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Feasibility Study on a Large Scale Solar PV System

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The Bachelor´s thesis discusses the design of a 300 kW grid-connected Photovoltaic system in the largest logistics center of Posti in Tikkurilantie 148, Vantaa. Furthermore, an analysis of the payback time of the system was also carried out. The key goal of the environmental program of Posti is to reduce the carbon-dioxide emissions by 30 percentage by the year 2020 (compared to the 2007 level) by improving energy efficiency and using renewable energy sources with lower emissions levels.

The annual consumption of electricity in the logistics center is approximately 9200 MWh of which a small portion will be produced by the designed PV system in the near future as green energy. As a part of sustainability, Posti Group has managed to reduce the consumption levels significantly in the recent years. 1200 PV panels are going to be installed on the roof of the property and each panel will produce a maximum of 250 Wp resulting in a 300 kW_p PV system. There will be a 14 PV array where each array will have 75-100 PV panels. The Junction box and Inverters will be installed in the upper floor around the center of the building to reduce the length of the cable. By the use of PVGIS estimation of power production, we can see significant power production from April to August.

Because of green electricity tariffs and investment incentives in renewable energy sources, this system will be vitally important in achieving its goal by the year 2020.

Keywords	Photovoltaic system, energy subsidy, PVGIS

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Abbreviations

kWh	kilowatt-hour
kW	kilowatt
PV	photovoltaic
DC	Direct Current
AC	Alternating Current
BOS	Balance of system equipment
PR	Performance Ratio
EU	European Union
STC	Standard Test Condition
W	Watt
ROI	Return of investment

1 Introduction

Finland is one of the leading users of renewable sources of energy in the world. About 1/4th of the total energy consumption in Finland is provided by renewable energy sources. Bio-energy, wood-based fuels, wind energy, geothermal heat and solar energy are the most common sources of renewable energy.

The key goal of the environmental program of Posti Group is to reduce the carbon dioxide emissions by 30 percentage by the year 2020 (compared to the 2007 level) by improving energy efficiency and using renewable energy sources with lower emissions levels.

Posti has managed to reduce the electrical consumption by 3 % and heating consumption by 17%. Temperature adjusted heat consumption has been decreased by 9 %. Generally, 80 % of the consumed electricity is used in large properties such as parcel sorting, warehouse, and postal center.

The plan is to design a grid connected to the solar PV system which supplies the electricity for one of the largest logistics centers of Posti located in Vantaa. This kind of a grid connected system has been popular nowadays because of governmental tariff prices and investment incentives.

There has been a significant decrease in the consumption of the electricity as the production facilities of the logistics center have been decreased by one degree Celsius by improving the capturing of exhaust air and updating the timing of lights.

2 Methodology

Following steps were used for the design:-

- The power consumption demand of the logistics centre was collected and analysed.
- The size and choice of electronic equipment like inverter, cable etc. were determined.
- The size of PV module was chosen.
- The size and length of cable were decided in order to minimize the loss.
- Engineering design: - The optimum angle and azimuthal angle were taken into account when designing PV Array in order to get maximum power output from the system.

3 Description of the site

The logistics center is located in Tikkurilantie 148 which is quite close to Helsinki-Vantaa International airport. The latitude of the site is 60^{0}18’6” North and the longitude is 24^{0}55’30” East and 45 meters above the sea level. The total area of the whole property is 91,965 square kilometers, of which 28,536 square kilometers belong to the Parcel sorting terminal and 63,429 square kilometers account for the Warehouse terminal 1-5. The PV panels will be kept on the roof surface of the logistics center. The total area of the roof is approximately 80,000 square kilometers. There are not any obstacles which could make a shadow to the panels mounted on the rooftop of the property.

The logistics center has a warehouse and a parcel sorting department. It is open from Monday to Sunday including evening and night shifts. The majority of the parcels, approximately 90,000 parcels a day, passes through this logistics center. The satellite view of the location is shown below in figure 1 using google maps.

Figure 1 Google satellite view of the logistics center

3.1 Consumption data of 2015

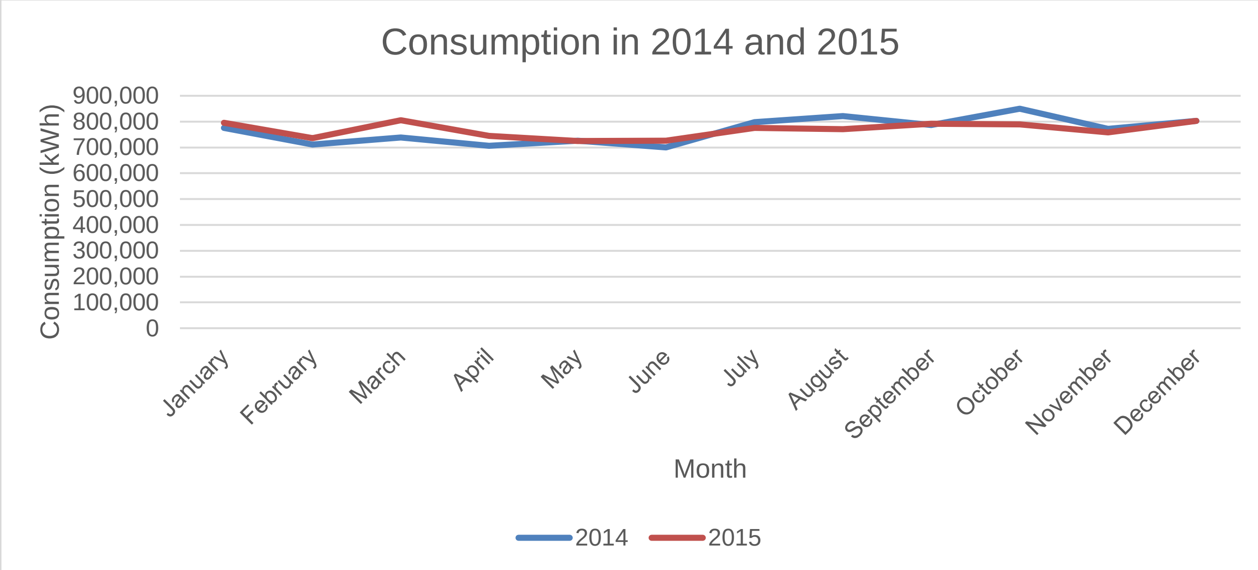

Figure 2 consumption data of 2015

During the summer months, the consumption scenario is comparatively less as there is less need for space heating and the number of the parcels is relatively low because of summer holidays. In the winter months, the electricity demand is relatively higher. The consumption data of the years 2014 and 2015 is shown in figure 2 and the trend of electricity consumption from the year 2008 to 2015 is shown in table 1.

Table 1 Annual Electricity consumption data from the year 2008 to 2015

	2008	2009	2010	2011	2012	2013	2014	2015
Consumption (MWh)	11,789	12,015	10,027	10,027	9,903	9,629	9,188	9,219
Change %		1.90%	-16.50%	0.00%	-1.20%	-2.80%	-4.60%	0.30%

From table 1 it is clear that the amount of total consumption has decreased significantly from 2008 to 2015. There was a huge decrease in the consumption in the year 2010. The average consumption of the property is about 9200 MWh annually.

The maximum consumption in the year 2015 was 1840 kWh and the minimum consumption was 160 kWh.

Table 2 Electricity consumption scenario in Parcel Sorting department from 2008 to 2015

Parcel Sorting	2008	2009	2010	2011	2012	2013	2014	2015
Consumption[kWh]	3 907 552	3 664 488	3 626 464	3 494 424	3 397 944	3 337 328	3 508 223	3 327 130
change [%]	-	-6.20%	-1.00%	-3.60%	-2.80%	-1.80%	5.10%	-5.20%
Maximum Consupmtion [kW]	680	616	648	624	656	648	640	640
Average Consumption [kW]	445	419	414	399	387	381	400	380
Minimum Consumption [kW]	120	128	120	0	80	96	80	80
Distribution								
Day (07-22) [%]	63.40%	61.50%	61.70%	61.50%	63.10%	63.40%	64.50%	64.40%
Night (22-07) [%]	36.60%	38.50%	38.30%	38.50%	36.90%	36.60%	35.50%	35.60%
Weekdays [%]	56.40%	54.40%	55.90%	56.50%	58.20%	57.70%	58.60%	59.20%
Night/weeke-nd [%]	43.60%	45.60%	44.10%	43.50%	41.80%	42.30%	41.40%	40.80%

In the Parcel Sorting terminal, the consumption has been dropped except the year 2014. The maximum consumption is about 650 kWh whereas the minimum consumption is about 80 kWh in recent years. The consumption from 7 am to 10 pm is almost double than rest of the hours. The parcels are sorted in the night and even in the weekend that is why the consumption is higher in night and weekend. The detail of the consumption in parcel sorting department is mentioned in Table 2.

Table 3 Electricity consumption scenario in warehouse from 2008 to 2015

Warehouses	2008	2009	2010	2011	2012	2013	2014	2015
Consumption [kWh]	7 882 296	8 351 344	6 401 032	6 533 456	6 505 600	6 292 608	5 680 665	5 892 102
change[%]	-	6.00%	-23.40%	2.10%	-0.40%	-3.30%	-9.70%	3.70%

Maximum Consumption[kW]	1 312	1 288	1 344	1 336	1 320	1 296	1 200	1 200
Average Consumption[kW]	897	954	731	746	741	718	648	673
Minimum consuption [kW]	208	160	160	0	112	96	80	80
Distribution								
Day(07-22) [%]	68.10%	66.10%	72.80%	74.00%	72.30%	74.10%	74.00%	72.00%
Night (22-07) [%]	31.90%	33.90%	27.20%	26.00%	27.70%	25.90%	26.00%	28.00%
Weekdays [%]	61.00%	58.30%	68.80%	70.50%	69.50%	69.90%	69.60%	68.40%
Night/ weekend[%]	39.00%	41.70%	31.20%	29.50%	30.50%	30.10%	30.40%	31.60%

The consumption scenario in warehouse department has been reduced quite a lot in comparison with 2007 level shown in table 3. As the warehouse has bigger space, obviously there is much more consumption of district heating which results in the increase in overall consumption. Mostly, the warehouse related work is done in the day time that is why the consumption from 7 am to 10 pm accounts for 68 percentage.

3.2 Consumption in summer and winter day

In the logistics center, the consumption data is measured in hourly level. According to the 2015 weather data, the hottest day was 3rd of July and coldest day was 6th of January. But the 6th of January was Ephiphany day which is national holidays so consumption data is quite low on that day. So, the hourly level data of 14 January and 3 July was plotted in figure 3. As we can see from the graph the consumption is higher in the evening time from 4 pm to 11 pm.

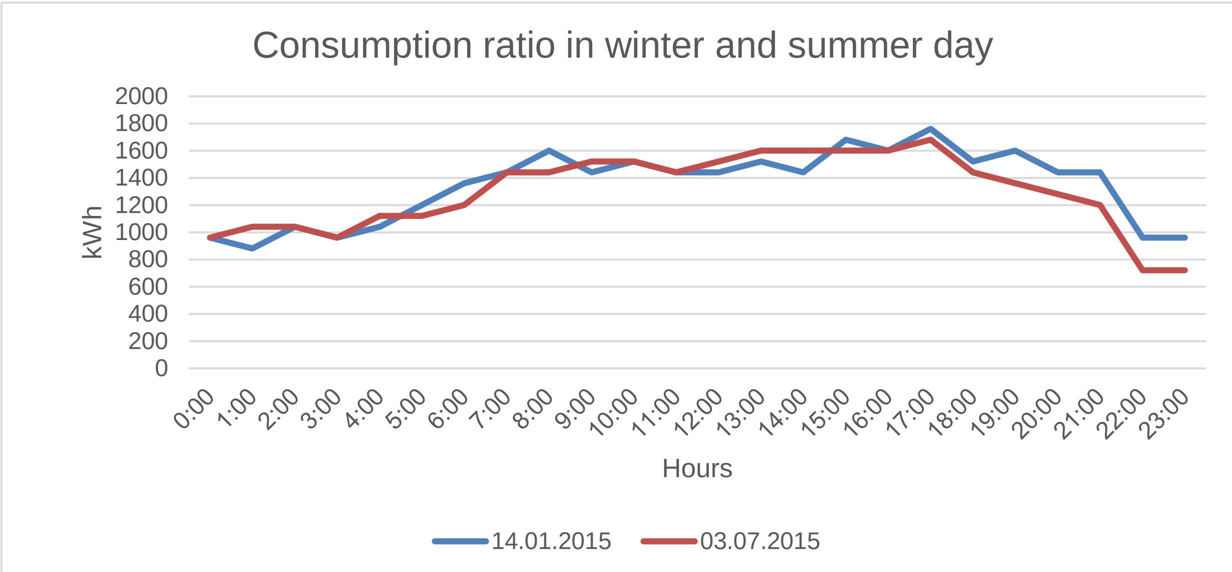

Figure 3 electricity consumption in winter and summer day

4 The Solar PV System

Solar PV System is a power system in which power is produced using solar radiation. It is also known as solar PV power system or PV system. The cost of the PV has decreased dramatically in the recent years. The average price of PV system has been dropped by 1/3rd since 2011.

Normally, the composition of solar cells is either crystalline or thin-filmed semi-conductor material. Silicon cells are costly although they have higher efficiency. Thin-film materials are cheaper but they have lower efficiency. Schematic diagram of grid-connected PV system is shown in figure 4.

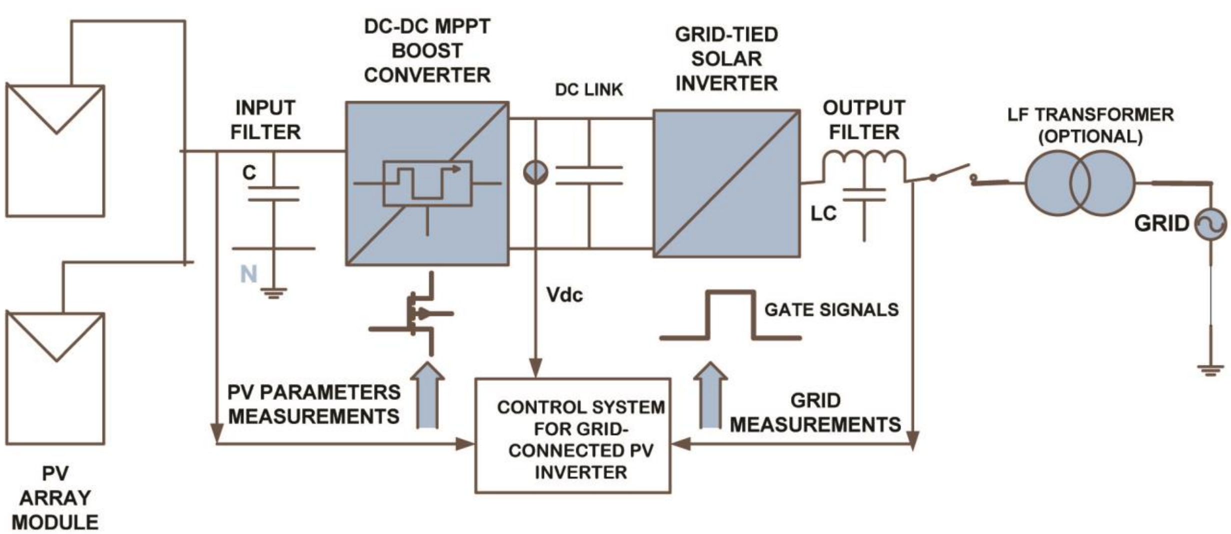

Figure 4 Generalized Block Diagram of Grid-Connected PV System (Source: Electrical India)

4.1 Major system Component

Solar PV system includes various components and they are chosen depending on the site location, system type, and applications. The major component of the system includes PV panels, junction box, inverter, battery banks and loads.

- PV Array- It is made up of PV modules and they are an environmentally-sealed collection of PV cells which convert sunlight to useful energy. The most common PV cell size vary from 0.5 to 2.5 square meter. Normally bigger PV cells are used for the bigger system.

- The Balance of system equipment (BOS) - It includes mounting system and wiring system. Ground-fault protection is also included in the wiring system. It is responsible for the regulating the voltage and current coming from PV Panels and helps battery from overcharging and prolongs battery life.

- Inverter- DC power coming from PV array is changed to standard AC by the inverter.

- Metering- It is used to provide an indication of system performance.

- Other components- Utility switch

4.2 PV Energy potential in Europe and Finland

Germany is world's superpower country in the context of solar energy production. According to 2011 data solar energy production (32,411 MW_p) was around 3 % of total energy consumption. From the picture below it is clear that southern coastal part of Finland has a good potential which can be seen in figure 5.

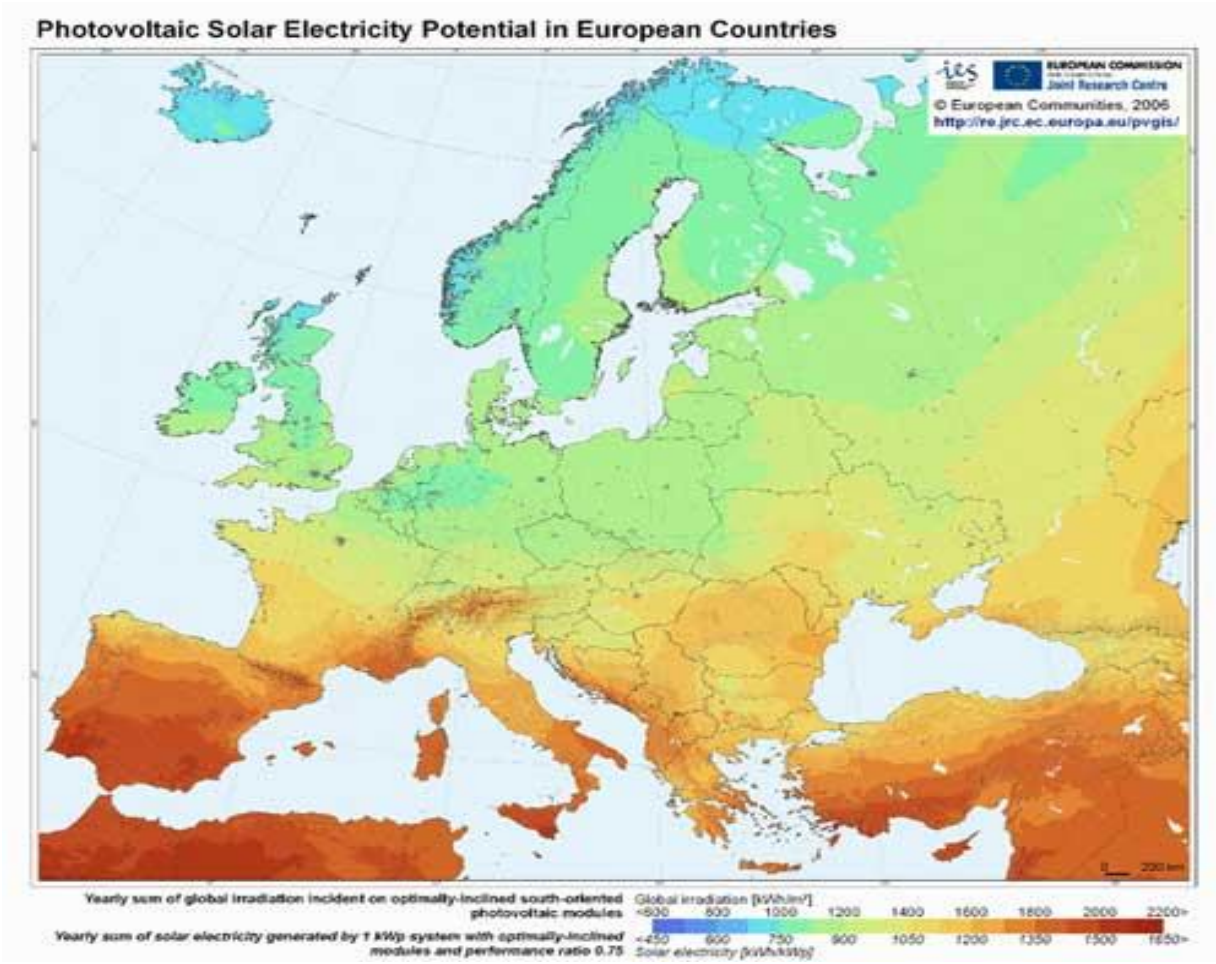

Figure 5 PV potential in Europe (source: PVGIS, European Union, 2001-2012)

In Finland, the amount of solar energy production is higher in summer month from May till August because of longer sunny days while during the winter month the production is significantly low. The solar energy reaching Finland from the sun is about 1000 kWh per square meter annually. The amount of solar irradiation data of Vantaa area is given in Table 4 below.

Table 4 Solar irradiation data of Vantaa

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
kWh/m^2/day	0,32	1,10	2,44	3,96	5,41	5,63	5,40	4,09	2,54	1,18	0,50	0,20

(*Source: Solar Electricity Handbook 2016 Edition*)

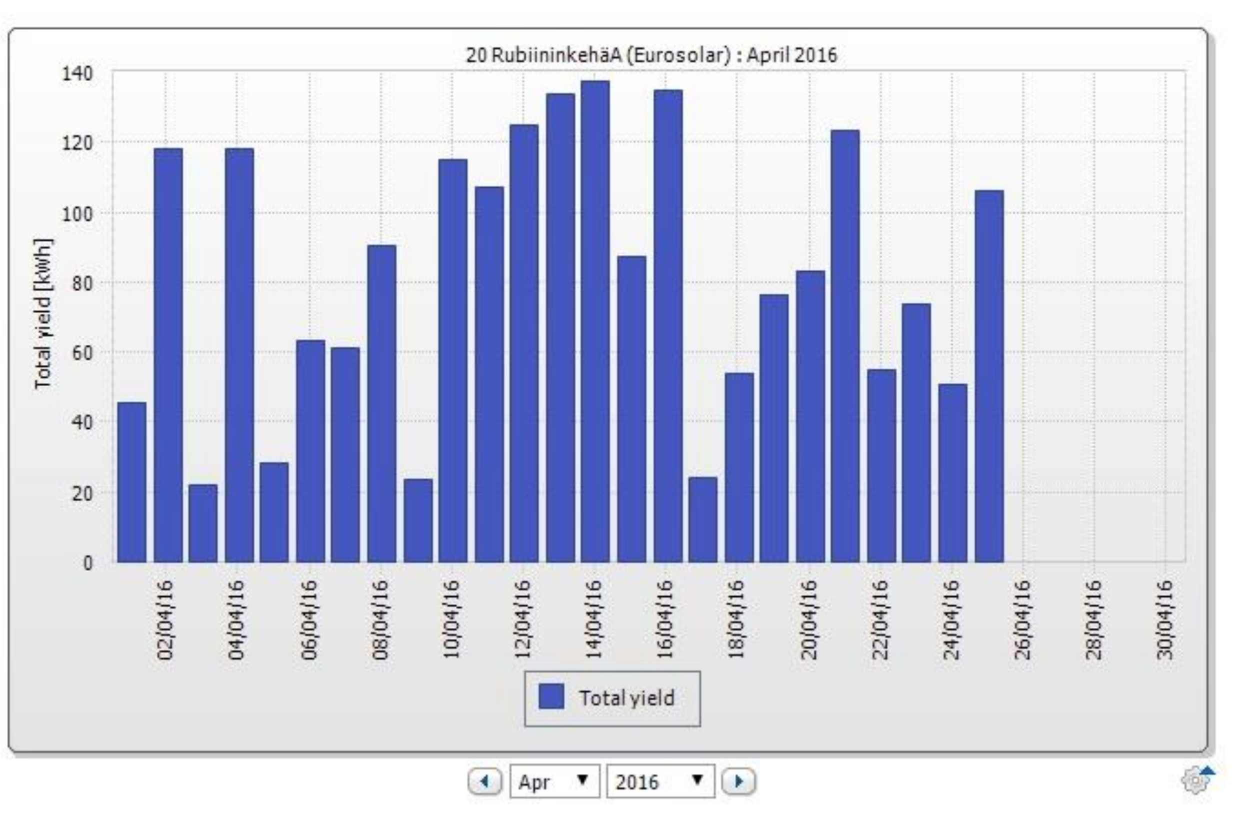

Figure 6 power produced from 20 RubiininkehäA PV system in April 2016

The amount of power produced is dependent upon the weather condition. The power production is maximum when there is enough sun and power production drop dramatically when it is raining, snowing and shadowing. In April 2016, there were many days where power production is close to 120 kWh/day and there are few days where production is nearly 20 kWh as shown in fig 6.The sunshine and daylight hours of Vantaa, Finland is shown in table 5

Table 5 Sunshine and daylight hours in Vantaa, Finland

Month	Avaerage sunlight hours/Day	Average daylight hours and minutes/Day	Sunny and cloudy daylight hours (%)
Jan	01:05	06:47	17(83)
Feb	02:13	09:05	26(74)
Mar	04:21	11:47	38(62)
Apr	06:08	14:37	43(57)
May	08:42	17:14	52(48)
Jun	09:48	18:46	53(47)
July	09:30	18:03	54(46)
Aug	08:05	15:41	53(47)
Sep	05:04	12:53	41(59)
Oct	02:27	10:03	25(75)
Nov	01:00	07:27	14(86)
Dec	00:34	05:59	10(90)
Annual	04:56	12:00	41(59)

4.3 Energy Losses in PV System

Depending on the site, technology, sizing system and weather condition might affect performance ratio (PR). The losses are as follows,

4.3.1 Pre-module Losses

- This type of losses is due to shadows, dirt, snow, reflection and tolerance of power. The module can have tolerance up to 5 % and Losses due to snow and dust might be 2 % and Shadow can result into loss of 80% power.

4.3.2 Module losses

Conversion and thermal losses are the modules losses. With increasing temperature, conversion losses increase. The losses due to weak radiation can be 3% to 7%.

4.3.3 System Losses

- Inverter losses (4% to 15%)
- Temperature losses (5% to 18%)
- DC cable losses (1% to 3%)
- AC cables losses (1% to 3%)

The details of energy losses in grid-connected PV System are shown in figure 7.

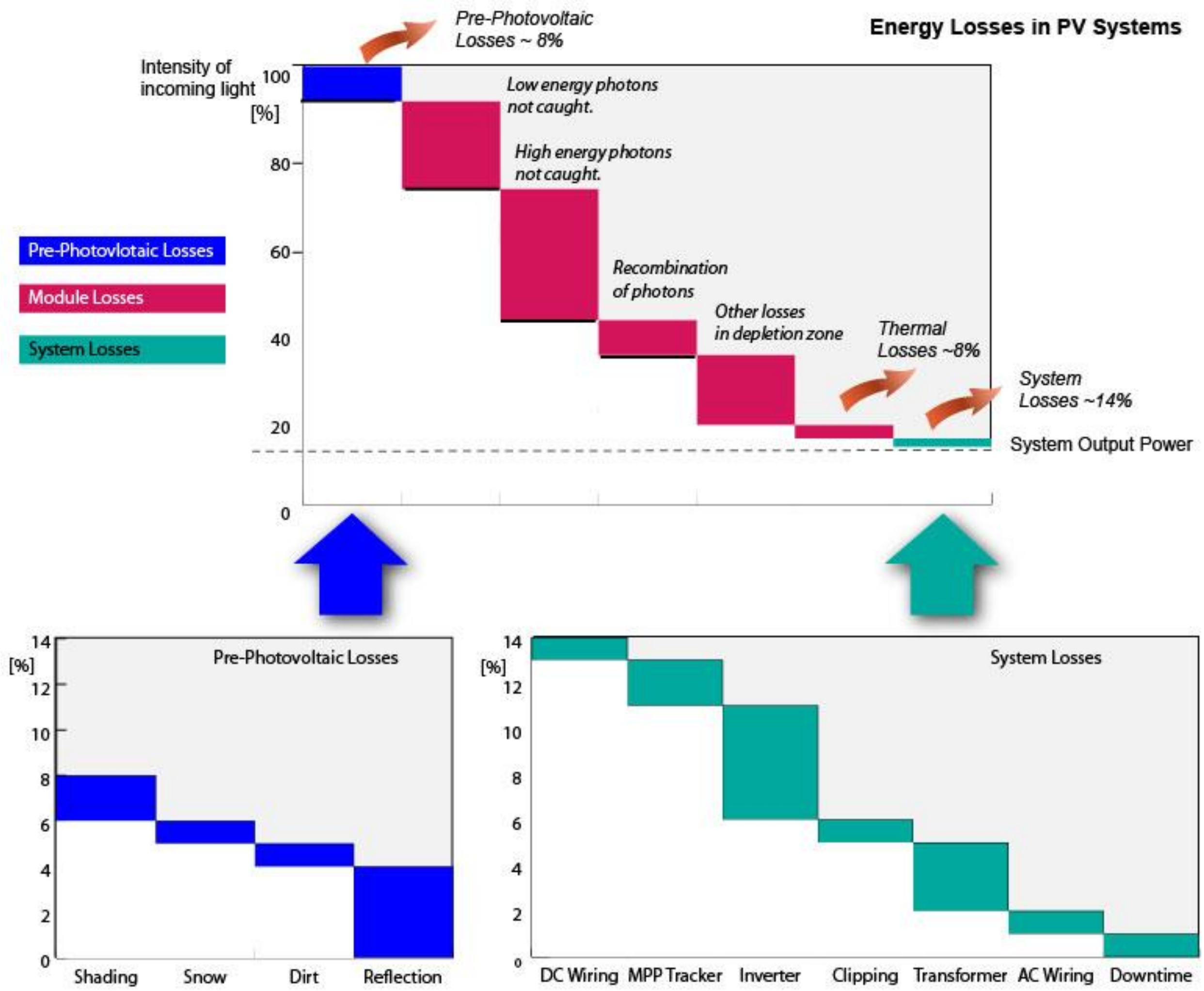

Figure 7 Energy losses in PV System

5 Design Parameters

Energy consumption and production are the two major parameters when designing the solar PV system. The consumption is so high in this logistic center so the PV system will supply few portion of needed power in the summer month.

5.1 Selection and sizing of PV-Panels

In the off-grid PV system, the system sizing is more complex because of load considerations and battery backup system. However, in grid connected system the size of the suitable area for Panels and buying and selling prices of the electricity are crucial. Generally if the production is higher than the demand then the electricity can be sell to the local electricity distributor through grid. The size of the PV panels is shown in figure 8.

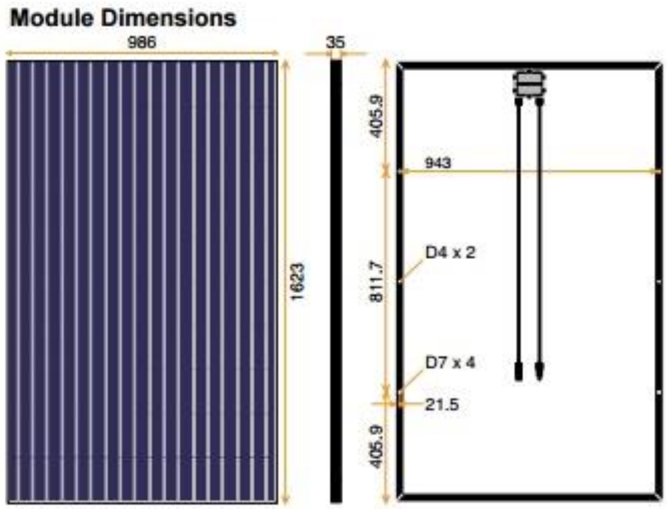

Figure 8 Module dimension of PV Panel

The number of total PV panels to be installed are dependent on the amount of maximum energy consumption at the certain time. Here, we are planning to design the 300kW PV System. The panels are of 250 W_p. So, 1200 panels are going to be installed to get 300 kWh power from the system. The module dimension and specification of the panel's type are given below in table 6.

Table 6 Technical details of the PV modules

Mechanical details

Overall length (mm)	1623
Overall Width (mm)	986
Area (square meter)	1.201
Weight (kg)	21.1

Construction

Cell type	Polycrystalline 3BB
Cells	60
Cell dimensions (mm)	156*156

Efficiency Reduction from STC

Reduction (approximately) %	3
Cell temperature (^{0}C)	25
Irradiance change (W/m^2)	From 1000 to 200

The performance of PV Panels at standard test condition is shown in figure 9.

Performance at STC	250 TP3 MBW
Maximum power (W/Pmax)	250
Maximum power tolerance (W)	+5/-0
Current (typical at max power) (A/Ip)	8.23
Voltage (typical at max power) (V/Vp)	30.4
Short circuit current (typical) (A/Isc)	8.66
Open circuit voltage (typical) (V/Voc)	37.6
Module efficiency (minimum) (%)	15.6
Module efficiency (maximum) (%)	15.9
Performance at NOCT and 800 W/m²	**250 TP3 MBW**
Maximum power (W/Pmax)	182.7
Current (typical at max power) (A/Ip)	6.60
Voltage (typical at max power) (V/Vp)	27.7
Short circuit current (typical) (A/Isc)	7.02
Open circuit voltage (typical) (V/Voc)	34.9

Figure 9 Specification of the PV modules

5.2 Azimuth

Azimuth angle defines the horizontal direction or the point of the compass where panels are facing. Azimuth angle range is from 0^0 (south) to $+180^0$ (West) and to -180^0 (East). Usually, 0^0 is best and most used azimuth angle for fixed solar system in the northern hemisphere because the sun altitude angle is at its highest when it is south.

5.3 Inclination

PV panels are normally installed facing towards the south as the radiation intensity is higher in the summer. During the summer time, the sun also shines from a higher angle so there will be more production. Inclination range is from horizontal 0^0 to vertical 90^0. In Finland inclination of 45^0 results into maximum annual energy production. The optimum tilt angle for the different month is shown below in table 7.

Table 7 Optimum Tilt of Solar Panel by month in Vantaa, Finland

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
14^0	22^0	30^0	38^0	46^0	54^0	46^0	38^0	30^0	22^0	14^0	6^0

5.4 Array Spacing

PV Array spacing are designed according to the roof area and the number of PV panels to be installed. The dimension of the panels and tilt angle also plays a vital role when installing. PV Array spacing is done in such a way that there is less chance of shadowing from one row to another row. In the picture shown below Y denotes for the spacing between PV Arrays. Figure 10 illustrates the PV Array spacing during the design phase.

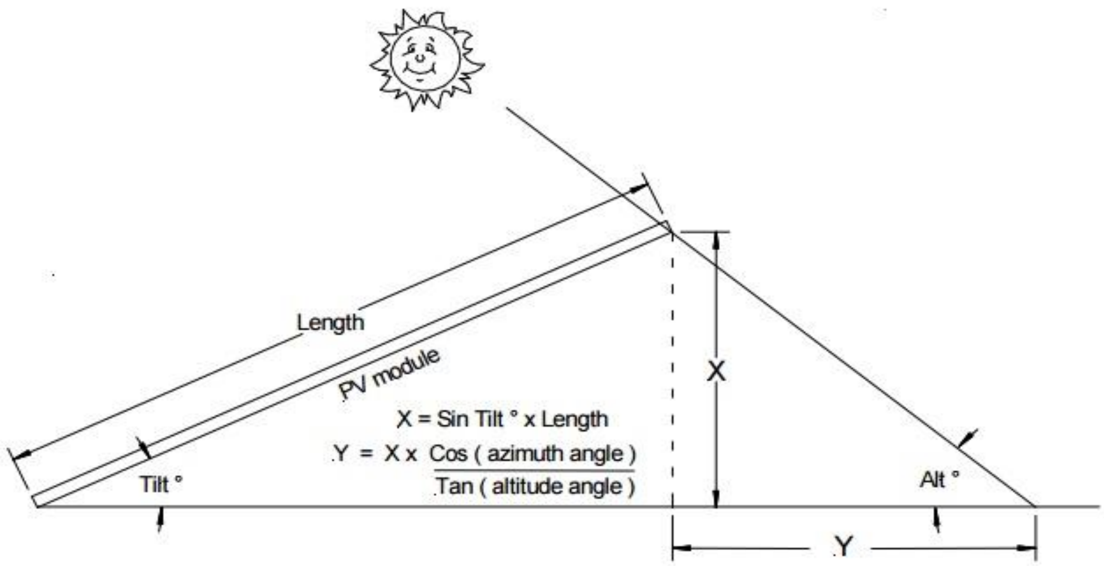

Figure 10 PV Array spacing

1200 PV modules with a dimension of 1623 mm*986 mm will be installed on the roof facing south. There is 14 row altogether. The longer row will have 100 panel and shortest one will have 75 panels.

If the wiring cable is too long there might be the chance of more loss in the power production so Panels will be kept in the following design as shown in figure 11 in order to minimize the losses.

Figure 11 Preliminary design of Roof after PV Panel installation

5.5 Temperature co-efficient

The power production from a silicon cell decreases by 0.5 % for every centigrade rise. The power decrease is due to the open-circuit voltage of the cell. On the other hand, the increase is less than the decrease in voltage. Thus, the result is decrease in power at higher operation temperature. (Patel 2006, P174.)

Normally, PV panels are all rated at 25^0 Celsius but when they are installed on the roof the generally reach a higher temperature.

We can see this value from manufacturer's data sheet. The temperature coefficient of the PV panels in this design is mentioned in table 8.

Table 8 Temperature coefficient value at STC

Open circuit voltage (V/K)	-0.125
Short circuit current (A/K)	0.00477
Maximum power (%K)	-0.42

5.6 Inverter selection and manufacture type

The power coming from photovoltaic system is DC so the inverter is needed to convert the output power into AC. For grid-connected PV system, the input rating of the inverter should be same as PV array rating to allow for safe and efficient operation. ABB pro 33 types of the inverter will be connected to the system (an example). There will be 8 inverters altogether. The sample picture is shown in figure 12 below

Figure 12 ABB Pro 33 inverter

5.6.1 Features of ABB Pro 33 inverter

- High power, compact and wall-mountable package
- Maximum Dc input voltage of up to 100 V
- IP65 rating suitable for outdoor installation

The technical data of the inverter is given below in figure 13.

Type designation	33 kW
	PRO-33.0-TL-OUTD
Input side	
Absolute maximum DC input voltage ($V_{max,abs}$)	1100 V [3]
Startup DC input voltage (V_{start})	610 V
Operating DC input voltage range ($V_{dcmin}...V_{dcmax}$)	580 to 950 V
Rated DC input voltage (V_{dcr})	580 V
Rated DC input power (P_{dcr})	33 700 W
Number of independent MPPT	1
MPPT input DC voltage range ($V_{MPPTmin}...V_{MPPTmax}$) at P_{acr}	580 to 850 V
Maximum DC input current (I_{dcmax})/for each MPPT ($I_{MPPTmax}$)	58 A
Maximum input short circuit current for each MPPT	80 A
Number of DC inputs pairs for each MPPT	1 in standard and -S version/8 in -SX version
DC connection type	Tool-less PV connector Phoenix Sunclix on -SX version/screw terminal block on standard and -S version

Figure 13 Technical data of ABB pro 33 inverters

6 Output Power

The annual energy production was estimated using PVGIS application. The technology was chosen as crystalline silicon and radiation database was used as classic PVGIS.

The slope for the PV panels was 45 degrees. Following are the losses in this system:

i) Estimated loss due to angular reflectance effects is 3%
ii) The losses from Cables and inverters is about 14%
iii) PV system losses (inverter losses, tolerance) equals about 23%

The estimated output power from above-mentioned parameters is shown in table 8.

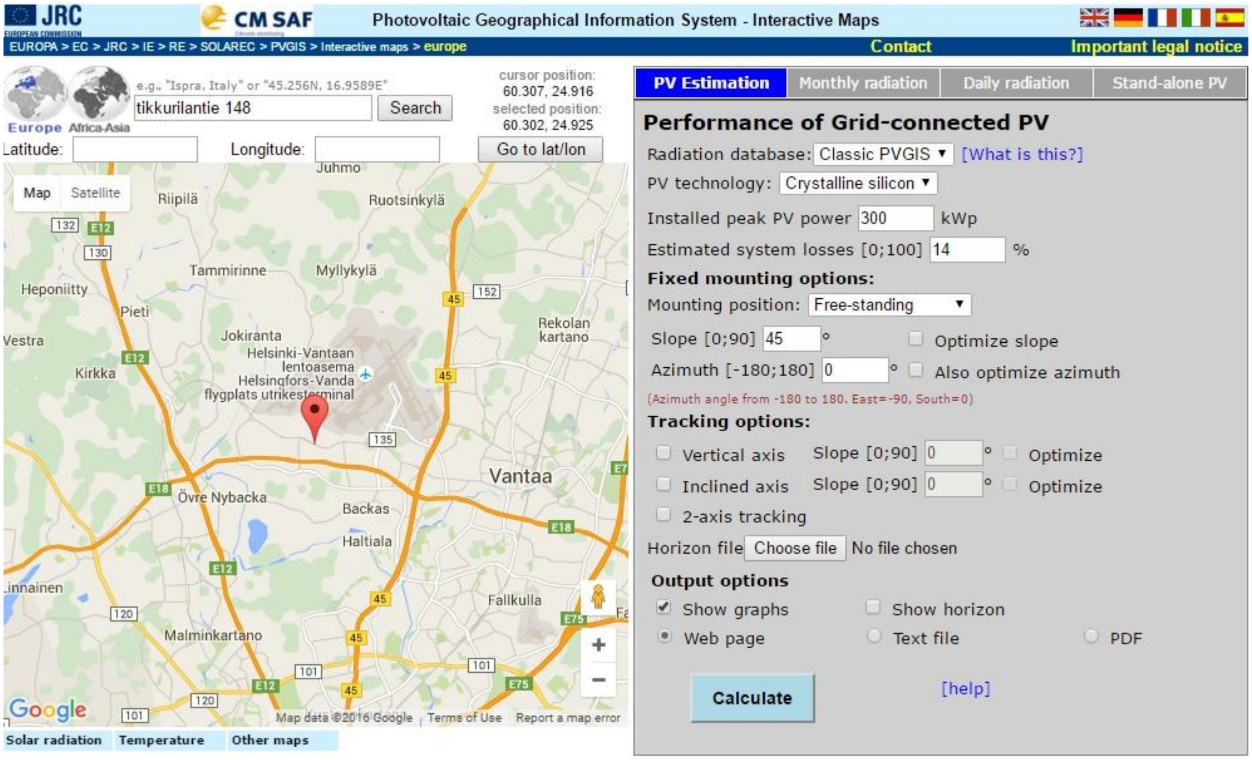

Figure 14 Estimated power output using PVGIS

The location of the site was used to get the estimate of solar electricity generation. The system was assumed to be fixed system with an inclination of 45^0 and orientation of 0^0. Figure 14 shows the basic parameters for the system and Table 9 gives the estimated output power using PVGIS.

Table 9 PVGIS estimate of solar power

Month	E_d	E_m	Hd	Hm
Jan	155	4,820	0.59	18.3
Feb	511	14,300	1.97	55.3
Mar	772	23,900	3.11	96.4
Apr	1,090	32,800	4.63	139
May	1,240	38,500	5.51	171
Jun	1,210	36,200	5.49	165
Jul	1,200	37,300	5.55	172
Aug	953	29,500	4.3	133
Sep	678	20,300	2.93	87.8
Oct	396	12,300	1.63	50.5
Nov	154	4,610	0.61	18.2
Dec	84.5	2,620	0.32	10.1
Yearly average	705	21,400	3.06	93
Total for year(kWh)		257,000		1120

Where,
E_d: Average daily electricity production from the given system (kWh)
E_m: Average monthly electricity production from the given system (kWh)
H_d: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)
H_m: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)

6.1 Power production in a summer day

According to weather data of 2015, 3rd July was the warmest day in Finland. So, the power output from the 300kW system in that day is shown in fig 15.

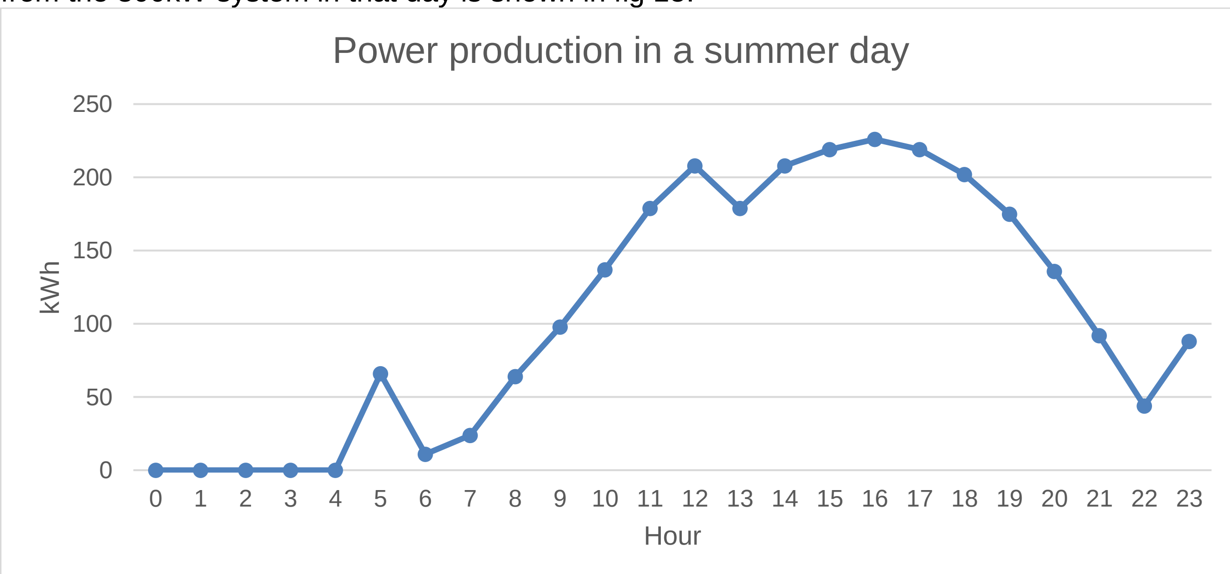

Figure 15 power production on a summer day (based on weather data of 03.07.2015)

6.2 Production Vs Demand

The bar diagram shows the amount of power produced from the system and amount of power needed for the logistic centre. The production is negligible in winter month and it rises with the start of summer month especially from March to August when there are enough sunny hours. Figure 16 shows the production and demand of the electricity in the year 2015.

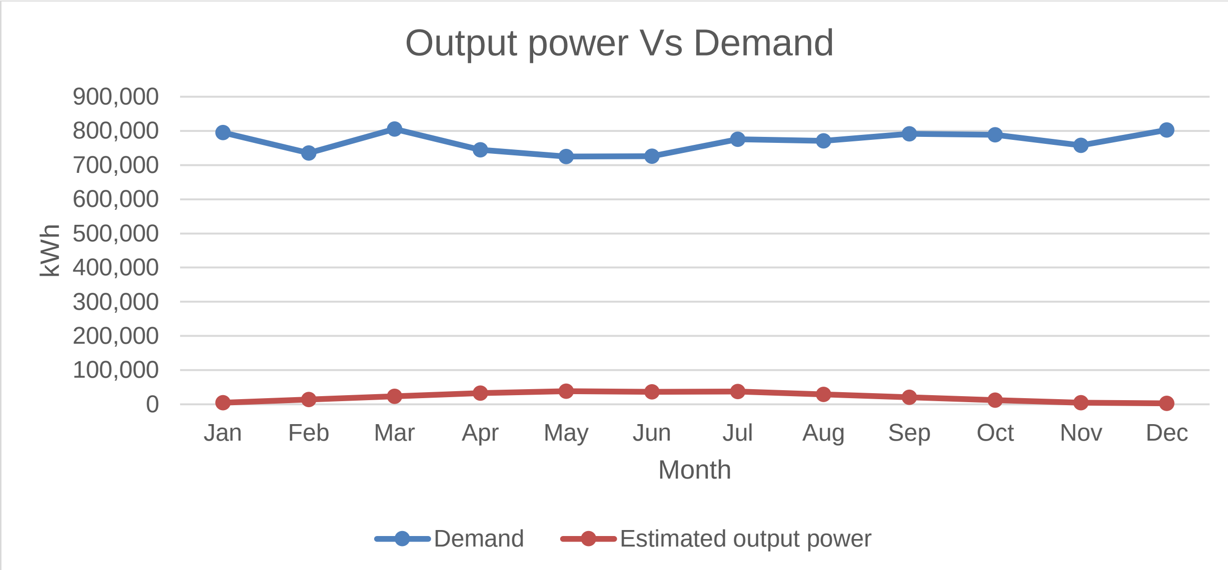

Figure 16 Demand Vs Output power

7 Payback time

The payback time depends on the price of equipment cost which includes photovoltaic panel, inverters, cabling, connectors, frame price and Labour cost which includes planning cost, Assembly, commissioning cost, permit cost as well as interest rate.

The exact payback period depends on the different factors, including:

- The amount of green energy produced from the designed PV system.
- The price of grid electricity in the locality. In markets with expensive utility rates, the payback times are relatively shorter.
- The total cost of the installation including incentives.

  The price of PV modules has been dropped dramatically in recent years. The main reason for the price drop was because of the low rate of raw material polysilicon and increasing efficiency of solar cells, dramatic manufacturing technology improvements, economies of scale and intense competition which resulted to module oversupply

The preliminary estimation of the price is shown below in table 10.

Table 10 Estimated price

Items		Quantity	Price (EUR)
1) Equipment cost			
i.	Solar PV modules	1,200	225,000
ii.	Grid-tied Solar inverter and wiring	8	60,000
iii.	Support cost		200,000
iv.	Transport/Mounting		150,000
	Total investment		635,000

If the Loan duration is 25 years with interest rate of 25 %.
Annuity factor is given by,

Annuity factor = [i*(1+i) ^n]/ [(1+i) ^n-1]
= [0.05*(1+0.05) ^25]/ [(1+0.05) ^25-1] = 0.071
Now,
Annuities = 45,085 EUR/yr.
Maintenance cost =3, 000 EUR/yr.
Total yearly cost = 48, 085 EUR/yr.

A simple payback time was calculated using the ratio of cost of the system to the cost of the energy from the designed system. This can be given by,

$N = C_i / (E_p * P_e)$…………………… Equation 1

Where,
N = payback time
C_i = Initial cost of the system after incentives
E_p = Annual power production from the designed system
P_e = local price of the electricity (euro/kWh)

In this design the incentive is 30%. So,

C_i = (635,000-30% of 635,000) = 444,500 euros

E_p = 257,000

P_e = 0.12 euro/ kWh

After substituting the values in equation1. We get,

$$N = C_i / (E_p*P_e) = 444,500 / (257,000 \text{ kWh}*0.12 \text{ Euro/kWh}) = 15 \text{ years}$$

From the calculation, the payback time is about 15 years.

7.1 Uncertainty of the investment

The calculation is based on current market price assumption. There are many factors which could increase or decrease the total price cost. If the uncertainty is +/- 20 %, the payback time also changes dramatically (see table11). It is clear that if there is +20% increase of the project cost the payback time will be 18 years after 30% governmental incentives in investment while if the project cost is lowered by 20% the payback time will be 12 years.

Table 11 Uncertainty of investment effect on payback time

	+ 20 % uncertainty	-20% uncertainty
Price after uncertainty calculation	762,000 EUR	508,000 EUR
Payback time	18 Years	12 Years

7.2 Return of investment (ROI)

ROI is a tool which investigates the amount of additional profits produced when investing a certain amount. Investors use this calculation to compare the different scenarios for investment to see which would produce the bigger profit and benefit for the company.

ROI can be calculated using the formula,

ROI (%) = [(Gain from Investment- Cost of the investment)*100]/Cost of the investment

7.3 Price of electricity

The industries which consume 500 MWh to 2000 MWh of electricity has the average price of 0,120 euro/kWh. Finland has relatively cheapest electricity price for industrial customers in compared to other European countries.

In Finland, the center for Economic Development, transport, and Environment can grant up to 30% of the investment cost for solar projects installed in large scale. The price in 1992 was about $6 per watt while the price nowadays is near $0.50. The trend is decreasing (as shown in figure 17) except between years 2005-2008 when the price was a little bit higher because of silicon shortages.

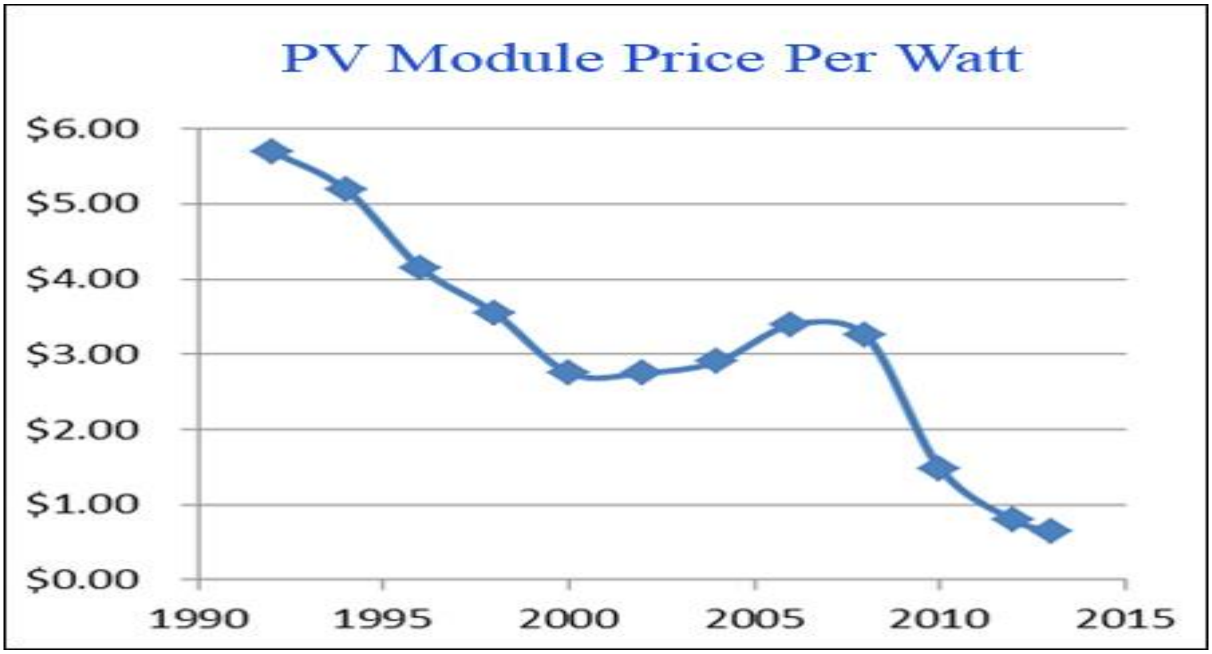

Figure 17 PV module price per Watt

7.4 Feasibility study

Incentives play a key role in enhancing the economic feasibility of renewable energy investments. Delays in the project because of permitting issues might take up to 50 % of project time in some cases and which rises the project cost. Without subsidies and with given development of investment cost and production rate, PV System is not feasible for the company. With 30 % incentives the payback time was 15 years and with 15 % incentives, the payback time is 18 years.

Two different cases were studied for the feasibility of the project. The first case was with the investment of 25 years and interest rate was 5% and the second case was with the investment of 15 years with 3% interest rate which is shown in table 12.

Table 12 Comparison of two different cases

	Case I	Case II
Investment	25 Years	25 Years
Interest rate	5%	3%
Annuity factor	0.071	0.056
Annuities (EUR/yr.)	45,085	35,560
Payback time	15 Years	13 Years

8 Conclusions

Energy produced from renewable energy sources like solar energy is getting popular as the energy produced is green energy and there are no greenhouse gas emissions. At the same time, the energy produced is free. Because of more emphasis on renewable energy, subsidies when installing the system, the PV installation is in increasing trend and payback time is becoming shorter. The operating and maintenance costs for PV panels are negligible, compared to the costs of other renewable energy systems.

There is a high possibility of obtaining benefits from on-grid solar systems when the consumption is less so that surplus electricity can be sold to the local electricity supply. In some countries, the power produced from renewable energy sources like wind energy, hydro energy, solar energy etc. have higher feed-in tariff rates.

In this design, PV panels will be installed on the roof of the property. So, no additional land is needed. Because of increasing trend of electricity price, carbon trade issues and clean development mechanisms, this type of a system will play a key role in achieving the EU's target for 20% of renewable energy supply by the year 2020.

The payback time for the system is estimated to be 12-15 years. Due to the uncertainty price in the investment the payback time vary significantly. Estimated lifetime of PV panel is more than 25 years, so in longer run system would bring economical benefit.

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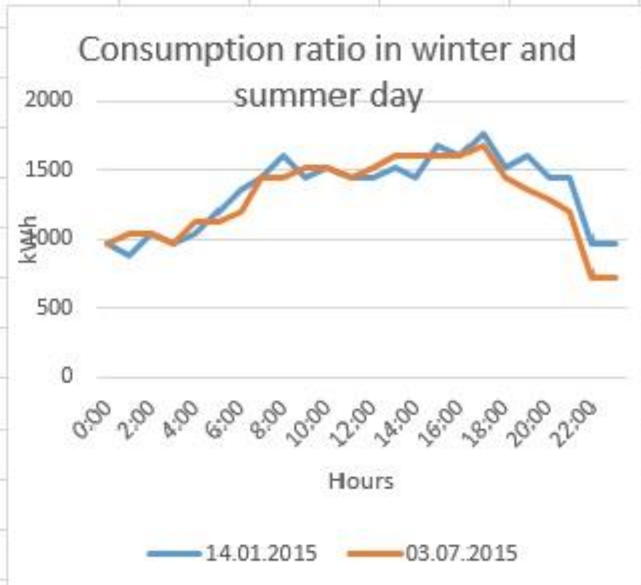
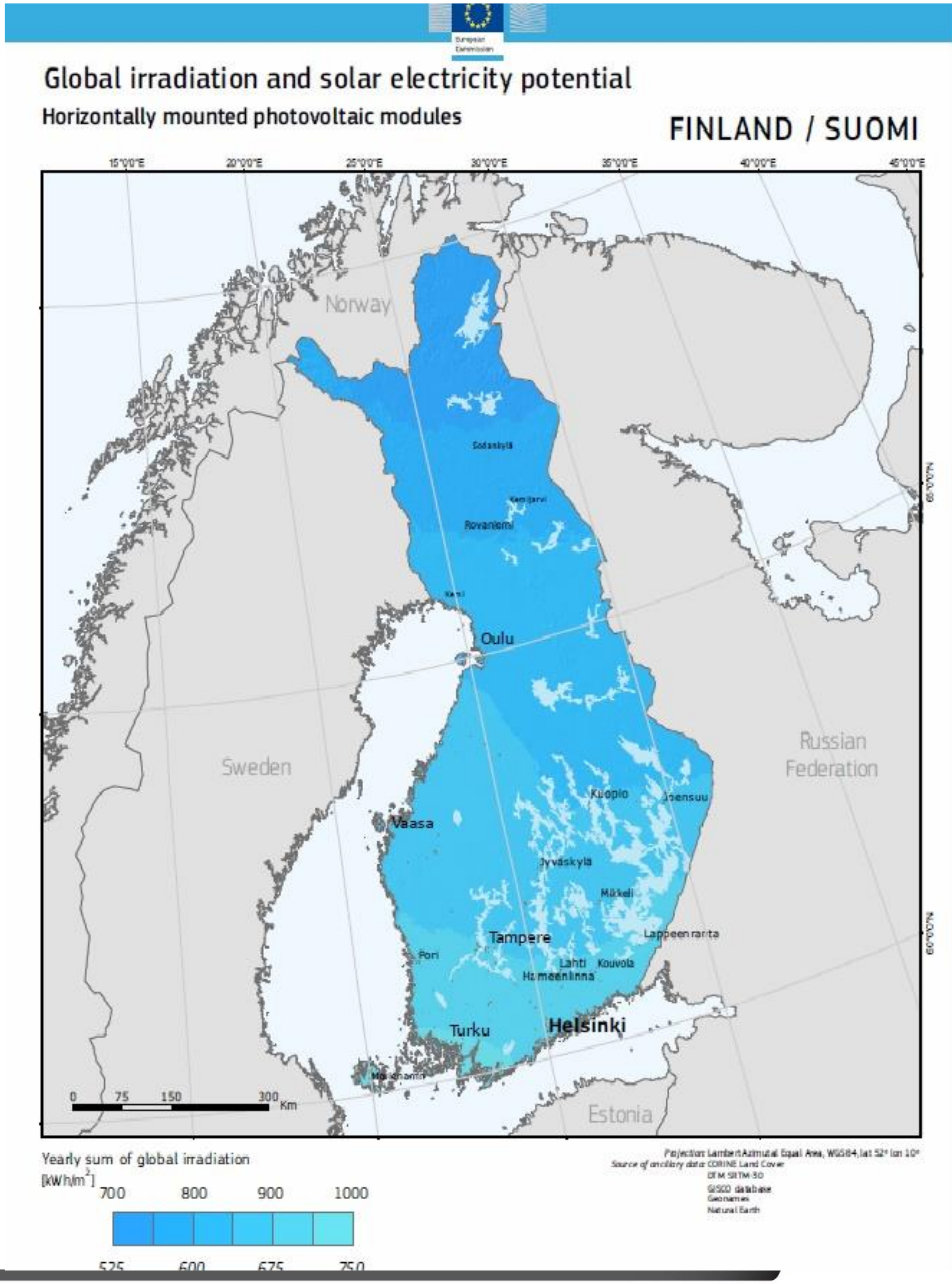
9 Appendices

9.1 Electricity consumption in summer day and winter day

	Date	Date
Hour	14.01.2015	03.07.2015
0:00	960	960
1:00	880	1040
2:00	1040	1040
3:00	960	960
4:00	1040	1120
5:00	1200	1120
6:00	1360	1200
7:00	1440	1440
8:00	1600	1440
9:00	1440	1520
10:00	1520	1520
11:00	1440	1440
12:00	1440	1520
13:00	1520	1600
14:00	1440	1600
15:00	1680	1600
16:00	1600	1600
17:00	1760	1680
18:00	1520	1440
19:00	1600	1360
20:00	1440	1280
21:00	1440	1200
22:00	960	720
23:00	960	720



9.2 Global irradiation and PV potential in Europe



9.3 Pre-sizing of the system using PVSYST software

PVSYST V6.43 | 24/05/16

Grid system presizing

Geographical Site **Vantaa** Country **Finland**

Situation Latitude 60.3°N Longitude 25.0°E

Time defined as Solar Time Altitude 58 m

Collector Plane Orientation Tilt 45° Azimuth 0°

PV-field installation main features

Module type Standard

Technology Polycrystalline cells

Mounting method Flat roof

Back ventilation properties Free standing

System characteristics and pre-sizing evaluation

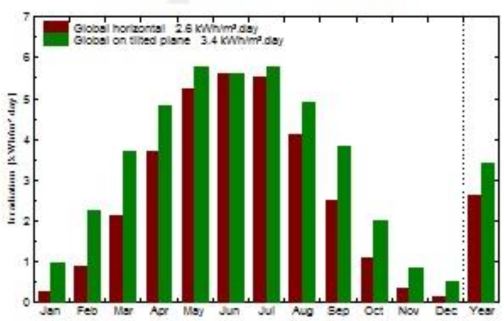
PV-field nominal power (STC) Pnom 300 kWp

Collector area Acoll 2000 m²

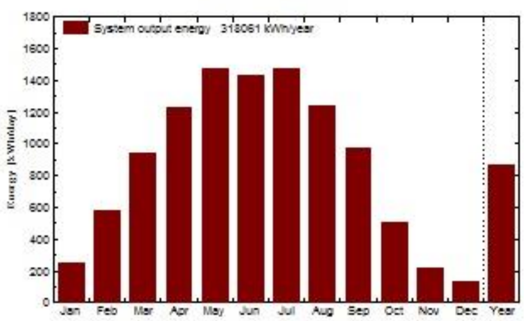
Annual energy yield Eyear 318 MWh Specific yield 1060 kWh/kWp

Economic gross evaluation Investment 876419 EUR Energy price 0.17 EUR/kWh

Meteo and incident energy



System output



	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh
Jan.	0.28	0.98	250.3	7760
Feb.	0.90	2.25	574.4	16083
Mar.	2.14	3.71	944.0	29263
Apr.	3.68	4.81	1225	36755
May	5.23	5.76	1467	45470
June	5.58	5.61	1431	42917
July	5.53	5.78	1472	45627
Aug.	4.11	4.88	1243	38548
Sep.	2.52	3.83	975.2	29257
Oct.	1.08	1.99	507.3	15726
Nov.	0.34	0.86	218.4	6552
Dec.	0.15	0.52	132.4	4103
Year	2.64	3.42	871.4	318061

PVsyst Evaluation mode

9.4 Saana 245-255 TP3 MBW specification

Naps Saana 245-255 TP3 MBW

Naps Systems' 30 years of solar power experience in all continents and conditions provide the highest level of quality and power in an attractive and dependable package.

High power and efficiency

Naps Saana series of solar modules contain 60 high efficiency polycrystalline solar cells. The cells are carefully selected to assure a narrow and positive power range, thus minimising mismatch losses in the system.

The high transmission structured glass has a light texture on the front and a deeper texture inside, which improves the adhesion of the EVA encapsulant. This combination of textures also gives improvement to the performance of the solar module compared to smooth glass.

Dependable construction and long life

Featuring the highest standards of construction and materials, Naps Saana solar modules are able to withstand the harshest environments and continue to perform efficiently. Properly installed, these modules have a design life well beyond the power warranty. Limited power warranties are given for both 10 and 25 years. The modules are tested to meet or exceed all relevant international standards and the highest requirements for quality and performance.

Glass type:	Frame colour:	Backsheet colour:
MATT	BLACK	WHITE

- Carefully selected polycrystalline silicon solar cells for close tolerance
- Solar cells treated for reduced reflection and for efficient conversion of both direct and diffuse light
- Electrical circuit laminated between layers of ethylene vinyl acetate (EVA) for electrical isolation, moisture resistance and UV stability
- Low iron content, tempered glass for mechanical protection and high light transmission
- The light textured surface of the matt glass improves the performance of the module
- The deep texture inside of the glass improves the adhesion of the EVA encapsulant
- Multi-layered polymer backsheet for resistance to abrasion, tears and punctures and dependable electrical insulation
- Rugged and lightweight anodised aluminium frame with mounting, grounding and drainage holes
- Junction box with pre-fitted cables and quick connectors designed for ease and safety
- Wired-in bypass diodes to reduce potential loss of power and damage from partial array shading
- Tested for a wide range of operating conditions (-40°C to +85°C)
- Tested to withstand the highest wind, hail storm and snow load requirements (5400 N/m²)
- Designed to meet or exceed the environmental requirements of IEC61215
- Designed to meet the requirements of IEC61730, including Safety Class II to IEC61140

www.napssystems.com

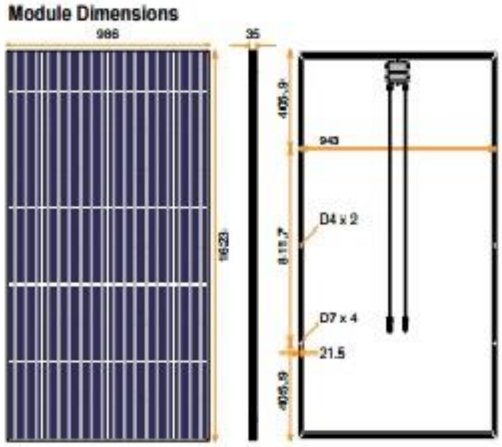
NAPS
Power of Light

Saana 245-255 TP3 MBW

Specifications

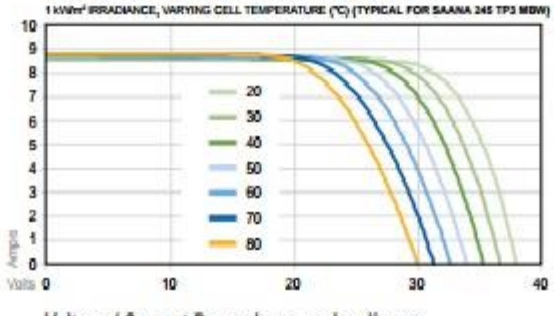
Performance at STC	245 TP3 MBW	250 TP3 MBW	255 TP3 MBW
Maximum power (W/Pmax)	245	250	255
Maximum power tolerance (W)	+5/-0	+5/-0	+5/-0
Current (typical at max power) (A/Ip)	8.13	8.23	8.33
Voltage (typical at max power) (V/Vp)	30.1	30.4	30.6
Short circuit current (typical) (A/Isc)	8.58	8.66	8.74
Open circuit voltage (typical) (V/Voc)	37.3	37.6	37.9
Module efficiency (minimum) (%)	15.3	15.6	15.9
Module efficiency (maximum) (%)	15.6	15.9	16.2
Performance at NOCT and 800 W/m²	**245 TP3 MBW**	**250 TP3 MBW**	**255 TP3 MBW**
Maximum power (W/Pmax)	178.9	182.7	186.6
Current (typical at max power) (A/Ip)	6.52	6.60	6.68
Voltage (typical at max power) (V/Vp)	27.4	27.7	27.9
Short circuit current (typical) (A/Isc)	6.96	7.02	7.09
Open circuit voltage (typical) (V/Voc)	34.7	34.9	35.2

Module Dimensions



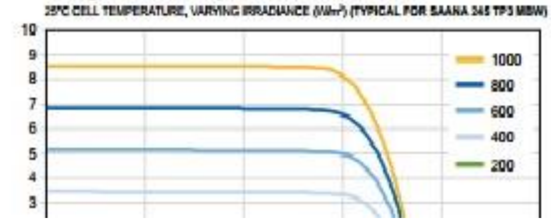
Voltage / Current Dependence on Temperature

1 kW/m² IRRADIANCE, VARYING CELL TEMPERATURE (°C) (TYPICAL FOR SAANA 245 TP3 MBW)



Voltage / Current Dependence on Irradiance

25°C CELL TEMPERATURE, VARYING IRRADIANCE (W/m²) (TYPICAL FOR SAANA 245 TP3 MBW)



Mechanical Details

Overall length (mm) 1623
Overall width (mm) 986
Area (m²) 1.601
Thickness at edge (mm) 35
Weight (kg) .... 21[illegible]

Construction

Cell type .... polycrystalline 3BB
Cells 60
Cell dimensions (mm) .... 156 x 156
Cell electrical circuit (series x parallel) .... 60 x 1
Cell layout (horizontal x vertical) .... 6 x 10
Glass thickness (mm) 4.0
Junction box type .... Hercules HBH
Bypass diodes factory fitted 3
Cables (4.0 mm²) .... 2 x 1 m
Connector type H4C
Other connector options available to special order

Protection Class

IEC61730 Application Class A, equivalent to Safety Class II

Maximum System Voltage

Voltage (V) 1000

Overcurrent Protection

Series fuse protection rating (A) 15
Reverse current maximum (A) 15

Mechanical Load

Tested to (N/m² = Pa) 5400
According to IEC 61215-2 extended test for heavy snow load

Temperature Coefficients at STC

Open circuit voltage (V/K) .... -0.125
Short circuit current (A/K) 0.00477
Maximum power (%/K) .... -0.42

Efficiency Reduction from STC

Reduction (approximately) (%) 3
Cell temperature (°C) 25
Irradiance change (W/m²) .... from 1000 to 200
Air Mass 1.5

STC = Standard Test Conditions

Cell temperature (°C) 25
Irradiation (W/m²) 1000
Air Mass 1.5

NOCT = Normal Operating Cell Temperature

Cell temperature (°C) 46
Irradiation (W/m²) 800
Ambient temperature (°C) 20
Wind speed (m/s) .... ≤1