osaka, Japan.

References

[17] International Electrotechnical Commission (IEC),
Photovoltaic System Performance Monitoring - Guidelines for Measurement, Data Exchange and Analysis,
Standard IEC 61724.

[18] Guidelines for the Assessment of Photovoltaic Plants,
Document A, Photovoltaic System Monitoring, Issue 4.2, June 1993,
Document B, Analysis and Presentation of Monitoring Data, Issue 4.1, June 1993,
JRC, E.S.A.S. I-21020 Ispra Italy.

Annex

Annex A - Overview of recorded and derived parameters

Table 10, Recorded and derived parameters for performance evaluation and normalised representation.

Parameter	Symbol	Equation	Unit
Plant data			
Nominal power	P_0	at STC	W
Array area	A_A		m^2
STC reference inplane Irradiance	G_{STC}	1 000	W
Nominal array efficiency at STC	η_{A0}	$P_0 / (A_A \bullet G_{STC})$	—
Recorded parameters			
Irradiation	H_I		kWh / m^2
Ambient temperature	T_{am}		°C
Module temperature	T_m		°C
Non-availability to load	t_{NAV}		h
Energy from PV array	E_A		kWh
Potential energy from PV array	E_{pot}		kWh
Energy to inverter	E_{II}		kWh
Energy from inverter	E_{IO}		kWh
Energy from backup	E_{BU}		kWh
Net energy to storage	E_{TS}		kWh
Net energy from storage	E_{FS}		kWh
Energy to utility grid	E_{TU}		kWh
Energy from utility grid	E_{FU}		kWh
Derived parameters			
Energy to all loads	E_L	$E_{lac} + E_{ldc}$	kWh
Total input energy	E_{in}	$E_A + E_{BU} + E_{FU} + E_{FS}$	kWh
Useful energy from system	E_{use}	$E_L + E_{TU}$	kWh
PV array fraction	F_A	E_A / E_{in}	—
PV contribution of Euse	$E_{use,PV}$	$F_A \bullet E_{use}$	kWh
Outage fraction	O	t_{NAV} / τ	—
Operation of plant	1 - O	1 - O	— or %
Reference Yield	Y_r	$\int_{day} G_I \, dt / G_{STC}$	kWh / kW
Array Yield	Y_A	$E_{A,d} / P_0$	kWh / kW
Final Yield	Y_f	$E_{use,PV,d} / P_0$	kWh / kW
Array capture losses	L_c	$Y_r - Y_A$	kWh / kW
System losses	L_s	$Y_A - Y_f$	kWh / kW
Performance ratio	PR	Y_f / Y_r	— or %
Matching factor	MF	$PR \cdot F_A$	—
Production factor	PF	Y_A / Y_r	—
Usage factor	UF	E_A / E_{pot}	—
Overall PV plant efficiency	η_{tot}	$E_{use,PV,\tau} / \int_\tau G_I \cdot A_A \, dt$	%
Mean array efficiency	$\eta_{A,mean}$	$E_A / \int_\tau G_I \cdot A_A \, dt$	%
Efficiency of the inverter	η_I	E_{IO} / E_{II}	%
Mean module temperature	$T_{m,mean}$	$\sum (G_I \cdot T_m) / \sum G_I$	°C
Annual irradiation, in plane of array	$H_{I,y}$	$\int_{year} G_I \, dt$	kWh / m^2
Annual reference yield	$Y_{r,y}$	$\int_{year} G_I \, dt / G_{STC}$	kWh / kW
Annual array yield	$Y_{A,y}$	$E_{A,y} / P_0$	kWh / kW
Annual final yield	$Y_{f,y}$	$E_{use,PV,y} / P_0$	kWh / kW

Annex B - Glossary of terms and abbreviations

AIST	National Institute of Advanced Industrial Science and Technology, Japan
BFE	Bundesamt für Energie (Swiss Federal Office of Energy)
BIPV	Building integrated photovoltaics
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BOS	Balance of systems (cost of components other than modules and inverter)
BRE Environment	Building Research Establishment Ltd., United Kingdom
CPI	Consumer price index
EPIA	European Photovoltaic Industry Association
EU	European Union
EWZ	Elektrizitätswerk der Stadt Zürich (Municipal Utility of Zurich)
FL	State of Florida, USA
FY	Fiscal year
GC-BIPV	Grid-connected building-integrated PV
GCS	Grid-connected systems
HExR	Historical exchange rate
IEA	International Energy Agency
IEC	International Electrotechnical Commission
JET	Japan Electrical Safety & Environment Technology Laboratories
KW	Kraftwerk (Power station)
MW	Megawatt
NEDO	New Energy and Industrial Technology Development Organization (Japan)
OECD	Organisation for Economic Co-operation and Development
PV	Photovoltaics
PVDFT	PV Domestic Field Trial, United Kingdom
PVPS	Photovoltaic Power Systems Programme
R&D	Research & development
S	South
SAS	Stand-alone systems
SSW	South-southwest
W	West
ZAE Bayern	Bavarian Center for Applied Energy Research, Germany

Annex C - 2005 Exchange rates

	Japan	Sweden	Switzerland	United Kingdom	United States	EURO
Country code	JPN	SWE	CHE	GBR	USA	
Currency code	JPY	SEK	CHF	GBP	USD	EUR
Exchange rate (1 USD =)	110.1	7.47	1.25	0.55	1	0.81