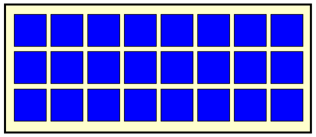
PV system

Components of a PV system

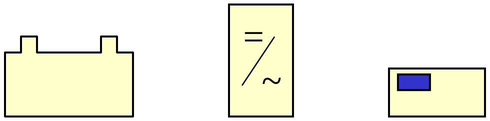
PV device

- cell, panel, array
- dc electricity

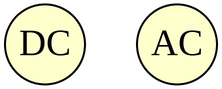


Balance of system (BOS)

- mounting structures
- storage devices
- power conditioners

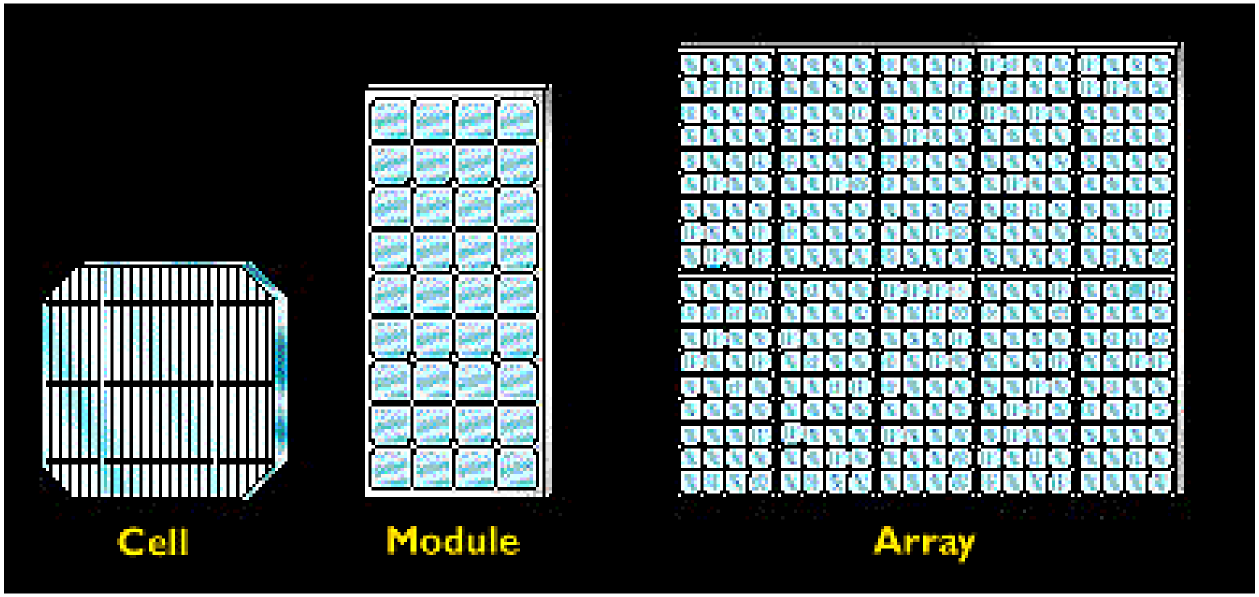


Load (dc or ac electricity)



PV system

From a solar cell to an array: modularity



Cell (c-Si 10×10 cm^2 η=15% P=1.5W_p V=0.5V I=3A)

Solar panel (36 c-Si cells P=54W_p I=3A V=18V)

Solar array

Specifications of PV modules

Module Type		Shell SM50-H	Shell ST40	Kaneka PLE	First Solar FS-50
Solar cell type		Mono c-Si	CIS	a-Si:H	CdTe
Rated power P_{max}	[W_p]	50	40	50	52
Rated current I_{MPP}	[A]	3.15		3.03	0.80
Rated voltage V_{MPP}	[V]	15.9	16.6	16.5	63
Shirt circuit current I_{SC}	[A]	3.40	2.68	3.65	0.95
Open circuit voltage V_{OC}	[V]	19.8	23.3	23.0	88
Configuration	[V]	12	12	12	12
Cells per module		33			
Dimensions	[mm]	1219x329	1293x328	952x920	1200x600
Warranty	[years]	25	10	10	20
		www.shell.com	www.shell.com	www.pv.kaneka.co.jp	www.firstsolar.com

c-Si PV module

Electrical parameters
(1000W/m^2, 25 °C, AM1.5)

Rated power	150 W_p
Cells per module	72
Cell dimension	12.5×12.5 cm

Configuration	12/24 V
Rated current, I_{MPP}	8.8/4.4 A
Rated voltage, V_{MPP}	17.0/34.0 V
Short circuit current, I_{SC}	9.4/4.7 A
Open circuit voltage, V_{OC}	21.5/43.0 V

SolarWorld SW 150 module

Components of a PV system

Storage devices (batteries)

Advantages:

- reliable energy source available at night or on cloudy days

Drawbacks:

- decrease the efficiency of the PV system
- about 80% of the energy channeled into them can be reclaimed
- add to the expense of the overall system
- replacement every five to ten years
- floor space, safety concerns, periodic maintenance

Components of a PV system

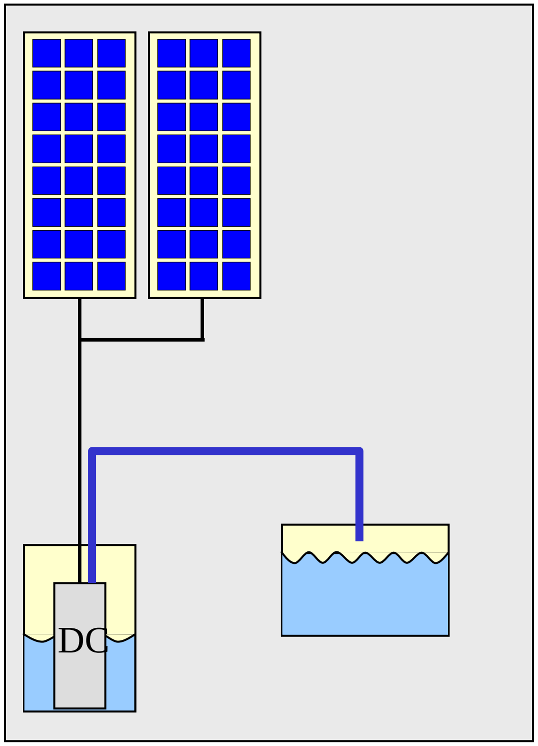
Power conditioners (inverters)

- Limit current and voltage to maximize power output
- Convert dc power to ac power
- Match the converted ac electricity to a utility's electrical network
- Safeguard the utility network system and its personnel from possible harm during repairs

Types of PV systems

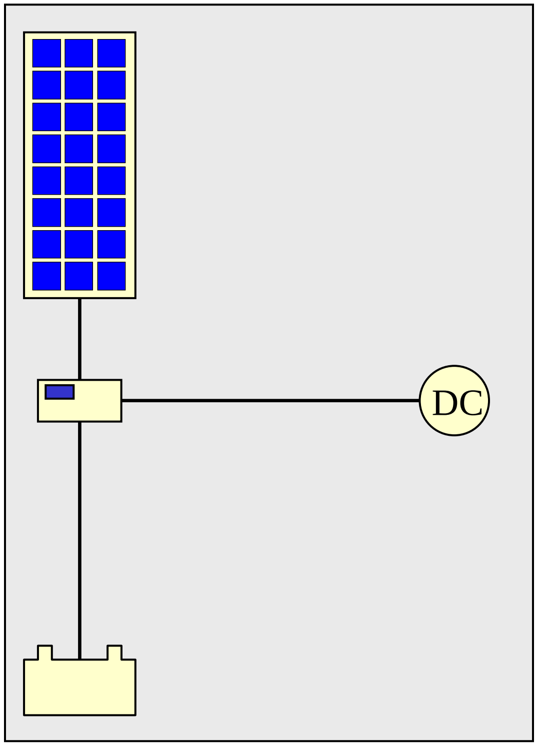
Simple DC

- direct powering of the load
- no energy storage



Small DC

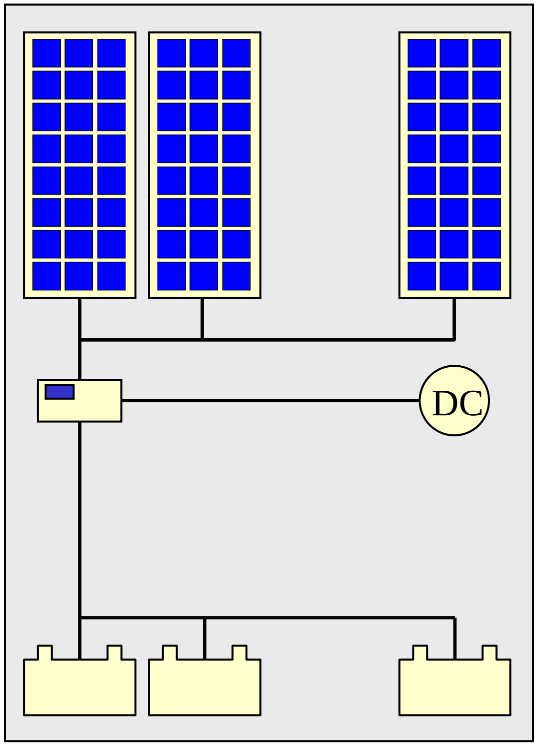
- home and recreational uses



Types of PV systems

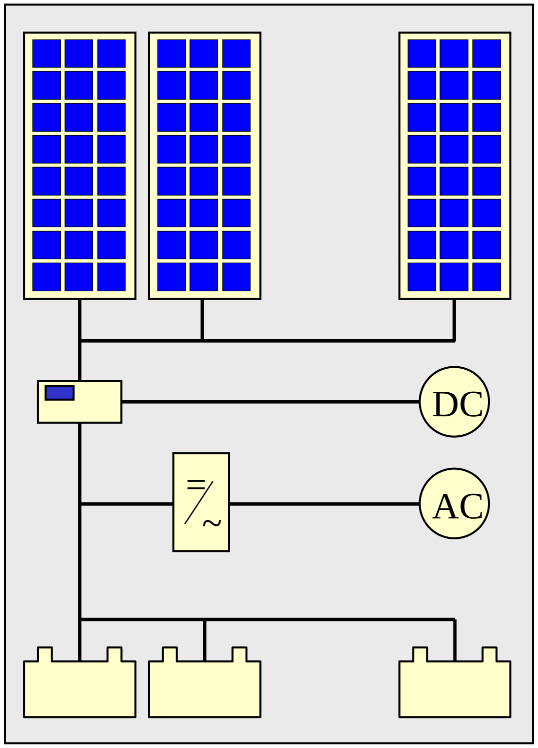
Large DC

- home and recreational uses
- and industrial applications



Large AC/DC

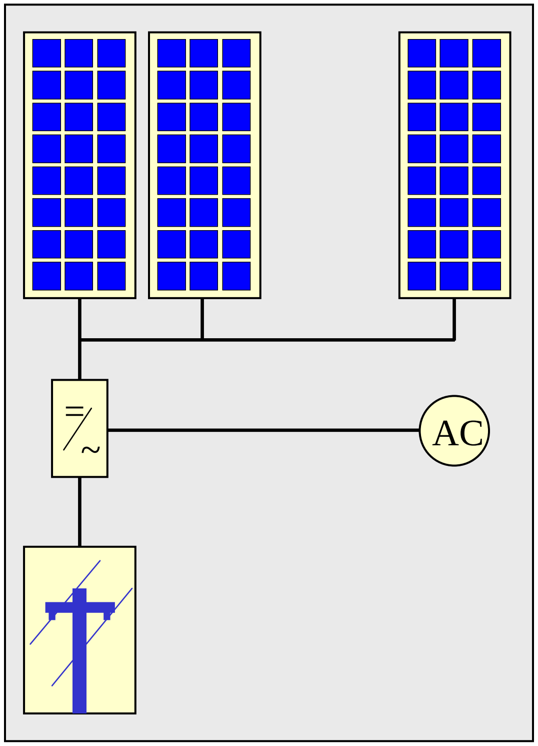
- both AC and DC loads used



Types of PV systems

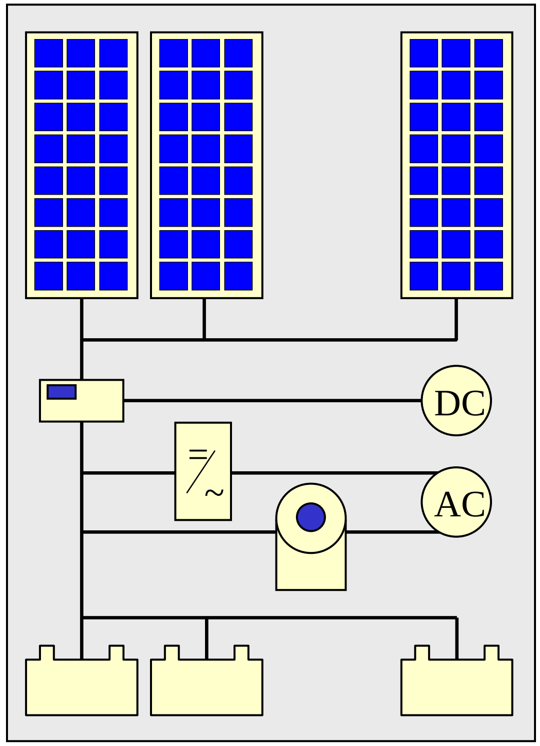
Utility grid-connected

- no on-site energy storage



Hybrid system

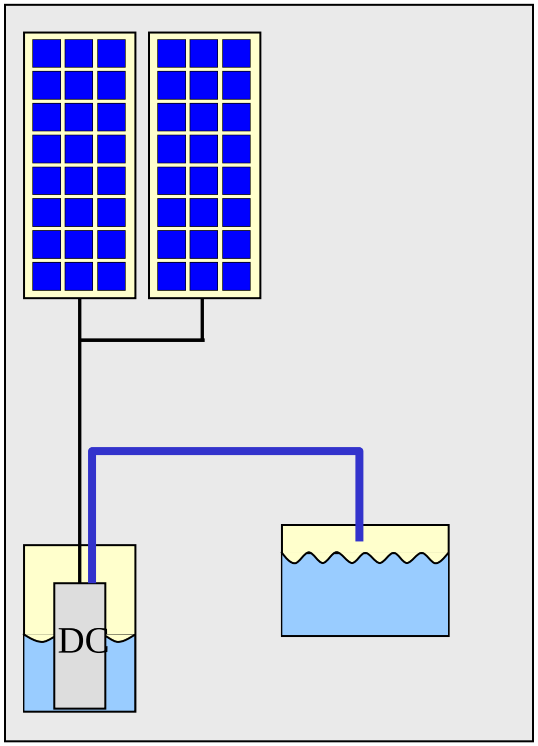
- supplemental generator



Off-grid PV system

Off-grid simple DC PV system

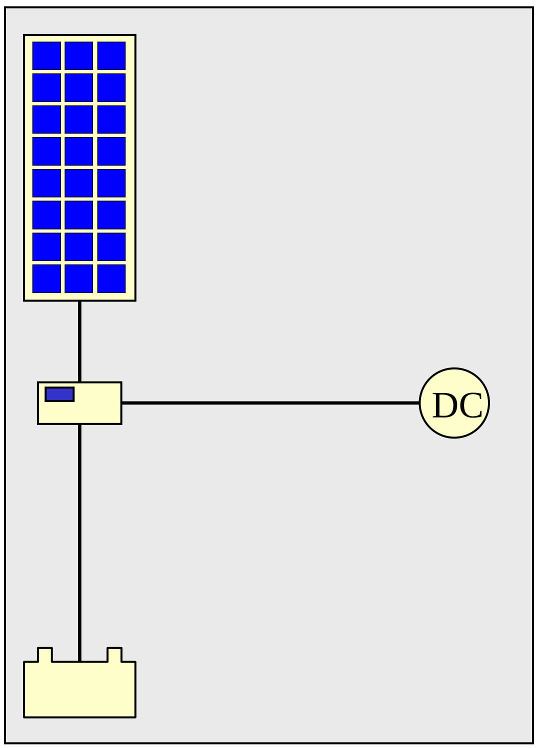
- direct powering of the load
- no energy storage



Off-grid PV system

Off-grid small DC PV system

- home and recreational uses

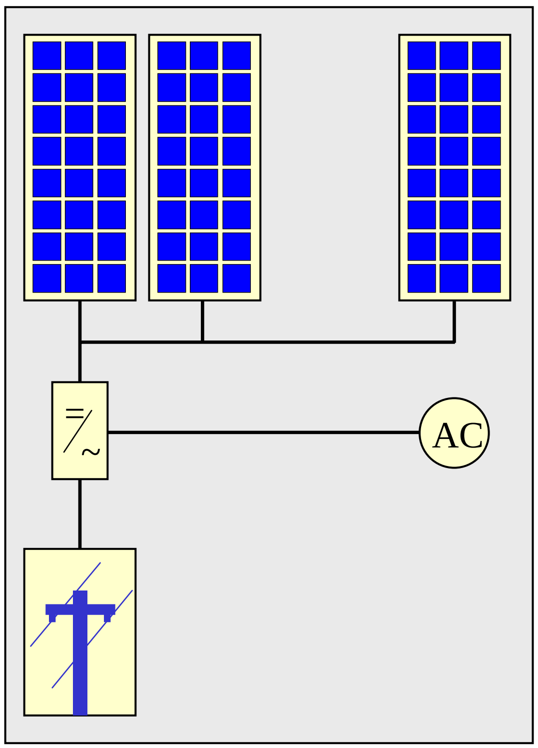


World Solar Car Race 2005
The winner: Nuna 3

Grid-connected PV system

Grid-connected large PV system (1 MW_p a-Si PV solar power plant)

Components:

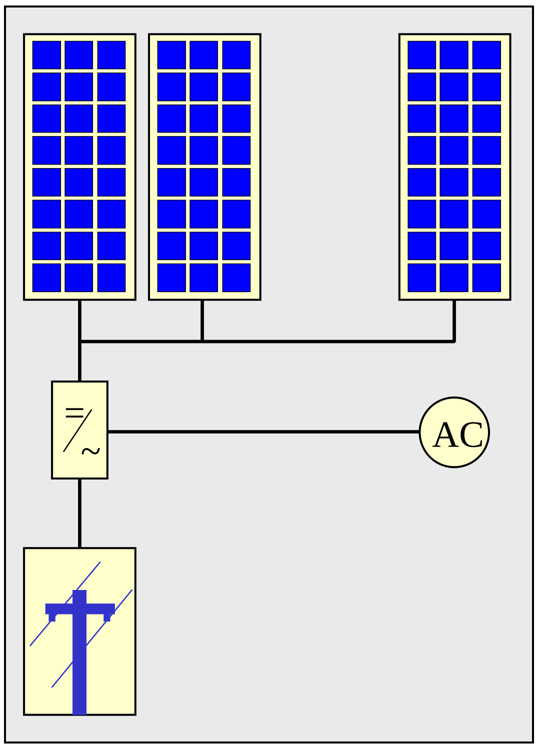


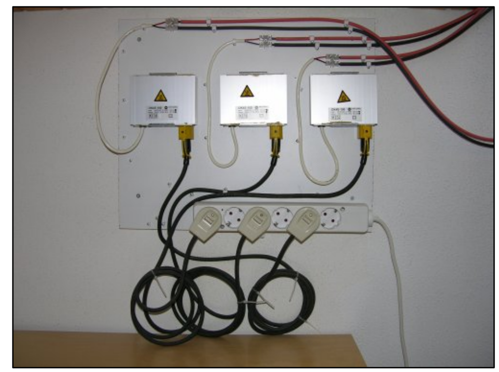
Buttenwiesen in the suburbs of Munich

Grid connected PV system

Grid-connected home system (3×150 W_p system)

Components:



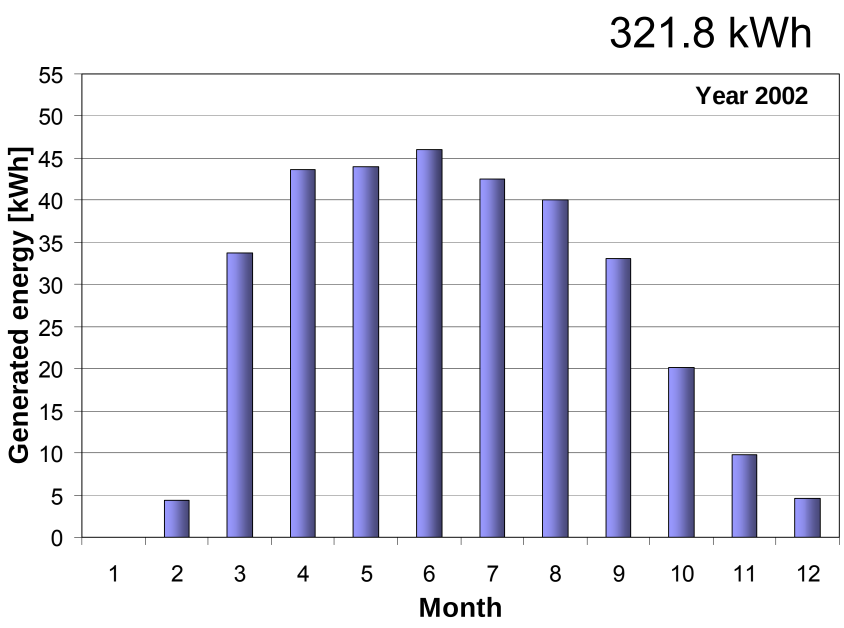


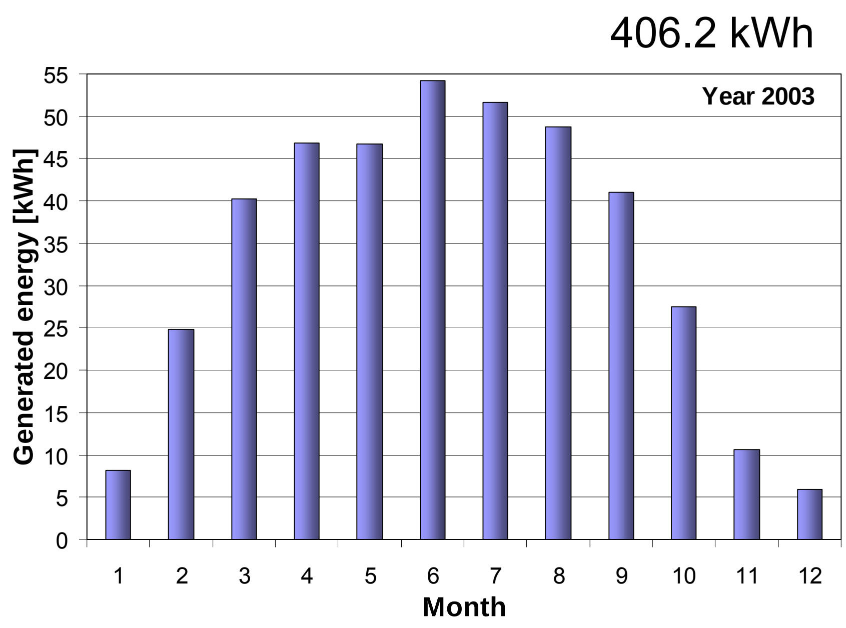
M. Zeman, Delft

Grid connected PV system

Grid-connected home system (3×150 W_p system)

Performance:





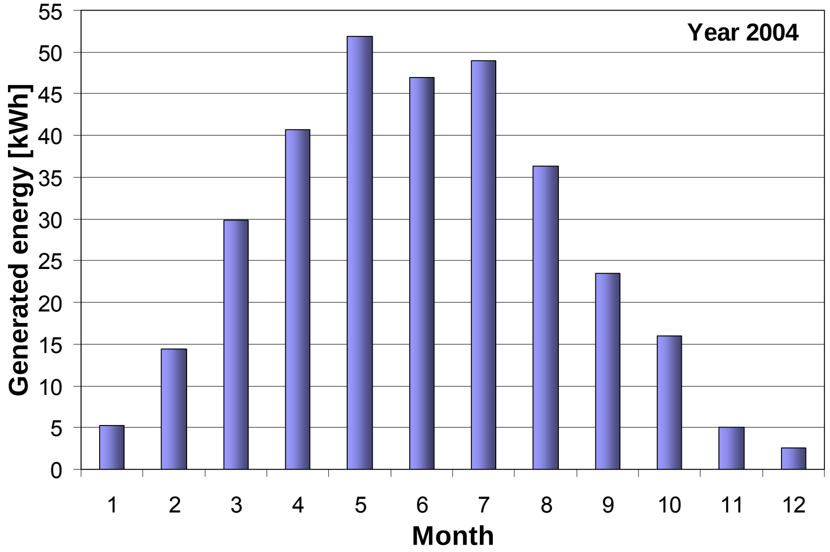
M. Zeman, Delft

Grid connected PV system

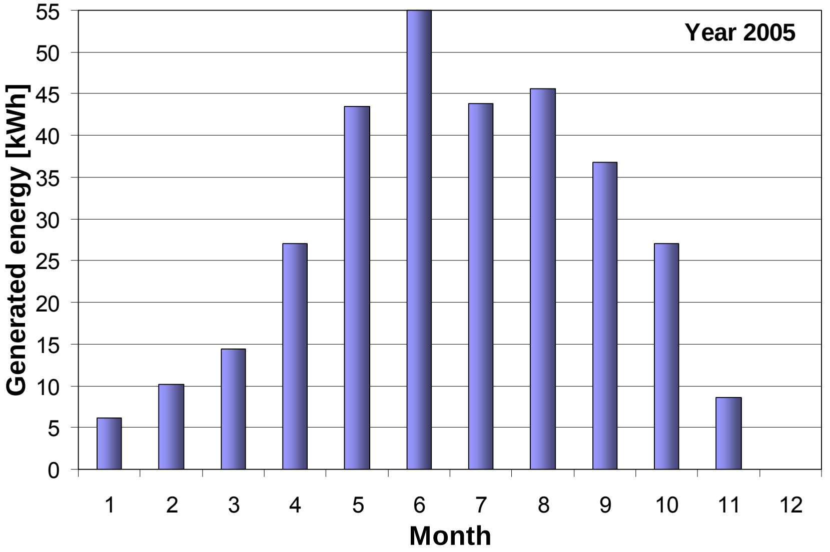
Grid-connected home system (3×150 W_p system)

Performance:

321.4 kWh



318.2 kWh



M. Zeman, Delft

Grid connected PV system

Grid-connected home system (3×150 W_p system)

Cost:

M. Zeman, Delft

Modules	Power	Price	EPR subsidy	EPA bonus	ENECO subsidy	Delft subsidy	Total subsidy	Cost buyer
3×SM-150	450 Wp	€ **3100**	€ 1532	€ 383	€ 613	€ 113	€ 2641	€ **459**

Standard EPR subsidy: € 3.4/ Wp for SM-150 module € 510

EPA bonus: 25% of the EPR subsidy for SM-150 module € 127.5

EPR Energiepremie regeling

EPA Energie Prestatie Advies

Grid connected PV system

Nederland:

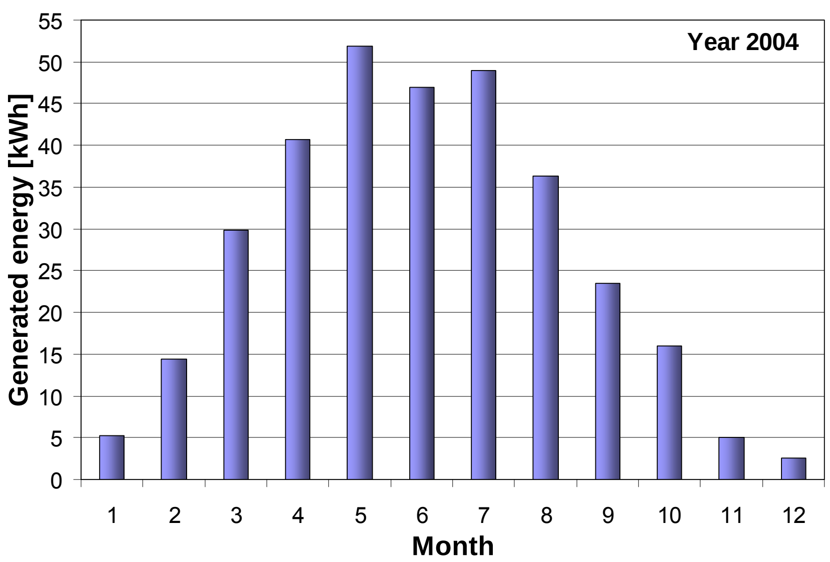
System: SolarWorld SW 150 module

Power: $3 \times 150\ W_p = 0.450\ kW_p$ Area: $3 \times 0.75 \times 1.50 = 3.375\ m^2$

Performance: 330 kWh/year

Annual yield: $730\ kWh/kW_p$ $98\ kWh/m^2$

321.4 kWh



Case:

Average electricity use in NL:
3000 kWh/year

Area needed:

$3000\ kWh / 98\ kWh/m^2 = 31\ m^2$

Number of modules:

3000 kWh/ 110 kWh = 28 modules

PV applications

Akzo-Nobel symposium 2002, Gert Jan Jongerden

PV with Battery Storage

PV applications

PV with Battery Storage:

- PV modules are connected to a battery and the battery to the load
- can be designed to power dc or ac equipment
- lights, sensors, recording equipment, switches, appliances, telephones, televisions, and even power tools

- charge controller (properly charged battery)
- battery maintenance
- optimal design of PV system size required to balance the costs

PV system design rules

1. Determining the total load current and operating time requirements in Ampere-hours

2. Taking care of system losses and safety factors

3. Determining the worst case (wintertime) equivalent sun hours

4. Determining total solar array current requirements

5. Determining optimum module arrangement for solar array

6. Determining battery size for recommended reserve time

PV system design rules

DC device	Device Watts	Hours of daily use	DC Watt-hrs. per day

Total DC Watt-hrs. per day [ ]

AC device	Device Watts	Hours of daily use	AC Watt-hrs. per day

Total AC Watt-hrs. per day [ ]

AC/0.85=DC Watt-hrs. per day [ ]

1.	Total DC Watt-hrs./day (DC loads)		
1.	Total DC Watt-hrs./day (AC loads)	+	
1.	Total DC Watt-hrs./day (All loads)	=	
	System nominal DC voltage	÷	
	Total DC Ams-hrs./day	=	
2.	Battery system losses	×	1.2
	Total daily Ams-hrs. requirement	=	
3.	Design insolation (ESH)	÷	
4.	Total PV array current (Amps)	=	
	Select module type		
5.	Module operating current (Amps)	÷	
	Number of modules in parallel	=	
	System nominal volatge		
	Modules nominal voltage	÷	
	Number of modules in series	=	
	Number of modules in parallel	×	
	Total modules required	=	
6.	Total daily Amp-hrs. requirement		
	Recommended reserve time (days)	×	
	Percent of usable battery capacity	÷	0.8
	Minimum battery capacity	=	

Power consumption

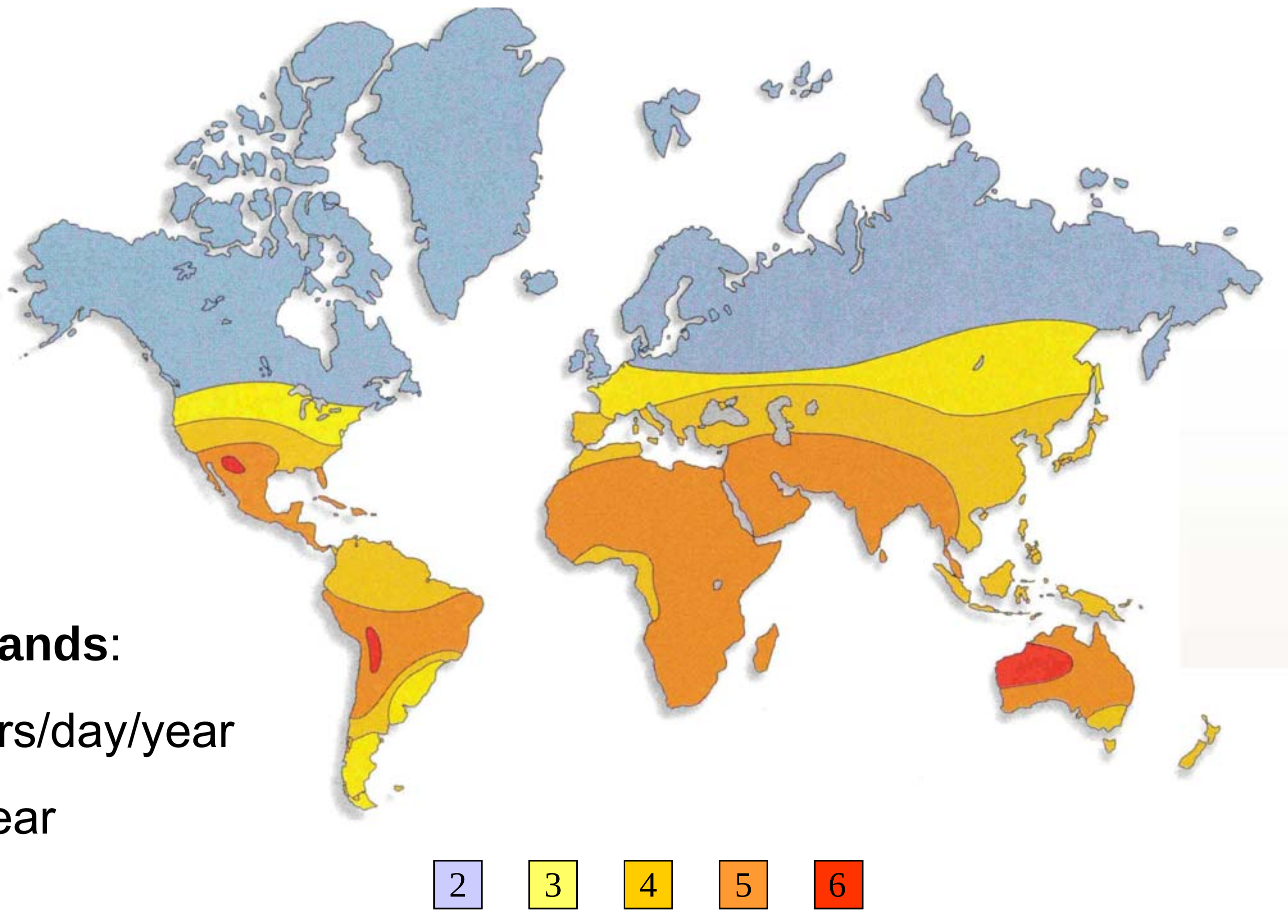
DC	[W]
Television	60
Refrigerator	60
Fan	15-30
Radio/tape	35
Lighting	
Bathroom	25-50
Bedroom	25-50
Dining room	70
Kitchen	75
Living room	75

AC	[W]
Television	175
Radio/tape	70-80
Lighting	
Bathroom	75
Bedroom	75
Dining room	100
Kitchen	100
Living room	75

AC	[W]
Refrigerator	350
Freezer	350-600
Microwave oven	300-1450
Toaster	1100-1250
Washing machine	375-550
Coffee maker	850-1500
Air conditioner	3000-4000
Tools	
Saw circular	800-1200
Saw table	800-950
Drill	240

Solar irradiation

Solar irradiation (solar irradiance integrated over a period of time)



Annual average of daily hours of sunlight

The Netherlands:

2.7 sun hours/day/year

1000 kWh/year

PV system design rules

DC device	Device Watts	Hours of daily use	DC Watt-hrs. per day
laptop	60	3	180
fridge	150	5	750
lamps	60	3	180
radio	40	3	120
television	60	1	60

Total DC Watt-hrs. per day 1290

AC device	Device Watts	Hours of daily use	AC Watt-hrs. per day
Wash. mach	400	0.3	120

Total AC Watt-hrs. per day 120

AC/0.85=DC Watt-hrs. per day 140

1.	Total DC Watt-hrs./day (DC loads)		1290
1.	Total DC Watt-hrs./day (AC loads)	+	140
1.	Total DC Watt-hrs./day (All loads)	=	1430
	System nominal DC voltage	÷	24
	Total DC Ams-hrs./day	=	60
2.	Battery system losses	×	1.2
	Total daily Ams-hrs. requirement	=	72
3.	Design insolation (ESH)	÷	6
4.	Total PV array current (Amps)	=	12
	Select module type		
5.	Module operating current (Amps)	÷	3.5
	Number of modules in parallel	=	4
	System nominal volatge		24
	Modules nominal voltage	÷	34
	Number of modules in series	=	1
	Number of modules in parallel	×	4
	Total modules required	=	4
6.	Total daily Amp-hrs. requirement		72
	Recommended reserve time (days)	×	4
	Percent of usable battery capacity	÷	0.8
	Minimum battery capacity	=	360

Selected module:

Solarex High Power MSX module

MSX120

Peak power:120W

Peak voltage: 34.2V

Peak current: 3.5A

PV system design rules

DC device	Device Watts	Hours of daily use	DC Watt-hrs. per day
laptop	60	3	180
fridge	150	5	750
lamps	60	3	180
radio	40	3	120
television	60	1	60

Total DC Watt-hrs. per day: 1290

AC device	Device Watts	Hours of daily use	AC Watt-hrs. per day
Wash. mach	400	0.3	120

Total AC Watt-hrs. per day: 120

AC/0.85=DC Watt-hrs. per day: 140

1. Total DC Watt-hrs./day (DC loads)		1290
1. Total DC Watt-hrs./day (AC loads)	+	140
1. Total DC Watt-hrs./day (All loads)	=	1430
System nominal DC voltage	÷	24
Total DC Ams-hrs./day	=	60
2. Battery system losses	×	1.2
Total daily Ams-hrs. requirement	=	72
3. Design insolation (ESH)	÷	6
4. Total PV array current (Amps)	=	12
Select module type		
5. Module operating current (Amps)	÷	4.4
Number of modules in parallel	=	3
System nominal volatge		24
Modules nominal voltage	÷	34
Number of modules in series	=	1
Number of modules in parallel	×	3
Total modules required	=	3
6. Total daily Amp-hrs. requirement		72
Recommended reserve time (days)	×	4
Percent of usable battery capacity	÷	0.8
Minimum battery capacity	=	360

Selected module:
SolarWorld
SW 150

SW 150
Rated power:150W
Rated voltage: 34.0V
Rated current: 4.4A

Cost of a PV system

Excercise:

1. What must be the production costs of a PV system, which generates electricity at a price that is comparable with the price of conventional electricity?

2. What are the costs of this system per Wattpeak?

(Given: The efficiency of PV modules that comprise the PV system is **14%** and the lifetime of the modules is **20** years. The PV system is located in The Netherlands where the average price for conventional electricity is **0.10** € per kWh. The average energy per unit area delivered by sunlight during one year is in The Netherlands **1000kWh/(m^2 year)**. We neglect the conventional electricity price change due to inflation or other circumstances.)

Module area

Excercise:

1. **How big area of a roof must be covered with PV modules in order to generate an average household annual use of electricity?**

2. **How expensive must the PV system be in order to deliver electricity at the same price, as is the price of conventional electricity?**

(Given: The efficiency of PV modules that comprise the PV system is **12%** and the lifetime of the modules is **20** years. The PV system is located in The Netherlands where the average price for conventional electricity is **0.10** € per kWh and the average energy per unit area delivered by sunlight during one year is **1000** kWh/(m^2 year). The household average electricity use is **2500** kWh per year.

DC device	Device Watts	Hours of daily use	DC Watt-hrs. per day

Total DC Watt-hrs. per day [ ]

AC device	Device Watts	Hours of daily use	AC Watt-hrs. per day

Total AC Watt-hrs. per day [ ]

AC/0.85=DC Watt-hrs. per day [ ]

1. Total DC Watt-hrs./day (DC loads)		
1. Total DC Watt-hrs./day (AC loads)	+	
1. Total DC Watt-hrs./day (All loads)	=	
System nominal DC voltage	÷	
Total DC Ams-hrs./day	=	
2. Battery system losses	×	1.2
Total daily Ams-hrs. requirement	=	
3. Design insolation (ESH)	÷	
4. Total PV array current (Amps)	=	

Select module type

5. Module operating current (Amps)	÷	
Number of modules in parallel	=	
System nominal volatge		
Modules nominal voltage	÷	
Number of modules in series	=	
Number of modules in parallel	×	
Total modules required	=	

6. Total daily Amp-hrs. requirement		
Recommended reserve time (days)	×	
Percent of usable battery capacity	÷	0.8
Minimum battery capacity	=	