Teemu Heikkinen

PV SYSTEM DESIGN AND FEASIBILITY STUDY FOR JUHANNUSLEHTO BUSINESS PARK

Degree Programme in Environmental Engineering
2013

samk
Satakunnan ammattikorkeakoulu
Satakunta University of Applied Sciences

PV SYSTEM DESIGN AND FEASIBILITY STUDY FOR JUHANNUSLEHTO BUSINESS PARK

Heikkinen, Teemu
Satakunnan ammattikorkeakoulu, Satakunta University of Applied Sciences
Degree Programme in Environmental Engineering
December 2013
Supervisor: Lähde, Petri
Number of pages: 49
Appendices: 2

Keywords: Photovoltaic, renewable energy, feasibility study

The purpose of this thesis was to design grid-connected photovoltaic (PV) systems for two similar buildings of Juhannuslehto Business Park in Pori and additionally make the feasibility studies for the designs. Design of both buildings included two different size PV system options that were the maximum option and the 50kW option. Client for the design and feasibility study was Lemminkäinen Building Construction, the company responsible for Juhannuslehto business park construction.

Basic component of a grid-connected PV system consists of PV modules, their mountings, inverters, junction boxes and the connecting cabling. In technical designing of the PV system the most important design factors are the available solar radiation, module orientation (azimuth and inclination) and in case of multi-row systems the inter-row shading effect affecting on row-spacing.

The annual electricity consumptions of the buildings were estimated to be about 400 and 340 MWh. From these the designed maximum size options, with peak power of c. 150kW were estimated to cover about one third, and the 50kW options were estimated to cover about 10%.

Cost calculations were based on two offers requested for the purposes of the design. Finnish offer included all costs and another one from Spain was added with installation cost estimation after which the system prices for the maximum options were 1.57€/Wp and 1.47€/Wp respectively. For the 50kW options there was no significant price difference.

For the payback time calculations couple of different methods both with 15% incentive assumption were used. Simple payback method gave 15-16 years for payback while more sophisticated method taking into account also estimated development for energy price rise, excise taxation, loan interests and PV degradation effect gave 14-16 years. Additionally life-cycle cost analysis was used to compare the cost effectiveness of different design options.

Finally sensitivity analysis was performed to estimate the reliability of the results. Especially with the payback time calculations there is lots of uncertainty related to the future development of electricity prices and other affecting X-factors.

CONTENTS

1 INTRODUCTION 5
2 SOLAR ENERGY IN FINLAND 6
  2.1 Solar Conditions 6
  2.2 PV Energy Potential 7
3 SOLAR POWER EQUIPMENT AND PV SYSTEM DESIGN PRINCIPLES 8
  3.1 Solar Panel 8
  3.2 Other Components 10
  3.3 PV System Design Parameters 10
    3.3.1 Available Solar Radiation 11
    3.3.2 Azimuth and Inclination 12
    3.3.3 Inter-row Shading and Array Spacing 13
    3.3.4 Choosing PV-panels 15
    3.3.5 Sizing the PV System 17
4 JUHANNUSLEHTO BUSINESS PARK 18
  4.1 Lemminkäinen Building Construction 20
  4.2 Possibilities for Solar Energy Implementation 20
5 PV SYSTEM DESIGN AND DIMENSIONING - TWO OPTIONS 21
  5.1 Scoping the Project 21
    5.1.1 Location and Building Information 21
    5.1.2 Smoke Vent Layout Estimation 22
    5.1.3 Annual Electricity Consumption Estimations 23
  5.2 Determining Design Parameters 26
    5.2.1 Selecting PV-panels 26
    5.2.2 Azimuth 26
    5.2.3 Inclination 28
    5.2.4 Array Spacing 28
    5.2.5 Final Design Parameters and System Outputs 31
  5.3 Sizing the Systems Components 35
6 PV SYSTEM COST AND PAYBACK TIME 37
  6.1 System Costs 38
  6.2 Final Cost Estimation 39
  6.3 Payback Time 40
    6.3.1 Photovoltaic Degradation 40
    6.3.2 National Energy Incentives 41
    6.3.3 Payback Time Calculations 41
    6.3.4 Life-cycle Cost Analysis 43
    6.3.5 Effect of Future Changes in Building Use to the Payback Time 44

7 SENSITIVITY ANALYSIS 45
7.1 Electricity Production 45
7.2 Electricity Consumption 45
7.3 Costs and Payback 46
8 GUIDELINES FOR CONNECTING ELECTRICITY PRODUCTION TO DISTRIBUTION NETWORK 47
REFERENCES 48
APPENDIX 1: Solar altitude table of Pori

APPENDIX 2: SMA Sunny design PV system dimensioning results (4 designs)

1 INTRODUCTION

Energy production and consumption are central factors when considering the effects humankind has on the environment. In the future, more efficient use of existing energy resources and wide application of renewable energy resources is a necessity.

Solar energy is free but not cheap. This phrase has been losing its factual background while the price of solar energy has been decreasing since the first commercial applications were sold. Solely during the past two and a half years the small-scale PV system prices have dropped about 40%. At the same time technology has been developed to a level that makes PV solar energy a reliable long term option for renewable energy production.

Due to the development towards more renewable and more climate friendly energy supply the grid-connected PV systems have become a very popular option in many countries around the world. This development has been assisted by governmental tariff prices and investment incentives. For natural solar resource reasons, the southern countries have been more active in this development but there are countries, like Germany that have made also a clear political decision to invest heavily on solar energy.

With the decreased cost and pressure for more sustainable energy economy the PV technology has become more feasible also for northern countries like Finland. Depending on the investment incentives and the future development of electricity prices the payback time of a PV system located in Finland is already close to 10 years.

Juhannuslehto Business Park acts as a good example of a business site where the use of solar energy can be well-founded. There is plenty of suitable roof space that could well be harnessed for solar electricity production. This would cut down the annual need for external electricity supply with even one third, at the same time making the business less vulnerable for future energy price changes. A clear advantage of applying solar energy on business buildings compared to residential houses is the overlapping of the solar energy production and the electricity consumption times enabling particularly high self-consumption share for the produced energy.

2 SOLAR ENERGY IN FINLAND

2.1 Solar Conditions

Finland is located in northern hemisphere, approximately between latitudes of 60°N and 70°N and longitudes of 20°E and 30°E. With this high latitude the conditions for solar energy production are naturally not ideal due to the long winter season with rather low solar altitudes. For instance, during the winter solstice in Pori region the sun is only about 5 degree above the horizon at solar noon. However, half of the year, between the vernal and autumnal equinoxes and especially during summer months the solar conditions are relatively good. Figure 1 illustrates the sun path at Pori location. In southern part of Finland, the solar radiation energy on a horizontal surface is annually about 1000kWh/m^2 (Erat, Erkkilä, Nyman, Peippo, Peltola & Suokivi. 2008, 13).

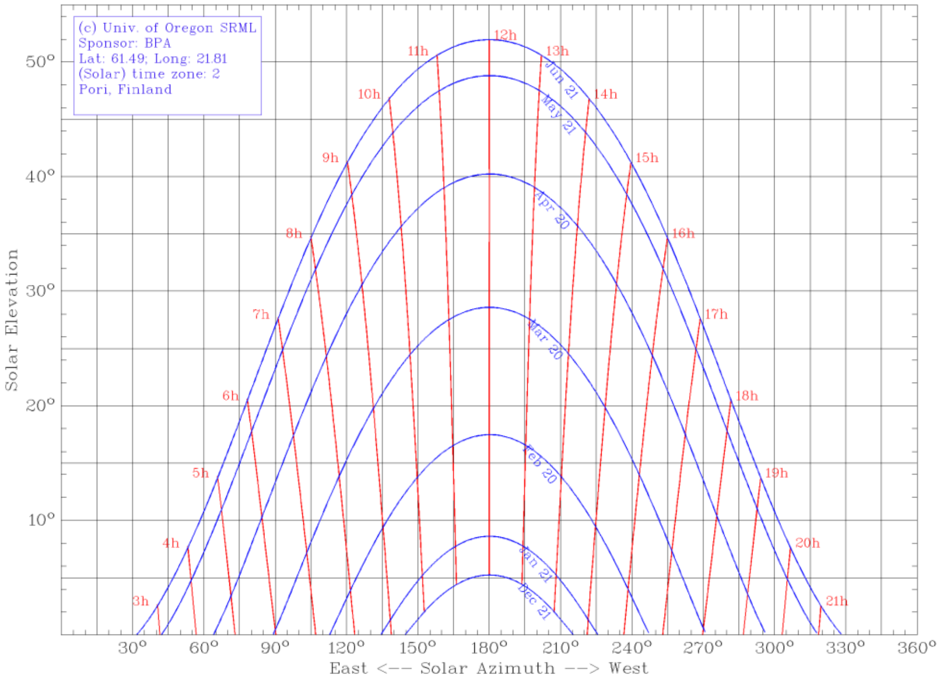


Figure 1. Sun path chart at Pori location (Website of University of Oregon 2013)

2.2 PV Energy Potential

Map of the Figure 2 illustrates well the potential for PV electricity production in Europe. It can be seen that southern coastal part of Finland has as good potential as in the northern half of Germany. When again comparing the use of solar energy between Germany and Finland, the difference is huge. Total power of installed photovoltaic capacity in 2012 in Germany was 32,411MWp and Finland 1MWp (EPIA 2013, 18).

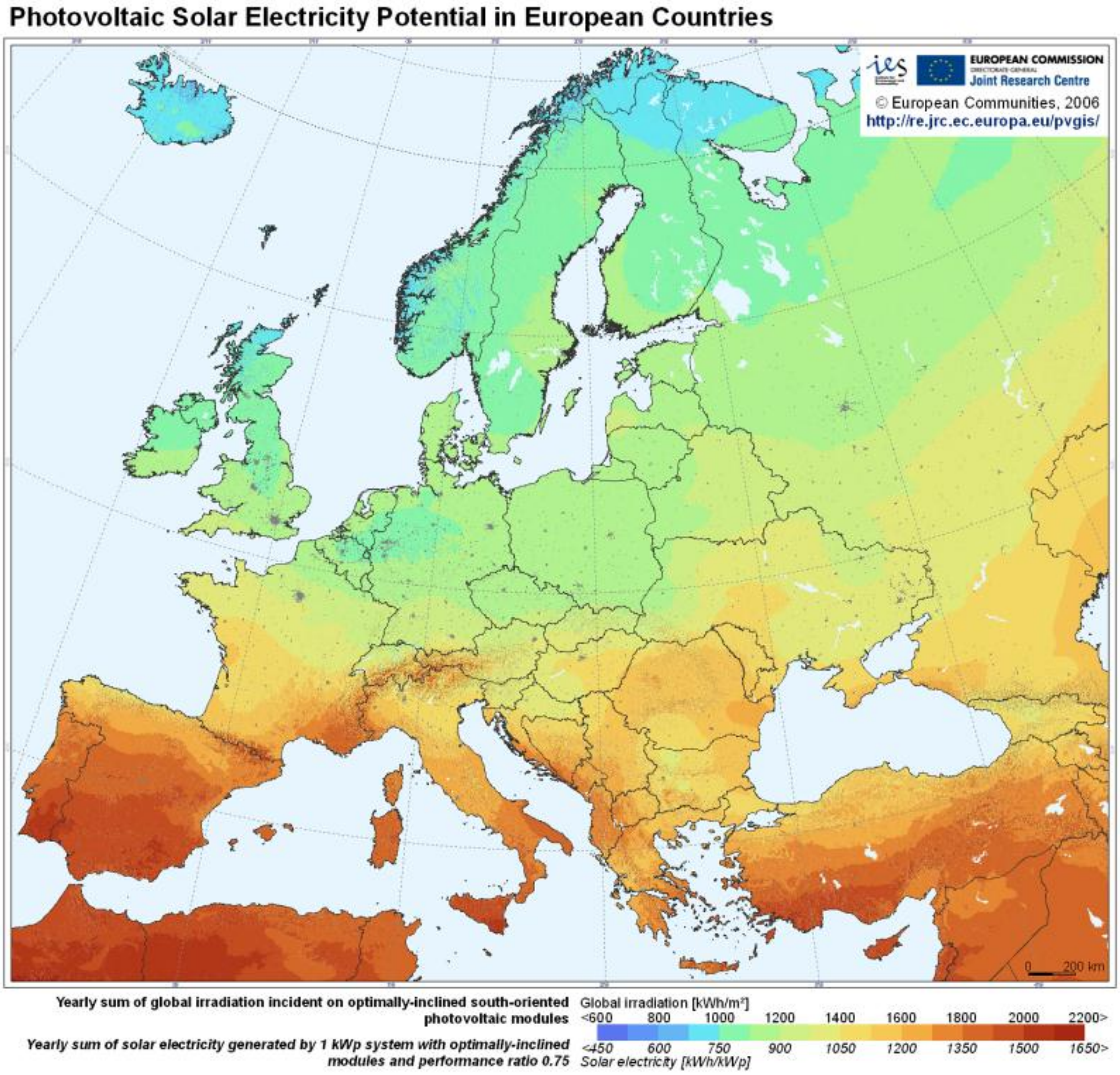


Figure 2. Photovoltaic solar electricity potential in European countries (Šúri, Huld, Dunlop & Ossenbrink 2007)

3 SOLAR POWER EQUIPMENT AND PV SYSTEM DESIGN PRINCIPLES

Figure 3. Polycrystalline solar panels in operation on the university roof

3.1 Solar Panel

Solar panel or photovoltaic (PV) module (Figure 3) is the basic electricity production unit of a PV system. Panel consists of PV-cells made from silicon each capable of producing DC-voltage of c. 0.5V. Size of a PV-cell is usually c. 10 x 10 cm with thickness of 0.1 to 0.4mm. See Figure 3 and Figure 4a for illustration. The type, quality, number and arrangement of the PV-cells used in constructing the panel determine the maximum DC-power output and the measures of the panel frame. (Erat, Erkkilä, Nyman, Peippo, Peltola & Suokivi. 2008, 121.)

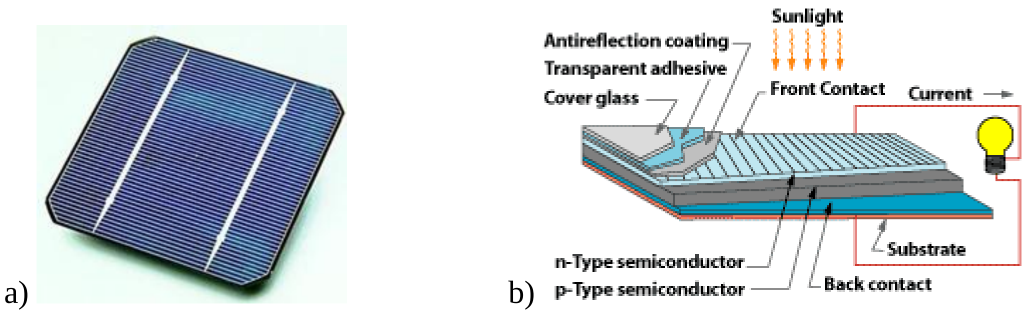


Figure 4. A silicon cell made from a mono-crystalline silicon wafer (a) and (b) illustration of a typical solar cell (Website of the U.S. Department of Energy 2013)

The function of a solar cell illustrated in Figure 4b is shortly as follows. The energy particles of the sun light i.e. photons displace electrons of the cell material (n-Type) from their orbit and these electrons travel through the load back to other side of the cell (p-Type) creating electric current.

In technology wise there are three general families of PV panels on the market today. They are *single crystal silicon*, *polycrystalline silicon*, and *thin film*. (Website of the Wholesale Solar 2013.)

“*Single crystal* modules are composed of cells cut from a piece of continuous crystal. The material forms a cylinder, which is sliced into thin circular wafers. To minimize waste, the cells may be fully round or they may be trimmed into other shapes, retaining more or less of the original circle. Because each cell is cut from a single crystal, it has a uniform colour, which is dark blue. “(Website of the Wholesale Solar 2013.)

“*Polycrystalline cells* are made from similar silicon material except that instead of being grown into a single crystal, they are melted and poured into a mould. This forms a square block that can be cut into square wafers with less waste of space or material than round single-crystal wafers. As the material cools, it crystallizes in an imperfect manner, forming random crystal boundaries. The efficiency of energy conversion is slightly lower. This merely means that the size of the finished module is slightly greater per watt than most single crystal modules. The cells look different from single crystal cells. The surface has a jumbled look with many variations of blue colour.” (Website of the Wholesale Solar 2013.)

In *thin film* panels, the active material is deposited as a microscopically thin layer on a sheet of metal or glass. Individual PV cells are deposited next to each other, instead of being mechanically assembled. Thin film technology is also called amorphous silicon, meaning "not crystalline". The active material may be silicon, or it may be a more exotic material such as cadmium telluride. (Website of the Wholesale Solar 2013.)

Some of thin film modules perform slightly better than crystalline modules under low light conditions. They are also less susceptible to power loss from partial shading of a module. The disadvantages of thin film technology are lower efficiency and uncertain durability. Current thin film materials tend to be less stable than crystalline, causing degradation over time. (Website of the Wholesale Solar 2013.)

3.2 Other Components

Depending whether the system is grid-connected or stand-alone (off-grid) system, in addition to solar panels also other components are needed. Electrical components can consist of inverters, junction boxes, batteries, voltage regulator, electricity meter and suitable cabling connecting all the components. Then there must be AC/DC load or electric grid that consumes the produced electricity. Figure 5 shows schematic of a PV system. Additionally some kind of mounting system is needed for the solar panels. The simplest PV system is actually the grid-connected system without any DC load. In simple grid-connected system only PV array, inverter and AC load are required.

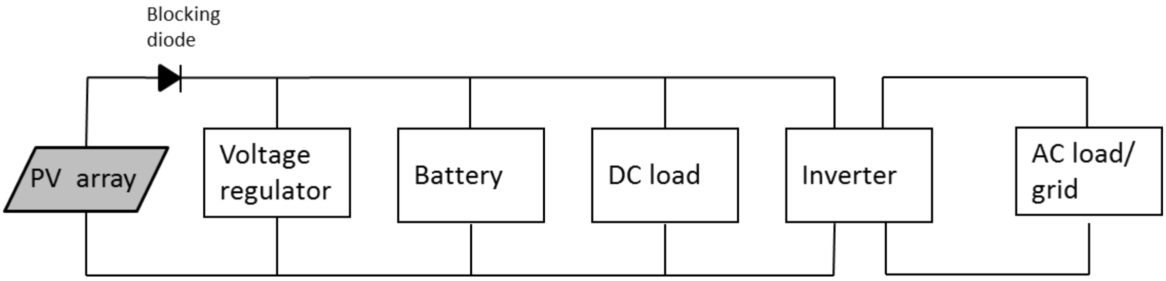


Figure 5. Schematic of a PV system

3.3 PV System Design Parameters

When designing a PV system, the basic idea is to install solar panels so that maximum power can be gained with minimum surface area. This is achieved best when sun rays are perpendicular to the panel area. This again can be achieved only when solar tracking systems are used to follow the sun movement during the day. However, due to their high cost tracking systems are rarely used and the fixed systems are prevailing technique. (Foster, Ghassemi & Cota 2010, 22.)

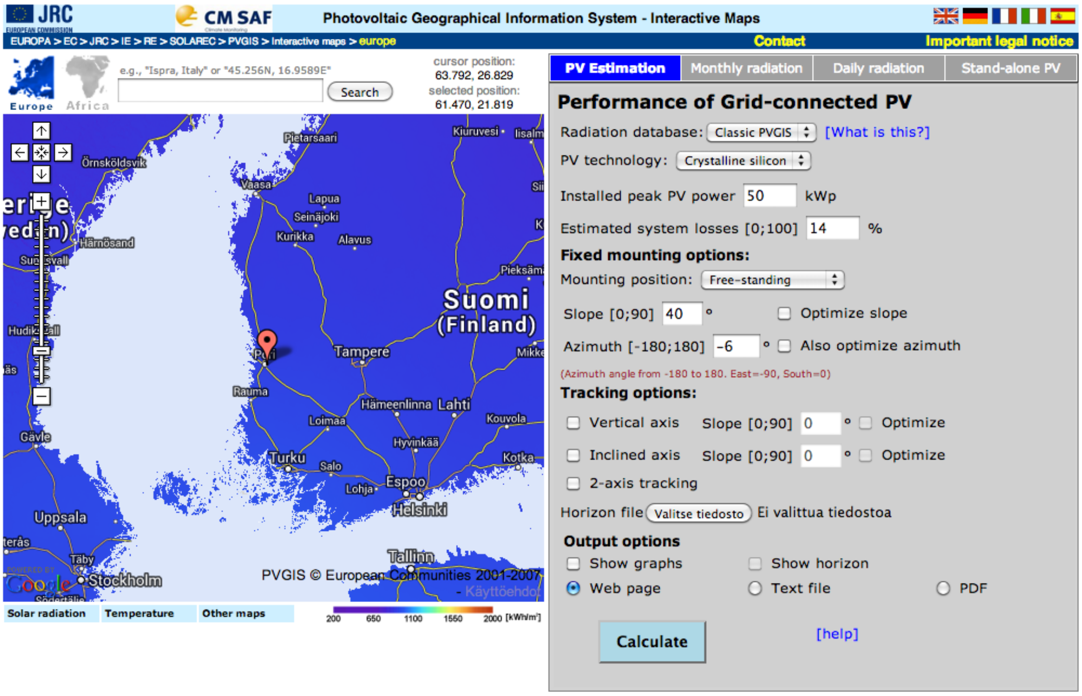
Other important factors influencing the design besides the sun angle are the sun intensity in designed location i.e. local solar conditions, shading effect, operation temperatures, and the load that should be powered by the system (Patel 2006, 170). Following subchapters describe in bit more details these design factors.

3.3.1 Available Solar Radiation

Information about local solar radiation availability is essential for the design and economic evaluation of solar energy system. Long-term measured data of solar radiation are available for a large number of locations in the world. Most of the solar energy is concentrated in the visible and the near-infrared wavelength range. The incident solar radiation is measured as irradiance, or the power per unit area, unit most often used being W/m^2. (Kreith & Kreider 2011, 283.)

Beam radiation, diffuse radiation, and their sum total solar radiation are terms used when measuring the solar radiation received from the sun. Beam radiation is the direct radiation received from the sun without been scattered by the atmosphere. Diffuse radiation again is the solar radiation after its direction has been changed by scattering or reflection. The most common measurements of solar radiation are total radiation on horizontal surface, often referred as global radiation. (Duffie & Beckman 2006, 10.)

Previously presented PV potential map in Figure 2 gives a general view of solar radiation in Europe. There are also specific web based applications for calculating global irradiation. One of the best ones is Photovoltaic Geographical Information System (PVGIS) implemented by the European commission (Šúri, Huld, Dunlop & Ossenbrink 2007). For using PV potential estimation tool one need select the location from the provided interactive map and insert some basic information regarding the planned setup. View from the PVGIS tool start-up window (Figure 6) shows what needs to be filled.



Performance of Grid-connected PV

Radiation database: Classic PVGIS [What is this?]

PV technology: Crystalline silicon

Installed peak PV power 50 kWp

Estimated system losses [0;100] 14 %

Fixed mounting options:

Mounting position: Free-standing

Slope [0;90] 40 ° ☐ Optimize slope

Azimuth [-180;180] -6 ° ☐ Also optimize azimuth

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

Tracking options:

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

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

☐ 2-axis tracking

Horizon file Valitse tiedosto Ei valittua tiedostoa

Output options

☐ Show graphs ☐ Show horizon

● Web page ○ Text file ○ PDF

Calculate [help]

Figure 6. View of PVGIS tool user interface (Šúri, Huld, Dunlop & Ossenbrink 2007)

3.3.2 Azimuth and Inclination

When the latitude of the designed solar system is other than equator the face of a fixed panel system should be oriented to the optimum direction in order to maximize the energy production. This orientation is commonly defined by terms of azimuth and inclination. Azimuth defines the horizontal direction angle or the point of the compass where panels are facing and inclination defines the angle or tilt from horizontal the panels should have. Azimuth range is from 0° (South) to +180° (West) and to -180° (East). Some applications use also normal compass definition where 180° is south etc. Inclination range is from horizontal 0° to vertical 90°. See figure 7 for illustration.

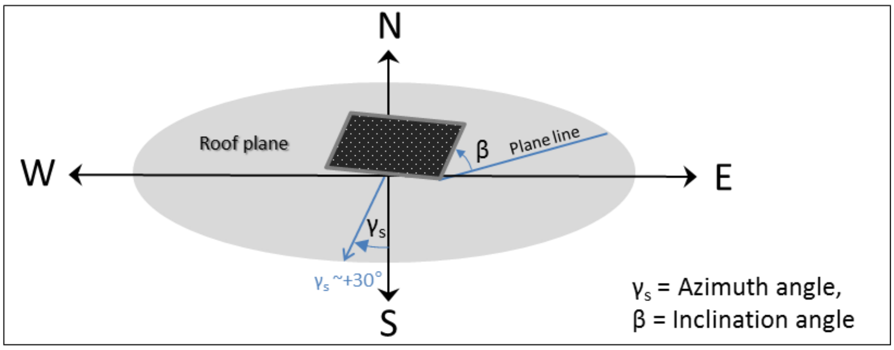


Figure 7. Azimuth and inclination angles of a solar panel

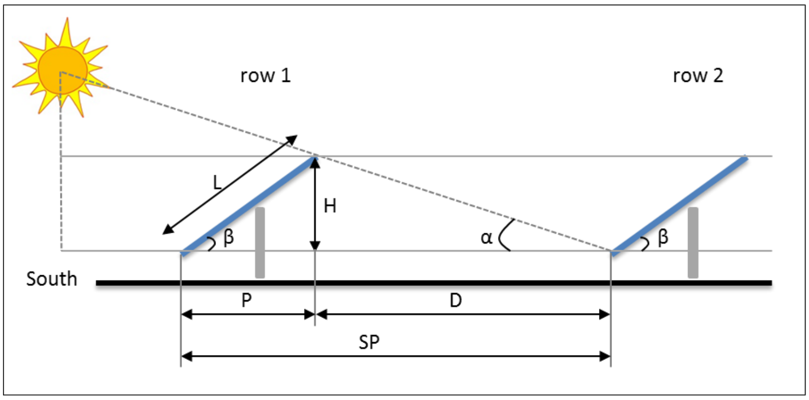
The best and most used azimuth angle for fixed solar systems in northern hemisphere is usually 0° i.e. the panel faces are towards south. The reason for this is that sun altitude angle is at its highest when it is in south. The bigger the altitude angle the smaller the irradiance attenuation effect and generally less shadowing problems to deal with.

In Finland, when trying to achieve the maximum annual energy production the inclination should be about 45°. In southern part of Finland this angle should be little less and in northern part little more. Again when optimizing production for summer time use, smaller inclination is preferred and for higher production in spring and autumn time inclination should be closer to the latitude value. Snowing and possible pile-up of the snow on the panels should be also considered and use inclination that decreases this snow effect. (Erat, Erkkilä, Nyman, Peippo, Peltola & Suokivi 2008, 84.)

3.3.3 Inter-row Shading and Array Spacing

When designing a solar array having more than one row of solar panels, the mutual shading of adjacent rows i.e. inter-row shading needs to be taken into account. This is especially important for PV systems due to significant power loss shading can cause. In inter-row shading the shading is uniform i.e. while the rows are spaced evenly also the shadow caused by the adjacent row is uniform and similar for all rows except of course for the first row of the array. The amount and configuration of the bypass diodes is important in relation to the panel orientation (portrait or landscape). If orientation is wrong one, in multi row array, the shading of the bottom row of cells i.e. about 15cm of one panel can cut down the power by 90% of the whole row instead of 20% of properly configured and oriented solar panels. (Jancauskas 2012.)

As starting point for calculating row spacing, usually the sun’s position in the sky on the winter solstice, December 21st and wanted minimum shade-free solar time window are used. For a 4 hour solar window, the sun’s altitude angles at 10 a.m. or 2 p.m. are defined. (Website of the Affordable solar 2013.) Figure 8 shows the basic idea of the previous. With designed panel inclination (β), minimum altitude angle (α), and panel length (L) of the used panels, the row spacing (SP) can be calculated using basic trigonometry.



α = Minimum altitude angle,
B = Panel inclination,
D = Distance between adjacent rows,
H = Height of panel row
L = Length of the panel
P = Length of the panel projection,
SP = Spacing of adjacent rows

Figure 8. Side view of tilted PV-array showing the minimum altitude angle and other dimensions

In practice, the geographical location and, in multi-row systems, the minimum shade-free solar window requirement set limits for the annual production period as well. As Figure 8 illustrates the minimum altitude angle describes the minimum altitude of the sun when all panels of the PV-array are still shade-free from the shading of the previous south side row. Figure 9 presents one approximate of atmospheric attenuation effect. Graph illustrates well how fast the solar intensity decreases with the declining solar altitude and this type of graphs can be used when designing the size of the minimum altitude angle.

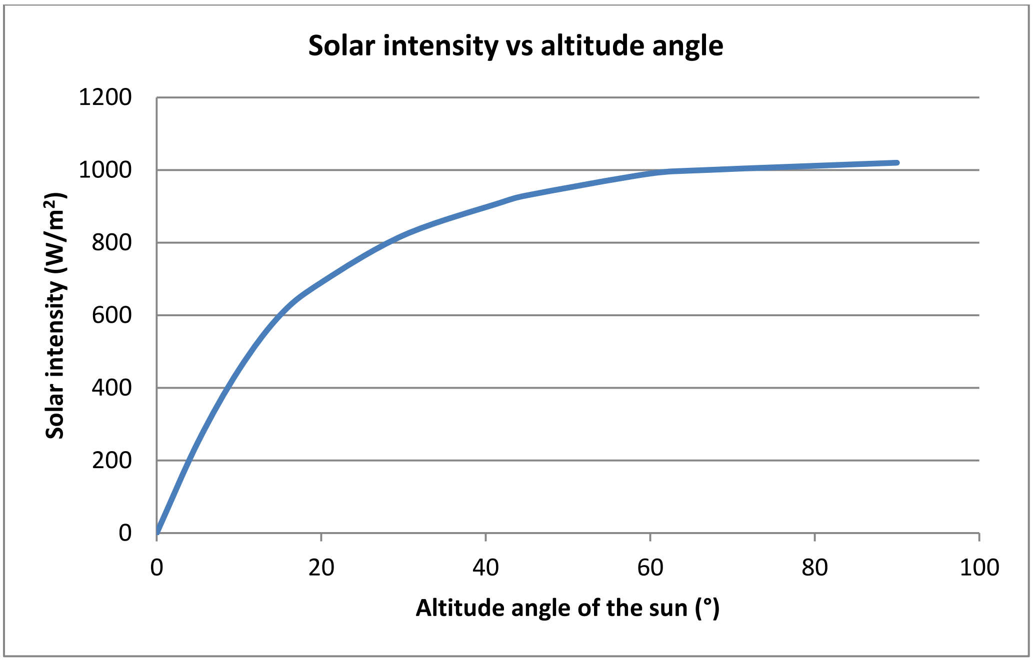


Figure 9. Atmospheric solar intensity attenuation effect (Meinel & Meinel 1976)

3.3.4 Choosing PV-panels

Maximum nominal power of the most commonly used commercially available solar panels today vary between 225-280W depending on the size, type, and efficiency of the panel. Typical physical dimensions of a commercial solar panel of this power rating, commonly used in roof mountings vary from 158cm to 196cm in length and 96cm to 105cm in width, thickness being 3-5cm and weight 19-25kg. (Website of TST Photovoltaic Shop 2013.)

As not all solar panels and module manufacturers are equal, there are a variety of other factors that should influence on purchase decision rather than focusing solely on cost. Following subchapter lists factors that should be considered according to one of the Australian largest solar energy companies. (Website of Energy matters 2013.)

3.3.4.1 Quality

One quality system widely used by PV module manufacturers is the Tiering system developed by Bloomberg New Energy Finance (BNEF). System includes three categories Tier 1, Tier 2 and Tier 3. Classification tells basically about the bankability and reliability of the manufacturer and generally the Tier 1 and Tier 2 companies are the preferred partners. (Website of the BNEF.)

3.3.4.2 Temperature co-efficient

The power output of a silicon cell decreases by about 0.5% for every degree centigrade rise. Thus, a cold day is actually better for the PV-cell, as it generates more power. Power decrease comes from the decrease of open-circuit voltage of the cell. On the other hand, the short-circuit current of the cell increases with the increasing temperature but the increase is much less than the decrease in voltage, the net effect is thus decrease in power at a higher operation temperature. (Patel 2006, 174.)

The temperature co-efficient rating mentioned in solar panel’s datasheets is important in determining what impact the heat has on a solar panel’s operation after installation. The lower the percentage per degree Celsius is the better. (Website of Energy matters 2013.) Table 1 shows the differences of losses due to local ambient temperatures between different selected locations in Europe according to PVGIS application.

Table 1. Estimated losses due to local temperature and low irradiance (Šúri, Huld, Dunlop & Ossenbrink 2007)

Pori Finland	7.2%
Hamburg, Germany	7.7%
Stuttgart, Germany	8.0%
Paris, France	9.0%
Athens, Greece	10.4%
Sevilla, Spain	12.3%

3.3.4.3 Tolerance

“Tolerance is the range a panel will either exceed or not meet its rated power. For example, a solar module may have 'nameplate' wattage of 200 watts; but due to quality control issues, may in reality only be 195 watts. A positive tolerance rating means the panel will not only generate 200 watts, but perhaps more under standard testing conditions.” (Website of Energy matters 2013.)

3.3.4.4 Conversion efficiency

The efficiency of how a solar panel converts light into electrical energy will determine how much power your system generates per area of solar panels (Website of Energy matters 2013). This is important when there is a limited area available for the panels and still the demand is high.

3.3.4.5 Embodied energy

“Another important aspect to look at is the embodied energy of the solar panel – that is how energy intensive the production of the panel was and how quickly it will have paid itself back by producing more energy.” (Website of Energy matters 2013.)

3.3.4.6 Durability Longevity and Warranty

“The durability or longevity of a solar panel is important for a number of reasons - it can be an indicator of the manufacturer's confidence in its products. Reputable solar panels will have warranty a period of 25 years.” (Website of Energy matters 2013.)

3.3.5 Sizing the PV System

With the off-grid PV systems the system sizing is more complex including load considerations and battery systems. There the sizing is also more important since usually certain set of electrical equipment are required to be powered by the system. Grid-connected PV systems are simpler consisting basically only of panels, inverters and connecting cabling.

When sizing a grid-connected PV system the size of the suitable area for panel installations and the buying and selling prices of the electricity are the most significant factors. If the price one gets from selling excess production is clearly lower than the price of bought power, oversizing of the PV system is not so feasible. In Finland where grid-connected PV systems are rather new phenomenon and net metering not used, the sizing is generally based on covering self-consumption at maximum.

Otherwise the sizing of the grid-connected PV system is mostly about selecting components that interoperate well together. This involves selecting inverter that complies with the chosen amount of panels so that the output voltage from the serial connected panels is within the range of the inverter input. Inverter needs also to comply with the quality requirements stated by the local power network operator. Suitable and thick enough cabling is selected to minimize the system losses. There is free designing software available by the inverter manufacturers that are helpful in the PV system sizing.

4 JUHANNUSLEHTO BUSINESS PARK

Lemminkäinen is planning to build a business park to Aittaluoto area at Pori. Area is owned by the company and the city plan of the site has been changed in 2012 from the initiative of the Lemminkäinen to be now applicable e.g. for large retail trade businesses. The maximum gross floor area according to the city plan is 13000m^2. (Porin kaupunki 2012.)

In practice, business park would consist of maximum of four flat roofed rectangle shaped one to two storage high buildings with gross floor area varying from about 3000m^2 to 4000m^2. See Figure 10 below with building layouts. From these four buildings the two topmost buildings, later called buildings 1 and 2, are the most likely to materialize and are also the ones concerned by the wanted solar electricity design.

Both of the building 1 and 2 are designed for large retail trade businesses without any daily consumer goods. For security reasons these type of buildings has also rather small amount of windows. Based on previous, electricity of the buildings will be consumed mostly on lighting, ventilation and cooling. Ventilation and lighting will be needed all year round and cooling is needed during the summer. Additionally specific products like TVs, from which demonstration samples are shown and switched on during the opening hours, should be considered when estimating the electricity consumption of the buildings.

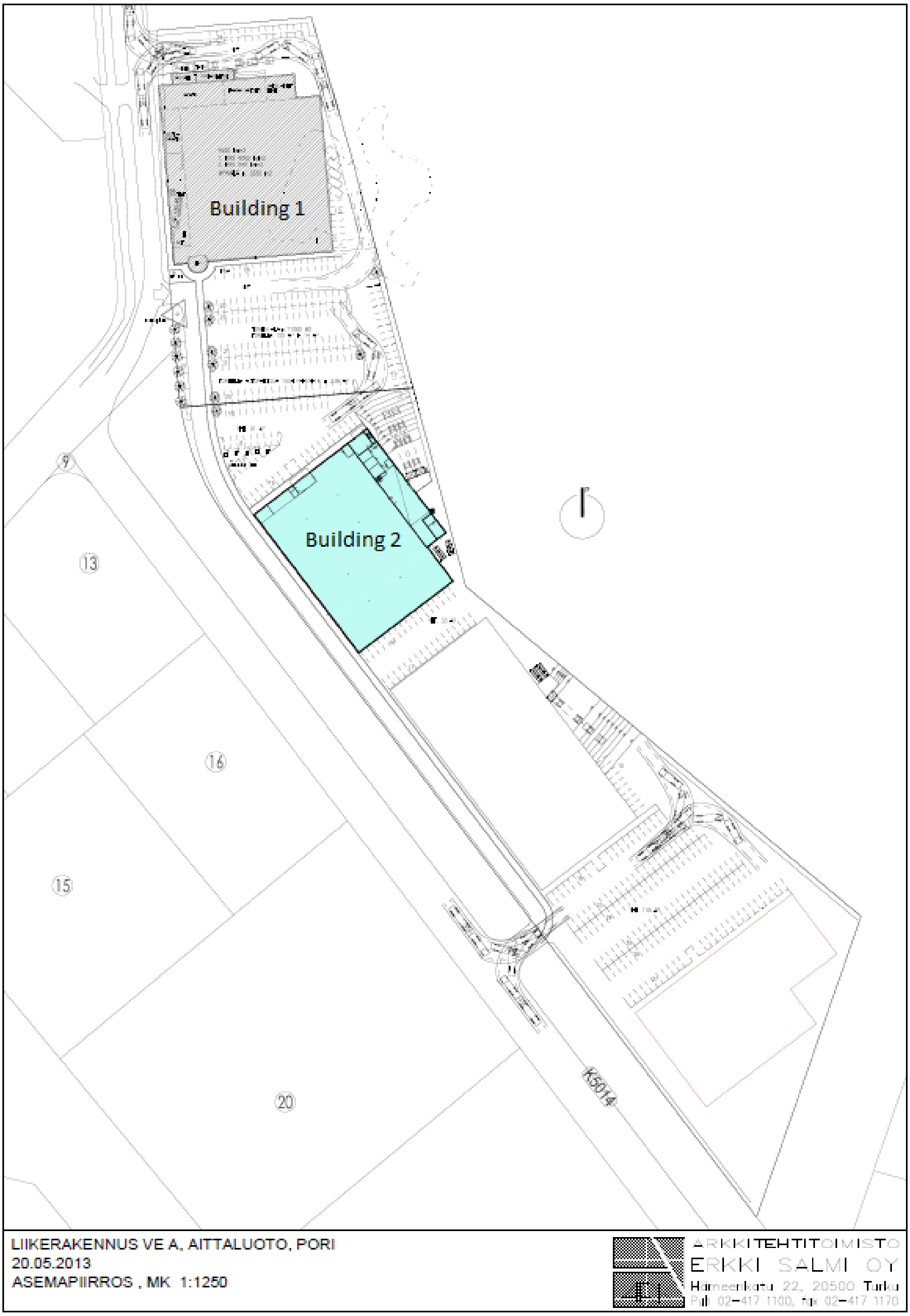


Figure 10. Juhannuslehto Business Park building layout (Porin kaupunki, 2012)

4.1 Lemminkäinen Building Construction

Lemminkäinen Corporation is one of the biggest infrastructure construction companies in the Baltic region with net sales of 2,267.6 M€ in 2012. Lemminkäinen Building Construction is one of the company's four business segments with a portfolio consisting of residential construction, commercial and office construction, construction of logistic centres and premises, industrial construction and renovation. Company provides also facility management services. Their key customers include private consumers, residential and other property investors, developers, leaseholders and owner-occupiers. (Website of the Lemminkäinen 2013.)

4.2 Possibilities for Solar Energy Implementation

Natural place for implementing the solar array field is the flat roof of the building. It was agreed with the client that the roofs of buildings 1 and 2 could be used for this purpose. Also the facade wall of at least building 1 could be appropriate place for solar panel installations. Building 1 is oriented almost optimally in south-north direction. Building 2 has less optimal orientation with best face pointing closer to south-east. See building layout in Figure 10. With flat roof solar array can basically be oriented more freely independent of the roof orientation but in this case the smoke vents and other roof structures will set some restrictions for this.

From the shading perspective the area has currently trees, mainly birches, which are up to about 15m high and thus could cause some shading effect if left near the buildings. However, according to client, existing trees will be removed from the area before the actual construction starts and new trees that will be planted afterwards will be of smaller type. Otherwise there are no high buildings or other obstacles nearby that could cause additional shading problems. However one possible structure that can cause disturbing shades on the roof of building 1 is the planned advertising sign tower. It is marked in the building layout with triangle locating by the road near the south-west corner of the building 1. Depending on the size and location of the tower its shading effect can be significant especially during spring and autumn time and anyhow something that should be considered in the design.

5 PV SYSTEM DESIGN AND DIMENSIONING - TWO OPTIONS

5.1 Scoping the Project

Originally it was decided together with the client and the supervisor that two design options for designing the PV system would be covered: first the maximum conceivable solar power production of buildings 1 and 2 (later ‘maximum option’) and second, design that would cover the estimated yearly electricity consumption of each building. However after calculations shown in chapter 5.1.3 and 5.2.5 it was evident that even the maximum option would not cover the annual electricity consumption of this size and type of buildings. Additionally, in Finland there exists an excise taxation of electricity when produced with bigger than 50kVA equipment (Valmisteverotuslaki 182/2010, section 2). Therefore it was decided with the supervisor that other design option would be the 50kW (later ‘50kW option’) system allowing also some room for the design based decisions.

Buildings of the Juhannuslehto business park are planned to be connected to local district heating network and therefore the feasibility of solar heating was seen low. The system should be grid-connected without need to store the produced electricity. The possible excess production would be transferred to local power-distribution network. Initial enquiries from the local power-distribution network operator were made for connecting this type of power plant to the grid and getting information about the tariffs etc. for selling the possible excess power.

5.1.1 Location and Building Information

Geographical coordinates used for the planned site:

Latitude: 61°29'12" N (61.4866667°N),
Longitude: 21°48'42" E (021.8116667° E) (Website of Google Maps 2013)

Orientation angles of the building (see Figure 10 for building layouts):

Building 1: -6° (south face from south 0° to east)
Building 2: -38° (south face from south 0° to east)

Available and suitable roof areas measured from the drawn 3D model were:

Building 1: ~ 3340m^2
Building 2: ~ 3030m^2

Note that in above numbers the edge zones and shaded areas, both coloured with darker grey in Figure 11 (next chapter), have already been excluded.

5.1.2 Smoke Vent Layout Estimation

One matter affecting on building roof layout and thus PV system design is the fire safety related smoke venting implementation. The idea is that in case of fire there should be enough suitable openings in the roof structure, through which dangerous smoke can be vented out from the building (The National Building Code of Finland 2005). At the time of the PV system design the building layout sketches of the roofs were available only for building 2 and its' smoke vent layout was applied also for building 1. See Figure 11a and b for used roof layouts.

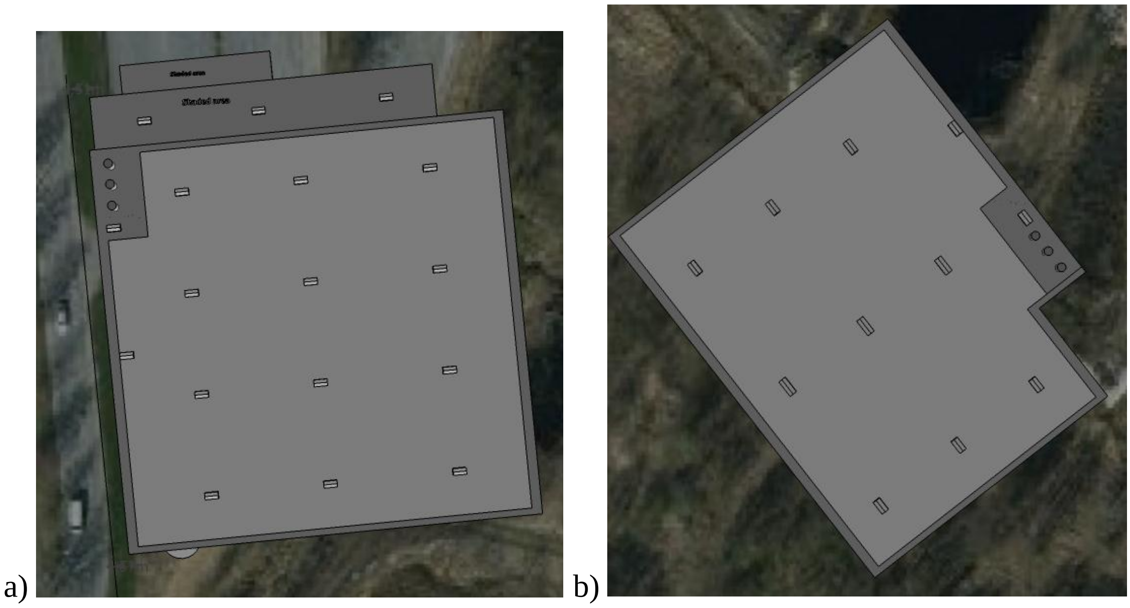


Figure 11. Used roof layouts of a) buildings 1 and b) building 2

5.1.3 Annual Electricity Consumption Estimations

In order to evaluate the annual electrical energy need of each building two different approaches were used. First one is based on national building code of Finland and the other uses consumption information of a reference building.

5.1.3.1 Computational estimation

For estimating the self-consumption quota, document The National Building Code of Finland D5 about calculating the energy consumption of a building was used. From a table 7.1 of specific electricity consumption of electrical devices of building type were found. See Table 2 below for an English translation. In the Table 2, the combined electricity consumption of lighting, ventilation and of other electrical devices for commercial building is 80kWh/grm^2/year. In the document the used gross area (grm^2) describes the total extent of the building floor area including the gross floor area of every floor independent of the usage of the rooms. Definition makes either no difference whether the rooms are heated or not and floor area includes also the area taken by the outer walls. (Suomen RakMK D5 2007, 4 and 33.)

Table 2. Specific electricity consumption of electrical devices of different building types (Suomen RakMK D5 2007, 33)

Building type	**Lighting** kWh/grm²/year	**Ventilation** kWh/grm²/year	**Other devices** kWh/grm²/year	**TOTAL** kWh/grm²/year
Apartment house	7	10	33	50
Row house	7	7	36	50
Single-family house	7	7	36	50
Office building	30	12	28	70
School building	23	12	25	60
Commercial building	48	17	15	80
Hotel	60	17	33	110
Restaurant	42	36	32	110
Sports facility	60	41	79	180
Hospital	60	28	12	100
Other	30	11	59	100

Note that Table 2 does not include the additional electricity needed for possible cooling. However, by using this information and related definitions we get already a rough estimation for the electricity consumptions of each building:

B1: (4240+329)m^2 x 80kWh/grm^2/year = <u>365 520</u> kWh/year
B2: (3370+446)m^2 x 80kWh/grm^2/year = <u>305 280</u> kWh/year

The used gross areas are based on the draft layout drawings of the buildings received from the client. These areas (inside the brackets above) represent the ground floor and first floor gross areas respectively. The electricity consumption of these three groups can be thought as being rather steady throughout the year. Cooling during summer time will add the annual electricity consumption.

5.1.3.2 Reference building based estimation

Reference information were received from a trade business store (e.g. Gigantti, Clas Ohlson, Halpa-Halli) that kindly provided some basic information of their commercial building and their monthly electricity consumption estimation figures from years 2011-2013. The gross floor area of this reference building is about 1500m^2. In year 2011 two similar heat pumps were installed for cooling causing clear increase in electricity consumption. The combined outputs of the installed heat pumps were 18.8kW in cooling mode and 16.0kW in heating mode. Charged monthly electricity consumption estimates have been 8477kWh in 2011 and 10511kWh in years 2012 and 2013. During this period the balancing payments from the power company have been insignificant.

Additional issue to consider in this case is the substantial power consumption of the 50 demonstration TV sets that have been on daily during the opening hours. With average power consumption of about 65W/TV (estimated based on web store product information) and the opening hours of the store (weekdays 10am-7pm, sat. 10am-4pm) it can be estimated that TVs consume directly:

(5 x 9.5 + 6.5)h/week x 51week/year x 50 x 65W = 8950kWh/year → = 746kWh/month,
Where real weekly opening hours with 15 min before and after them and 51 open weeks in year were used. From this energy about 60% is turned to heat (Suomen RakMK D5 2007, 41).
0.60 x 8950kWh/year = 5370kWh/year → 447.5kWh/month

This assists a bit with heating during the heating season but causes substantial additional cooling load during the months when heating is not needed.

When scaling these figures to the gross floor area of Juhannuslehto buildings 1 and 2, we get following:

TVs energy excluded:

Without the cooling/heat pumps:
B1: $4569m^2/1500m^2$ x (8477-746)kWh/month x 12month/year = 282 584 kWh/year
B2: $3816m^2/1500m^2$ x (8477-746)kWh/month x 12month/year = 236 012 kWh/year

With the cooling/heat pumps:
B1: $4569m^2/1500m^2$ x (10511-746)kWh/month x 12month/year = 356 930 kWh/year
B2: $3816m^2/1500m^2$ x (10511-746)kWh/month x 12month/year = 298 106 kWh/year

TVs energy included:

Without the cooling/heat pumps:
B1: $4569m^2/1500m^2$ x 8477kWh/month x 12month/year = 309 861 kWh/year
B2: $3816m^2/1500m^2$ x 8477kWh/month x 12month/year = 258 786 kWh/year

With the cooling/heat pumps:
B1: $4569m^2/1500m^2$ x 10511kWh/month x 12month/year = 384 198 kWh/year
B2: $3816m^2/1500m^2$ x 10511kWh/month x 12month/year = 320 880 kWh/year

By comparing these figures with the previous ones it can be seen that consumption rates based on The National Building Code of Finland D5 are rather close to the consumption rates of the scaled reference of with the heat pumps. If the yearly percentage of cooling need in the new buildings would be approximately the same as with the reference building (with heat pumps and without the TVs) we can use equation:

$$[E_{m,a}-E_{m,TV}-E_{TV,cooling}-E_{m,b}] / [E_{m,a}-E_{m,TV}-E_{TV,cooling}] \text{ x } 100\% \qquad \text{(Equation 1)}$$

Where
$E_{m,a}$ is the estimated monthly energy consumption after heat pumps (10511kWh),
$E_{m,b}$ is the estimated monthly energy consumption before heat pumps (8477kWh),
$E_{m,TV}$ is the estimated monthly consumption of TVs (746kWh) and
$E_{TV,cooling}$ is the estimated monthly cooling load of TVs (447.5kWh)

We get for the share of cooling energy to be:
(10511-746-447.5-8477)kWh / (10511-746-447.5)kWh x 100% = ~9.0%

Using this approximation and the earlier figures from the computational estimation:

B1: 365 520 kWh/year / (1 - 0.09) = 401 670 kWh/year (9% is 36 150kWh)
B2: 305 280 kWh/year / (1 - 0.09) = 335 473 kWh/year (9% is 30 193kWh)

5.2 Determining Design Parameters

In following chapters parameters needed for grid-connected PV system design are analysed and defined. In all design options portrait oriented single panel rows were applied.

5.2.1 Selecting PV-panels

Knowing the dimensions of the used PV module is important when designing the PV-array layout. For the purposes of this thesis and PV system designs no particular PV panel model was selected but all panels complying with the dimensions mentioned in the chapter 3.3.4 apply. From the power output point of view it seems that currently 240W panels are the most cost-effective panels to use but in the future this surely evolves towards higher nominal power panels. In this design 260Wp and 240Wp panels were used for the production and cost evaluation calculations presented in chapter 6.

5.2.2 Azimuth

Based on the results given by a the PVGIS application the differences in annual energy output between PV systems oriented parallel to buildings faces and systems oriented optimally to azimuth 0° were insignificant. For building 1 (azimuth -6°) the difference to optimum was less than one tenth of a per cent and for building 2 (azimuth -38°) it was less than three per cent. See Table 3 for details.

Table 3. Production (kWh) of 20kW PV system in function of azimuth and inclination during March to October with 23% system losses (Šúri, Huld, Dunlop & Ossenbrink 2007)

Array tilt (°)	$E_{\mathrm{Mar\text{-}Oct}}$ in function of azimuth			% diff to azimuth 0°		% Diff to best of same azimuth		
	0°	-6°	-38°	-6°	-38°	0°	-6°	-38°
30	15456	15445	15058	-0.07	-2.58	-0.60	-0.60	-0.55
34	15513	15521	15117	0.05	-2.55	-0.24	-0.11	-0.16
35	15519	15517	15141	-0.01	-2.44	-0.20	-0.14	0.00
36	15535	15533	15115	-0.01	-2.70	-0.10	-0.03	-0.17
37	15550	15538	15109	-0.08	-2.84	0.00	0.00	-0.21
38	15516	15514	15123	-0.01	-2.53	-0.22	-0.15	-0.12
39	15531	15529	15107	-0.01	-2.73	-0.12	-0.06	-0.22
40	15526	15524	15110	-0.01	-2.68	-0.15	-0.09	-0.20
41	15511	15499	15083	-0.08	-2.76	-0.25	-0.25	-0.38
45	15428	15437	15004	0.06	-2.75	-0.78	-0.65	-0.90

If the PV-array of building 1 would be oriented to azimuth 0° the panel rows would be fragmented, which would both decrease the nominal output and make the installation more difficult and likely more expensive. See Figure 12a for illustration. In all, for building 1 it is evident that in both design options the PV-array should be installed parallel to the building facade that points almost south.

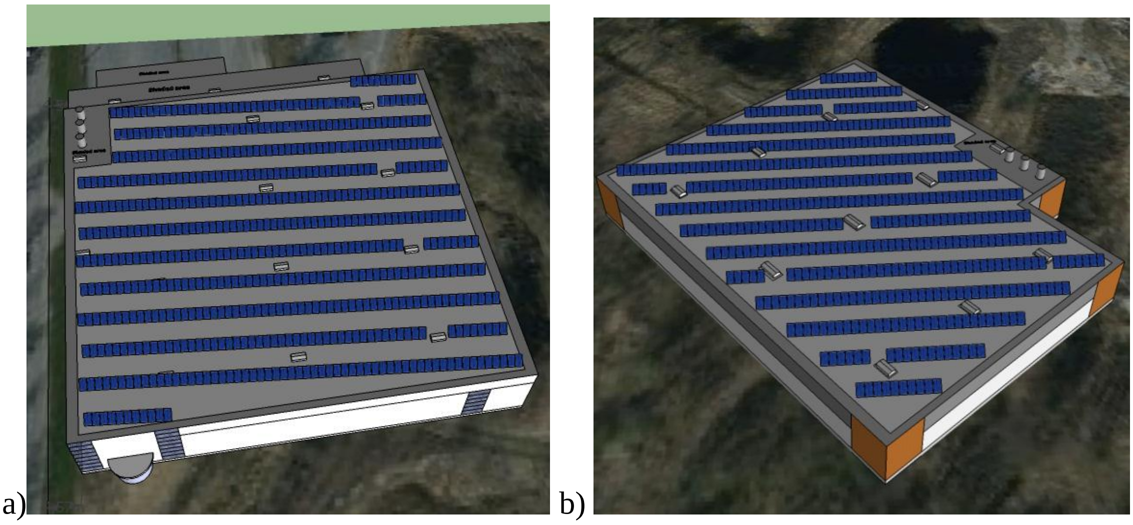


Figure 12. Azimuth 0° PV-array orientations of a) building 1 and b) building 2

For the PV-array of building 2 the azimuth optimal for each design option is less straightforward to define. With example spacing of 4.8m and azimuth -38°, PV-array would fit 622 panels when with azimuth 0° the number would be 559 panels. With more sensible segmentation shown in Figure 12b and with spacing of 5.0m the PV-array would fit 541 panels. With this setup and even with the 3% additional power gain due to more optimal orientation the maximum power output would still drop roughly 10%. In other words at least for maximum option also the PV-array of building 2 should be aligned with building faces. The 50kW options are covered in more details in chapter 5.2.4.2.

5.2.3 Inclination

According to PVGIS application results shown in Table 3 the optimal inclination for the roof arrays for the used production period of March to October would be 37° for the building 1 and 35° for the building 2. Taking that the differences between the system outputs with inclinations from 34° to 40° are all within 0.2%, and having at the same time bit more snow proof for the system, a 40° tilt angle seemed reasonable round figure and was chosen for the both buildings.

5.2.4 Array Spacing

In addition to smoke vent layout and row inclination, array spacing design is affected also by other factors. Wanted or feasible production period, required maximum system output, inter-row shading and other possible shading and structural limitation of the site are all factors that have an effect and that are also interdependent of each other. Naturally the economical evaluation over the whole is essential and cost-efficiency often the crucial factor.

We know, the solar altitude angle (α) at Pori on the winter solstice is about 5° at solar noon and we can see from the Figure 1 that α is about 2° two hours before and after the noon. For a four hour shade-free solar window using panel rows with inclination (β) of 40° and panel length (L) of 165cm this would give spacing of over 31 meters. This again would enable the installation of only about 15% of panels compared to of using 17° as α. Also due to the atmospheric attenuation (see Figure 9), with α 5° the sun intensity is about one fourth (~240W/m^2) of the maximum summer time values (~940W/m^2) and about one third of the 17° values (~640W/m^2). In Pori α is less than

17° for about four months around the winter solstice between weeks 42 and 8. See appendix 1 for sun altitude table.

5.2.4.1 Maximum Option

Figure 13a and b shows the designed final maximum option PV-array layouts of the buildings. Minimum altitude angle of 17° and inclination of 40° were used as the most determining factors. Smoke vent layout affected also to the PV-array layouts and the absence of B1 roof layout remains X-factor of the PV system design of building 1. Other common X-factors are the ventilation flues and other possible HVAC related devices that will be installed on the roof. For minimizing the mutual shading effect of adjacent rows, same spacing value was used for whole array being 5.2m for building 1 and 4.8m for building 2. About 1-1.5m wide zone around the used shade-free roof area was left for the maintenance activities.

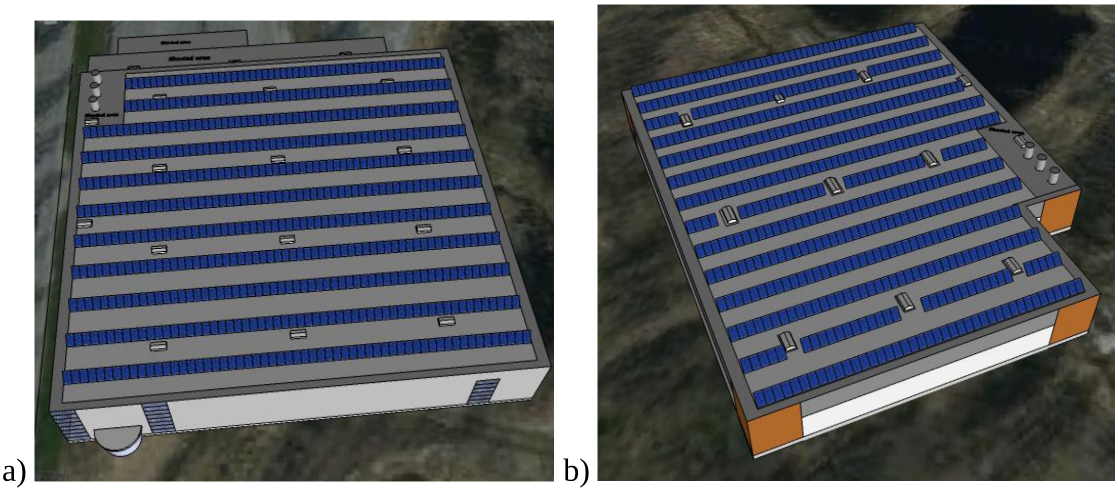


Figure 13. Final PV-array layouts for max option of a) building 1 and b) building 2

With building 1 more panels were fitted on the roof by taking away one whole panel row and increasing the spacing accordingly. Leaving the row would have caused the fragmentation of three other rows. Additionally, increase of row spacing will give a couple of degrees lower minimum solar altitude angle and thus a bit longer daily solar window for the electricity production.

In case of building 2 it was not possible to find equal row spacing that would have kept all the rows in one piece without losing a whole row of 50 panels. When the azimuth of the PV-array was set to 0°, about 80 panels less could have been fitted on the roof (see Figure 12). In this case the additional output of about 3% received with the more optimal azimuth angle is not enough to compensate the output lost with the 80 less panels. Finally the setup with pair of fragmented rows was seen as the best choice for the maximum option. However depending on the difference in installation costs, the azimuth 0° -option with smaller peak output, would likely be more cost-effective design solution.

5.2.4.2 50kW Option

When there are fewer panels and panel rows to fit into same area the possibilities to optimize the annual production per installed panel area and to design more cost-effective PV system are better. The row spacing can be increased, which again extends the production period from both ends and enables longer daily solar window. In all, the annual output per installed peak power watt is increased making the whole system more cost-effective. See Figure 14a and b for final PV-array layouts of the buildings 1 and 2.

In case of building 1, the row spacing was increased to 10m and 4 equal length full rows from 11 of the maximum option were left and located to the northern side of the roof. With this layout the harmful shading effect caused by the planned advertising sign tower in front of building 1 can mostly be avoided. Azimuth of the PV-array was not changed due insignificant impact on the power production. Final panel count using 240Wp modules is 208 giving total DC power peak output of 49.9kW.

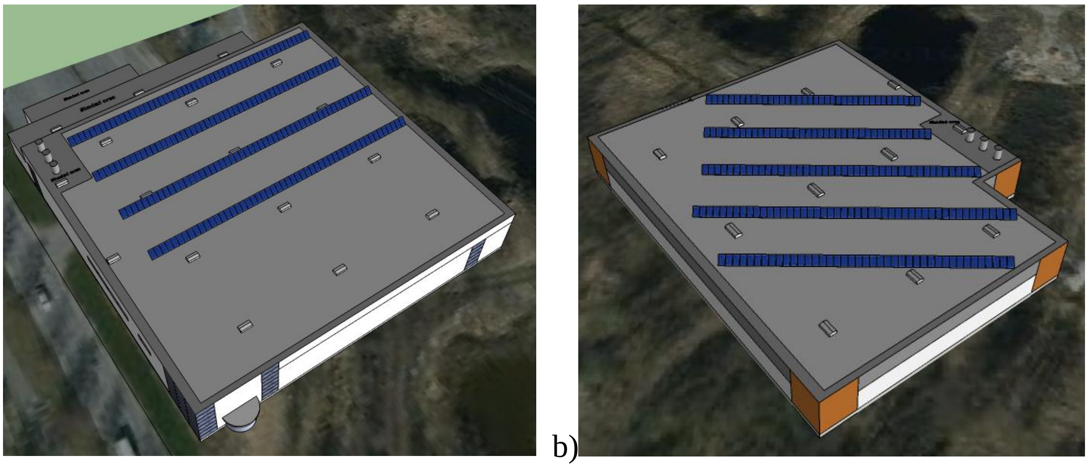

a) b)

Figure 14. Final PV-array layouts for 50kW option of a) building 1 and b) building 2

In case of building 2, the row spacing was increased also to 10m and the azimuth of the PV-array was changed to 0°. Figure 14b presents the approximated PV-array layout with total of 208 solar panels divided in five rows. Using 240Wp modules, field gives total DC power peak output of 49.9kW. In addition to the benefits mentioned already for building 1 the azimuth change increases the output with almost 3% lost in the maximum option case.

5.2.5 Final Design Parameters and System Outputs

PVGIS application was used in estimating the annual energy production rates of the different setups. PVGIS gives average monthly electricity production rates of the given system but does not take into account the inter-row shading effect. Therefore as estimation the monthly production of period March to October was used for the maximum options (narrow row spacing) and period February to October was used for the 50kW options (wide row spacing). Additionally, a comparison study using the production data of SAMK PV plant was performed for deriving a real reference based correction factor.

5.2.5.1 SAMK PV Plant Based Correction Factor

Real data of SAMK PV plant production rates was compared with the PVGIS application estimates of similar plant to verify the results and to generate a kind of reality based correction factor. Other option to use SAMK plant data would have been just to scale the production rates to the magnitude of Juhannuslehto designs but that way the effect of different azimuth and inclination would have been neglected. SAMK plant itself constitutes of 18 pieces of 210W panels having total plant power of 3.78kW. Panels are installed in three adjacent rows each having 6 landscape oriented panels and different inclination (30°, 45° and 60°). Azimuth of the whole array was measured to be about -21°. Using the production data of the SMA Sunny Portal provided with the SAMK PV system, monthly production rates from the period of May 2011 to August 2013 were gathered and averaged. Average yearly production rates were calculated for 30° and 45° -rows being the closest to the 40° inclination of the Juhannuslehto array design. The 45°-row is the middle row in the SAMK system. Still the shading effect of the low 30°-row about six meters in front of it is minimal causing minimum altitude angle of less than 5° for the 45°-row.

In comparison, the design parameters of SAMK PV plant rows 30° and 45° were used as input for PVGIS application and the results were compared with the real production rates of the SAMK plant. Correction factors were calculated for Mar-Oct and Feb-Oct periods. See Table 4 for the average production rates and correction factors.

Table 4. Comparison between PVGIS application and SAMK plant production rates.

	45°-row (kWh), Wp = 1.26kW			30°-row (kWh), Wp = 1.26kW		
Period	**SAMK avg**	**PVGIS**	$\mathbf{F}_{\mathbf{corretion}}$	**SAMK avg**	**PVGIS**	$\mathbf{F}_{\mathbf{corretion}}$
Full year	1067	1080	0.988	1058	1063	0.996
Mar-Oct	1037	964	1.076	1039	966	1.075
Feb-Oct	1059	1024	1.035	1052	1017	1.035

The full year production rates between SAMK plant and PVGIS estimates are practically the same but when subtracting three or four darkest months differences are clear. For some reason PVGIS tool estimates are higher for months from November to February than the real rates of SAMK system. In general in the PVGIS estimate, the production is divided bit more evenly for all months. Recorded data again shows that production rates rise faster in spring (Feb-Mar), are higher in summer time and again drop faster in autumn. Correction factors are practically the same for both rows giving credit to the results and indicating that the same correction factors can be used for 40° inclination as well.

5.2.5.2 Deriving the Final Production Estimates

Correction factors of Table 4 were used in calculation of the final system outputs. For comparison also direct up-scaling of the SAMK plant production rates were performed. Following tables (Table 5, Table 6) gather the results of corrected PVGIS production estimates. Note that the results for the 50kW options of B1 and B2 are practically the same and that the used panel type (240Wp or 260Wp) has no effect.

Table 5. Original and corrected production rate estimates using 240Wp panels.

	B1-max	**B1-50kW**	**B2-max**	**B2-50kW**
Total peak power (kW)	150.2	49.9	150.7	49.9
PVGIS estimates/period (kWh)	116460	41050	113650	41080
Corrected estim/period (kWh)	125266	42484	122243	42515

Table 6. Original and corrected production rate estimates using 260Wp panels.

	B1-max	**B1-50kW**	**B2-max**	**B2-50kW**
Total max power (kW)	162.8	49.9	163.3	49.9
PVGIS estimates (kWh)	126060	41050	123200	41080
Corrected estim/period (kWh)	135592	42484	132515	42515

Finally the following three tables (Table 7, Table 8 and Table 9) list the used design parameters and PV system production rates of both design options for both buildings. Table 7 list the common parameter that are the same for all designs and tables 8 and 9 shows the design parameters of both designs for building 1 and 2 respectively.

Table 7. Common design parameters of the Juhannuslehto PV systems

Parameter	**Value**	**Parameter**	**Value**
Inclination	40°	Panel width	982-994mm
Panel Power (P_{max})	240W, 260W	Panel length	1638-1665mm
Panel orientation	Portrait	Space between panels	20mm

Table 8. Design parameters of building 1 design options

B1 PV design	**Maximum option**		**50kW option**		
Parameter	240Wp	260Wp	240Wp	260Wp	Unit
Azimuth	-5.6	-5.6	-5.6	-5.6	°
Min altitude angle	15	15	7	7	°
Row spacing	5.2	5.2	10	10	m
Row count	11	11	4	4	
Panels/row	52-58	52-58	52	48	
Total panel count	626	626	208	192	
Total panel area	1025	1033	340	317	m^2
Total Max Power	150.2	162.8	49.9	49.9	kW
Production period	8	8	9	9	months
Annual energy (E_a)	123.6	133.9	42.0	42.0	MWh/a
E_a/panel area	120.6	129.6	123.3	132.5	kWh/m^2
E_a/gross floor area	27.1	29.3	9.2	9.2	kWh/grm^2

Table 9. Design parameters of building 2 design options

B2 PV design	**Maximum option**		**50kW option**		
Parameter	240Wp	260Wp	240Wp	260Wp	Unit
Azimuth	-38	-38	0	0	°
Min altitude angle	17	17	7	7	°
Row spacing	4.8	4.8	10	10	m
Row count	14	14	5	4	
Panels/row	41-50	41-50	38-47	39-51	
Total panel count	628	628	208	192	
Total panel area	1027.9	1036.2	334.6	316.8	m^2
Total Max Power	150.7	163.3	49.9	49.9	kW
Production period	8	8	9	9	months
Annual energy (E_a)	124.0	134.3	42.0	42.0	MWh/a
E_a/panel area	120.6	129.6	125.4	132.5	kWh/m^2
E_a/gross floor area	32.5	35.2	11.0	11.0	kWh/grm^2

According to PVGIS application the combined PV system losses are 22.7% including:

- Estimated losses due to temperature and low irradiance of 7.3% (using local ambient temperature),
- Estimated loss due to angular reflectance effects of 3.1% and
- Other losses (cables, inverter etc.): Default of 14.0% was used. (Šúri, Huld, Dunlop & Ossenbrink 2007.)

The differences in comparable 'E_a/panel area' values in above tables, between the maximum and 50kW options come from the energy production of February, for building 2 also partly from the azimuth optimization. In practice the differences would be bigger for two reasons. First, the roughly doubled array spacing of 50kW options extends the production period from both ends and enlarge the daily solar window with the morning and evening hours when α is between 7° and 15° (B1) or 7° and 17° (B2). Of course when the solar azimuth is closer to 90° and the sun shines from the side or behind the array, there is only the small diffuse radiation component left for energy production. The other reason for the bigger actual difference is that with maximum options the inter-row shading, not taken into account by the PVGIS application, cuts down the production rates more than just for Nov to Feb period. Additionally, depending bit on the panel bypass diode configuration, inter-row shading effect practically ends the daily production gradually within about one hour after α has reached the designed 15° or 17° minimum limit.

5.2.5.3 Comparing Production and Consumption

When comparing the estimated annual energy production rates with estimated consumption rates from chapter 5.1.3 it can be calculated that at its best the production will cover only about 37% (240Wp) of the annual total estimated electricity consumption:

B1 – maximum option: 123.6MWh/year / 401.7MWh/year x 100% = 30.77% → ~ **31%**

B1 – 50kW option: 42.0MWh/year / 401.7MWh /year x 100% = 10.46% → ~ **10%**

B2 – maximum option: 124.0MWh/year / 335.5MWh/year x 100% = 36.96% → ~ **37%**

B2 – 50kW option: 42.0MWh/year / 335.5MWh/year x 100% = 12.52% → ~ **13**%

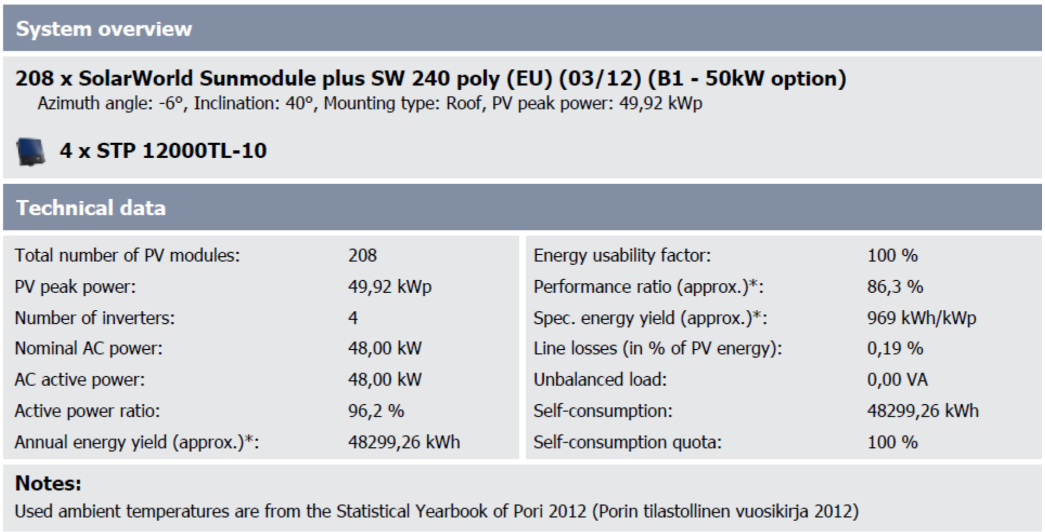
By comparing the annual production with the values in Table 2, listing the building type related specific electricity consumption of electrical devices, it can be seen that at its best (B2 – maximum option) the produced energy can cover the consumption of ‘air venting’ plus ‘other devices’ (32kWh/grm^2/year). With the smallest share (B1 – 50kW option) the estimated energy consumed for cooling (~9% of total) can be covered.

5.3 Sizing the Systems Components

In addition to PV panels and their mountings also junction boxes, inverters and other possible components are needed for operational PV system. Naturally also cabling connecting all the electrical components is needed. Typically inverter manufacturers provide design software for dimensioning the PV system. In this work Sunny Design SW application by SMA was used for designing proper inverter configuration and cabling. Due to feasibility reasons, this dimensioning was done only for the 50kW design options.

Dimensioning is started by giving information about the project data, location, cell or ambient temperatures and grid connection. In next phase the model of used PV modules, their amount, and orientation are added. Based on the previous, application calculates and proposes possible inverters configurations with presenting efficiencies and energy usability percentages. Some manual work is required to choose the best configuration that fits best the layout of the designed PV-array. At this point also the cabling can be designed. Cable lengths of DC and AC cables can be entered to the program to get the power loss caused by the cabling. Application gives the energy yield estimates of the PV plant and after this there is also possibility to estimate the self-consumption vs. grid feed-in figures.

Figure 15 and Figure 16 gives the system overview with basic technical data of the 50kW option designs. Note that the annual energy yields are clearly higher for not taking into account e.g. the shading effect and shorter production period. See more detailed Sunny Design reports from appendix 2.



System overview

208 x SolarWorld Sunmodule plus SW 240 poly (EU) (03/12) (B1 - 50kW option)
Azimuth angle: -6°, Inclination: 40°, Mounting type: Roof, PV peak power: 49,92 kWp

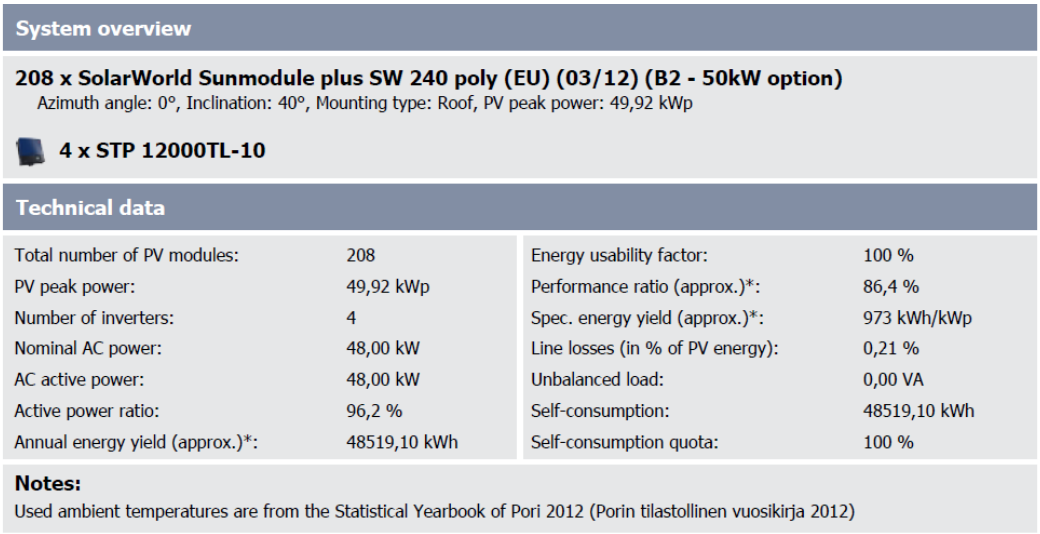
4 x STP 12000TL-10

Technical data

Total number of PV modules:	208	Energy usability factor:	100 %
PV peak power:	49,92 kWp	Performance ratio (approx.)*:	86,3 %
Number of inverters:	4	Spec. energy yield (approx.)*:	969 kWh/kWp
Nominal AC power:	48,00 kW	Line losses (in % of PV energy):	0,19 %
AC active power:	48,00 kW	Unbalanced load:	0,00 VA
Active power ratio:	96,2 %	Self-consumption:	48299,26 kWh
Annual energy yield (approx.)*:	48299,26 kWh	Self-consumption quota:	100 %

Notes:
Used ambient temperatures are from the Statistical Yearbook of Pori 2012 (Porin tilastollinen vuosikirja 2012)

Figure 15. Sunny Design system overview for B1 – 50kW option.



System overview

208 x SolarWorld Sunmodule plus SW 240 poly (EU) (03/12) (B2 - 50kW option)
Azimuth angle: 0°, Inclination: 40°, Mounting type: Roof, PV peak power: 49,92 kWp

4 x STP 12000TL-10

Technical data

Total number of PV modules:	208	Energy usability factor:	100 %
PV peak power:	49,92 kWp	Performance ratio (approx.)*:	86,4 %
Number of inverters:	4	Spec. energy yield (approx.)*:	973 kWh/kWp
Nominal AC power:	48,00 kW	Line losses (in % of PV energy):	0,21 %
AC active power:	48,00 kW	Unbalanced load:	0,00 VA
Active power ratio:	96,2 %	Self-consumption:	48519,10 kWh
Annual energy yield (approx.)*:	48519,10 kWh	Self-consumption quota:	100 %

Notes:
Used ambient temperatures are from the Statistical Yearbook of Pori 2012 (Porin tilastollinen vuosikirja 2012)

Figure 16. Sunny Design system overview for B2 – 50kW option.

6 PV SYSTEM COST AND PAYBACK TIME

The most critical factors in determining the value of electricity generated by PV systems are firstly the initial cost of the hardware and installation, and secondly the amount of electricity produced annually. When the system produces electrical energy for the grid, the price for which the electrical energy can be sold is also critical. For faster investment payback of grid connected systems, most of the energy should be used on site. That energy is worth the retail rate while selling to the utility is generally valued less because most power companies do not voluntarily want to purchase energy at the retail level from their customers. Net energy billing i.e. net metering allows for larger size systems because the system can be sized for producing all the energy needed on site. In net metering customer pays only for the net power consumed i.e. the customer produced electricity is reduced from the consumed electricity before billing. Net metering typically needs to be mandated by the government to be adopted by power companies. (Foster, Ghassemi & Cota 2010, 232.)

In Finland, net metering is not reality yet even the study of its possibilities has been listed in the program of the sitting government. Additionally there is no tariff price for PV production. In the Juhannuslehto case, the situation is good since practically all the produced energy, even with the maximum option, can be consumed on site. However in practice without any control devices in place, some power would be fed in the network e.g. during low consumption times like during closing days. In max system cases this would cause the need for paying the excise tax for the production of the particular month.

There are many economic factors that should be considered when purchasing a renewable energy system:

1. Load and energy, calculated by month or day for small systems;
2. Cost of energy from competing energy sources to meet the need;
3. Initial installed cost;
4. Production of energy (size of the system, warranty, solar resource, reliability);
5. Selling price of energy produced and anticipated energy cost changes;
6. Operation and maintenance costs;
7. Time value of money (interest rate, fixed or variable)

8. Inflation;
9. Legal fees (negotiation of contracts, titles, easements, permits);
10. Depreciation if system is a business expense; and
11. Possible national incentives there are. (Foster, Ghassemi & Cota 2010, 233.)

In following chapters the initial installed costs have been calculated and the payback times have been estimated. For simplicity and due to the fact that the design options of both buildings are practically identical the figures of maximum and 50kW design options of building 1 were used.

6.1 System Costs

Two approaches were used in estimating the cost of each PV system. As one, real or at least realistic offers were requested from the system and panel suppliers to estimate the total costs of each system. Additionally assistance was asked from the client for estimating the installation costs. Another and faster way was to study the development and estimations there are in the internet for PV energy prices in terms of euros per installed peak watt of PV energy, also called the PV system price (€/kWp).

Figure 17 shows the trend of the small-scale system price development for the last two and a half years. From the trend, the system prices drop of about 33% in last two years can be seen, current price being about 1 600€/kWp (All offers price). For commercial-scale systems or generally systems bigger than 50kWp the price is lower. Resent development of the trade dispute between EU and China has raised the module prices. The evolution of module prices (see Figure 18) is important, as modules account roughly 50% of the PV system cost. (Website of PV magazine 2013.)

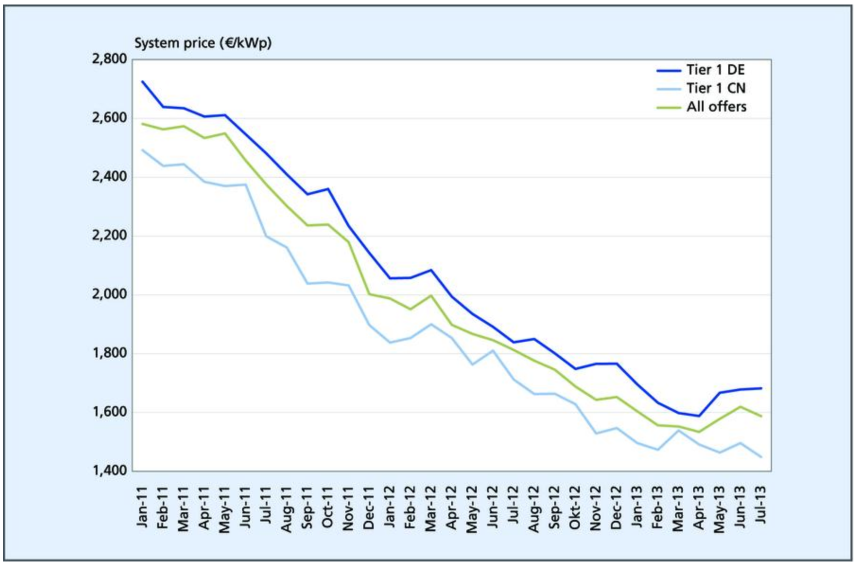
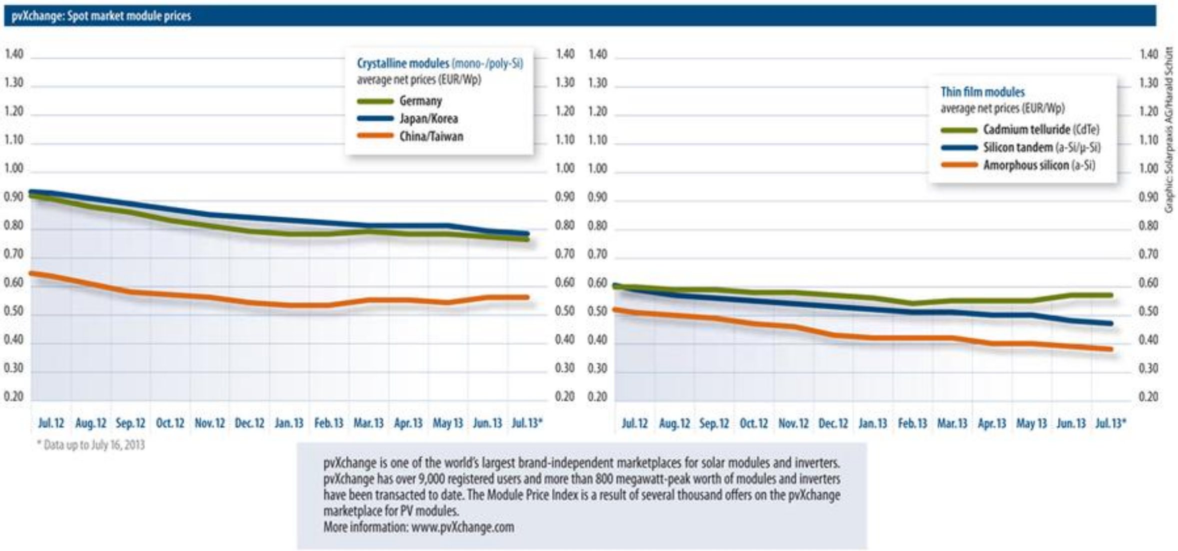


Figure 17. Small-scale system price development (Website of PV magazine 2013)



pvXchange is one of the world's largest brand-independent marketplaces for solar modules and inverters. pvXchange has over 9,000 registered users and more than 800 megawatt-peak worth of modules and inverters have been transacted to date. The Module Price Index is a result of several thousand offers on the pvXchange marketplace for PV modules.
More information: www.pvXchange.com

Figure 18. Market module prices (Website of PV magazine 2013)

6.2 Final Cost Estimation

In Table 10, a comparison of initial installed costs and system prices are presented. Design options of building 1 were used in the calculations, but the results can be applied for building 2 as well since differences in system sizes between the buildings are minor. Two separate offers were used as a basis for the calculations. Offer 1 was from a Finnish system supplier and included both hardware and the installation costs and the offer 2 was calculated using hardware offer from a Spanish supplier added with estimation of installation costs.

Table 10. Final cost comparison of installed system using 240W panels

SYSTEM COSTS (240Wp)	**Offer 1**		**Offer 2**	
Cost/Option	**Maximum**	**50kW**	**Maximum**	**50kW**
System max power, kWp	150	50	150	50
Hardware costs, €/Wp	included	included	1.05	1.13
Installation cost estim, €/Wp	included	included	0.17	0.17
System price, €/Wp (VAT 0%)	1.27	1.27	1.22	1.30
System price, €/Wp (VAT 24%)	1.57	1.57	1.47	1.57
Total price, € (VAT 0%)	190384	63259	182875	64757
VAT share, €	45692	15182	37860	13538
Initial installed cost, €	**236076**	**78441**	**220736**	**78296**

6.3 Payback Time

A renewable energy system is economically feasible only if its overall earnings exceed its overall costs within the lifetime of the system. The time at which earnings equal cost is called payback time. (Foster, Ghassemi & Cota 2010, 233.) In this case the earnings constitute practically solely of annual save of displaced energy. Energy price of 10.2cent/kWh based on the tariff of local power supplier Pori Energia was used as a starting price for the calculations. There are also additional issues that should be considered when determining the payback time or life-cycle costs. From these photovoltaic degradation and national incentives are explained shortly before the actual payback and life-cycle cost calculations.

6.3.1 Photovoltaic Degradation

The power output of a PV modules and systems is not stable over the course of time but is decreased with certain rate. Accurate quantification of power decline over time, also known as degradation rate, is essential to all stakeholders. Financially, degradation of a PV module or system is equally important, because a higher degradation rate translates directly into less power produced and, therefore, reduces future cash flows. For the purposes of this design degradation rate median of 0.59%/year for multi-silicon post year 2000 PV systems were used. (Jordan & Kurtz 2012, 1 and 18.)

6.3.2 National Energy Incentives

Incentives are very important factor in enhancing the economic feasibility of renewable energy investments. In year 2013, the support granted by the ministry of employment and economy of Finland, for PV energy projects by businesses, municipalities and communities was 30% (Website of the Työ- ja elinkeinoministeriö 2013). For the purposes of this thesis, when knowing the difficult economic situation Finland is facing, a bit more conservative incentive of 15% were chosen.

6.3.3 Payback Time Calculations

First a simple payback calculation was made. There the cost of the system is divided by the cost of energy displaced per year. Assumptions were that all the production is self-consumed and maintenance need is minimal and included into normal facility operation and maintenance costs. The initial installed costs from the Table 10 were used:

$$N_{pb,s} = C_i / (E_a \text{ x } P_e) \qquad \text{(Equation 2)}$$

where $N_{pb,s}$ = the simple payback in years
C_i = Initial cost of installation after incentive reduction [€]
E_a = Annual save/displacement of energy [kWh] (PV degradation effect excluded),
P_e = Price of energy displaced [€/kWh]. (Foster, Ghassemi & Cota 2010, 234.)

As example for offer 1/B1 50kW option with 240Wp panels and 15% incentive we get:

$$N_{pb,s} = (78\,441 – (15\% \text{ x } 78\,441)) / (42484\text{kWh x } 0.102€/\text{kWh}) = 15.3 \text{ years}$$

Table 11. shows the results for all configurations. With this method the payback time is about 19 years at maximum and about 15 years at minimum. The effect of the incentive is clearly visible cutting down the payback times with nearly three years in all cases.

Table 11. PV system payback times according to simple payback calculations

SIMPLE PAYBACK [years]	Offer 1		Offer 2	
SYSTEMS (240Wp panels)	Incent=15%	Incent=0%	Incent=15%	Incent=0%
B1 max option	15.6	18.4	14.6	17.2
B2 max option	16.0	18.8	15.0	17.6
B1 50kW option	15.3	18	15.3	18
B2 50kW option	15.3	18	15.3	18

In reality the electricity price is likely to rise in the future and on the other hand with this substantial investment loan financing is likely needed. Also the photovoltaic degradation was not considered earlier. By using more sophisticated method these variables can be considered too and more realistic values can be obtained. Following equation takes into account the predicted annual energy price and expense development:

$$N_{pb} = \frac{\ln(\frac{C_i*(p-d)}{P_e*Ea-T}+1)}{\ln(\frac{1+p}{1+d})} \qquad \text{(Equation 3)}$$

where C_i = Initial cost of the investment after incentive reduction [€],
P_e = Current energy price [€/kWh],
E_a = Annual save of energy [kWh] (PV degradation effect included),
T = Excise tax [€] (1.703cent/kWh),
p = Annual energy price rise [%],
d = Loss of interest and/or Loan interest rate [%]. (Duffie and Beckman 2006, 468.)

In addition to the initial investment, the cost of the loan in relation to the energy price development are crucial in terms of whether the payback times of the PV systems are economically feasible or not. Also the level of initial energy price is important. For residential houses the current electricity prices are generally higher (~0.12€/kWh) than for larger scale business user (~0.10€/kWh), which again extends the payback period of business facility related PV systems. On the other hand lower system price (€/Wp) of bigger-scale systems and possible national incentives level the differences.

Table 12 gives few scenarios for payback times. Maximum options include the excise tax of 1.703cent/kWh reduction from the annual save of energy extending the payback time of these options depending on the scenario with about 2.4 years, 1.5 years and 10 years respectively compared to situation without the excise taxation.

Table 12. Payback times with three different scenarios and with 15% incentive

Payback time N_{pb} [years]	**Offer 1**			**Offer 2**		
SYSTEMS (240Wp panels)	**p=5%, d=3%**	**p=10%, d=3%**	**p=2%, d=6%**	**p=5%, d=3%**	**p=10%, d=3%**	**p=2%, d=6%**
B1 max option	16.6	12.8	36.0	15.6	12.2	31.4
B2 max option	16.9	13.0	38.0	16.0	12.4	33.0
B1 50kW option	13.9	11.1	24.7	13.9	11.1	24.6
B2 50kW option	13.9	11.1	24.6	13.9	11.1	24.5

6.3.4 Life-cycle Cost Analysis

In order to gain true perspective to the economic value of solar energy system, it is necessary to compare them with conventional energy technologies on a life-cycle cost (LCC) basis. An LCC analysis gives the total cost of the system, including all expenses incurred over the lifetime of the system. There are two reasons to do an LCC analysis: (1) to compare different power technology options and (2) to determine the most cost-effective system design. Life-cycle costing is the best way of making purchasing decisions. On this basis, many renewable energy systems are economical. (Foster, Ghassemi & Cota 2010, 236.)

$$LCC = C_i + M_{pw} + E_{pw} + R_{pw} - S_{pw} \qquad \text{(Equation 4)}$$

Where

LCC = Life-cycle cost,

Ci = initial cost of the investment,

M_{pw} = Sum of all yearly operation and maintenance costs,

E_{pw} = Energy cost, sum of yearly energy cost displaced

R_{pw} = sum of yearly replacement part costs, and

S_{pw} = salvage value – net worth of the invested system at the end of final year. (Foster, Ghassemi & Cota 2010, 237.)

For the purposes of this thesis comparing different technologies was not worthwhile since the PV system is anyhow only an auxiliary system and not a real choice as primary electricity supply. However LCC analysis was used to compare the cost-effectiveness of the different design options. In the LCC analysis, when incentives were taken into account they were first subtracted from the initial cost before further calculations. M_{pw} was set to 2% and R_{pw} to 1% of initial cost for all years and S_{pw} were set to 10% of the initial cost. Additionally E_{pw} was used as a sum of energy cost saved during the system life-time (negative value). Present value method was applied for E_{pw} using discount rate of 3.59% (PV degradation rate of 0.59% included) and annual energy price rise of 5% starting with initial price of 0.102€/kWh. E_{pw} was the only value discounted from future to present, for other values even yearly cost percentages were used. Possible loan interests were not considered. Estimated system lifetime in the calculations was 25 years. Table 13 presents the results of the analysis.

Table 13. Cost effectiveness of different design options (240W) with 15% incentive.

LCC - system cost effectiveness comparison (incentive 15%)

	Offer 1			Offer 2		
LCC factors	**B1 - max**	**B2 – max**	**50kW**	**B1 - max**	**B2 - max**	**50kW**
Ci (after 15% incentive)	200665	200665	66675	187626	187626	66551
Mpw (2% of Ci x 25)	100332	100332	33337	93813	93813	33276
Rpw (1% of Ci x 25)	50166	50166	16669	46906	46906	16638
Epw	-322208	-314434	-120340	-322208	-314434	-120340
Spw (10% of orig cost)	-23608	-23608	-7844	-22074	-22074	-7830
TOTAL	**5348**	**13122**	**-11503**	**-15937**	**-8163**	**-11705**

Interpretation for the table 13 is such that the most cost-effective system has the smallest total value. In this comparison the most cost-effective system it is the B1 – maximum option of offer 2 with total value of -15 937€. Results highlights the basic fact that initial cost is the single most important factor affecting to the payback times and economic feasibility of a PV system investment.

6.3.5 Effect of Future Changes in Building Use to the Payback Time

What if the use of the building having the PV plant installed changes during the initial payback time period? Let us assume that after 10 years the use of the building is changed from daily opened trade business to a warehouse cutting down the annual electricity consumption of the building to 15% of the original. Thus the maximum option PV plants would produce annually about double the energy needed for the self-consumption and about 50% of the production would be extra and sold to the network. Following table 14 shows the changes in payback times of the maximum options in case the price for the sold energy after the change would be 50%, 75% and 100% (net metering) of the buying price. Note that if the net metering would be implemented before the use change there would be no changes to the initial payback times.

Table 14. Payback time development of the maximum option if building self-consumption would drop to 50% of production after 10 years of use.

P_{sell}/P_{buy}	Offer 1	Offer 2
50 %	18.6	17.2
75 %	17.4	16.4
100 %	16.4	15.8

7 SENSITIVITY ANALYSIS

When dealing with costly technology, which performance is highly dependent on the weather conditions or climate in general and when the lifetime of the investment can be over 25 years, the importance of sensitivity analysis stands out. Additionally, when the details of the PV system building site and the electricity consumption rates of the buildings to be are not known, and also while the prices of PV systems and electricity are constantly evolving, the rates presented in this thesis are actually based on different educated estimates and assumptions.

7.1 Electricity Production

The reliability of the production estimates were increased with the SAMK PV system real data correction factors making them rather reliable. However the used reference data was only from little over two year period, which when considering climate and weather changes is relatively short study period. Some vagueness was left also for the shading-effect impact. Additionally the PV degradation rate was not considered in production estimates but in life-cycle cost calculations it was taken in account with decrease rate of 0.59%/year. Degradation effect will naturally decrease the future production rates of the SAMK PV system as well.

7.2 Electricity Consumption

Generally the electricity consumption estimates indicate clearly that production cannot match with consumption in any case. In annual level all produced electricity can be consumed at the site. However the mentioned 100% self-consumption is not entirely true. This depends highly on the opening hours of the operating retail businesses. When the store is closed; lights and business related devices are switched off, and power need of air ventilation and conditioning decreases. The electricity consumption drops maybe 90% from the normal opening hour’s consumption causing excess solar energy production. Clear benefit is that the production of the PV plant is at highest during the opening hours. However there are shorter days like Sundays and days like religious holidays when the store is closed. Possible future changes in the building use may also have effect on the self-consumption rates.

Depending on the deal with the local power-distribution network operator some compensation can be achieved for these hours by selling the excess power. But currently and generally in Finland, there is no tariff price or net metering obligation for the power-distribution network operators and the selling prices are lower than the buying prices.

7.3 Costs and Payback

When considering the initial system price of this scale, already a few eurocent change in €/Wp price is thousands of euros in final costs. As example, with the 1.32€/W price from the offer 1, five cent price difference to both directions is 3.8%. This is ten thousand Euro change in investment cost in case of maximum options. In other words, every cent in €/W prices matters when deciding about the best offer. Price of solar modules is about half of the system price and module price development continues to be the most important single thing affecting on the system price. So far the module prices have been decreasing and it is likely that this trend will continue in the future too.

When determining the life-cycle costs and payback times there are numerous X-factors affecting on the calculation results. Initial investment cost and possible national incentive percentage will be determined when the actual investment decision for the PV system is made and the current rates and prices are known. Only future will define the electricity price development, real PV plant production rates, and maintenance and operation costs. Generally during the past ten years the electricity prices have been increasing and the PV system investment costs have been decreasing, which likely makes the PV systems more and more feasible in the future. Due to increasing pressure for governmental actions for fighting the climate change the national incentives are likely used also in the future and taxation of renewable energy production can be decreased.

8 GUIDELINES FOR CONNECTING ELECTRICITY PRODUCTION TO DISTRIBUTION NETWORK

Finish Energy Industries (FEI) is association representing the electricity and district heating industry in Finland. In one of it guidelines FEI is listing requirements and rules for connecting small-scale electricity production to distribution network. Main idea is to enable the use of the production plant so that no harm is caused for the distribution network or other electricity consumers in the network and to ensure the occupational safety of the people working in the distribution network. (Lehto 2011.)

Following list summarize the issues that should be considered before acquiring an electricity production plant. More detailed information and further readings can be found through the referenced document.

- Ask from the local authorities of supervision of building, what are the construction and operation permits needed
- Get confirmation from the local power-distribution network owner that the planned equipment meets the quality and safety requirements of the network. You cannot connect the system to the grid without their permission
- Contact your electricity seller before starting your production. There needs to be a buyer for the produced electricity (Lehto 2011.)

REFERENCES

Duffie, J. A., Beckman, W. A. 2006. Solar Engineering of Thermal Processes: Third edition. New Jersey: John Wiley & Sons, Inc.

Global Market Outlook for Photovoltaics 2013-2017. 2013. Brussels: European Photovoltaic Industry Association (EPIA). Referenced 14.11.2013. www.epia.org/news/publications

Erat, B. Erkkilä, V. Nyman, K. Peippo, K. Peltola, S. Suokivi, H. 2008. Aurinko-opas: Aurinkoenergiaa rakennuksiin. Porvoo: Aurinkoteknillinen yhdistys ry

Foster, R. Ghassemi, M. Cota, A. 2010. Solar Energy: Renewable Energy and the Environment. Boca Raton: CRC Press, Taylor & Francis Group.

Jancauskas, J. 2012. Inovateus Solar: PV Power UP - Shading. Referenced 18.10.2013. www.youtube.com/watch?v=wxyDIjQspKc

Jordan, D. C., Kurtz, S. R. 2012. Photovoltaic Degradation Rates – An Analytical Review. National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy.

Kreith, F. & Kreider, J. F. 2011. Principles of Sustainable Energy. Boca Raton: CRC Press, Taylor & Francis Group.

Lehto, I. 2011. Sähköntuotantolaitoksen liittäminen jakeluverkkoon. Helsinki: Energiateollisuus ry.

Meinel, A. B. & Meinel, M.P. 1976. Applied Solar Energy. Wesley Publishing Co. www.en.wikipedia.org/wiki/Air_mass_(solar_energy)

Patel, M. R. 2006. Wind and Solar Power Systems: Design, Analysis, and Operation: Second edition. Boca Raton: CRC Press, Taylor & Francis Group.

Porin kaupunki. 2012. Aittaluodon (7.) kaupunginosan korttelin 6 (osa) koskevan asemakaavan muutos 609 1609, kaavaselostus. Pori.

Suomen RakMK D5. 2007. Rakennuksen energiankulutuksen ja lämmitystehontarpeen laskenta. Ohjeet 2007. Helsinki. Ympäristöministeriö, Asunto- ja rakennusosasto.

Šúri, M., Huld, T.A., Dunlop E.D. & Ossenbrink H.A. 2007. Potential of solar electricity generation in the European Union member states and candidate countries. Solar Energy, 81, 1295–1305, http://re.jrc.ec.europa.eu/pvgis/

The National Building Code of Finland E2. 2005. Fire safety of production and warehouse buildings. Guidelines 2005. Helsinki: Ministry of the Environment, Housing and Building Department.

Valmisteverotuslaki. 2010. 182/2010.

Website of the Affordable solar. Reference date 18.6.2013. http://www.affordable-solar.com/Learning-Center/Building-a-System/Calculating-Tilted-Array-Spacing

Website of the Bloomberg New Energy Finance (BNEF). Referenced 27.8.2013. http://about.bnef.com/

Website of the Energy Matters. Referenced 26.8.2013. http://www.energymatters.com.au/choosing-solar-panels.php

Website of the Google Maps. Referenced 21.8.2013. https://maps.google.com/

Website of the Lemminkäinen. Referenced 6.11.2013. www.lemminkainen.com

Website of the PV magazine. Referenced 23.8.2013. http://www.pv-magazine.com

Website of the TST Photovoltaic shop. Reference date 29.7.2013. http://www.photovoltaik-shop.com.

Website of the Työ- ja elinkeinoministeriö. Referenced 14.11.2013. www.tem.fi/energia/energiatuki/tuen_maara

Website of Wholesale Solar. Referenced 31.10.2013. http://www.wholesalesolar.com/Information-SolarFolder/celltypes.html

Website of the University of Oregon. Reference date 21.8.2013. Solar Radiation Monitoring Laboratory Website: http://solardata.uoregon.edu.

Website of the U.S. Department of Energy. Referenced date 1.11.2013. http://energy.gov/eere/energybasics/articles/photovoltaic-electrical-contacts-and-cell-coatings

APPENDIX 1: Solar altitude table of Pori.

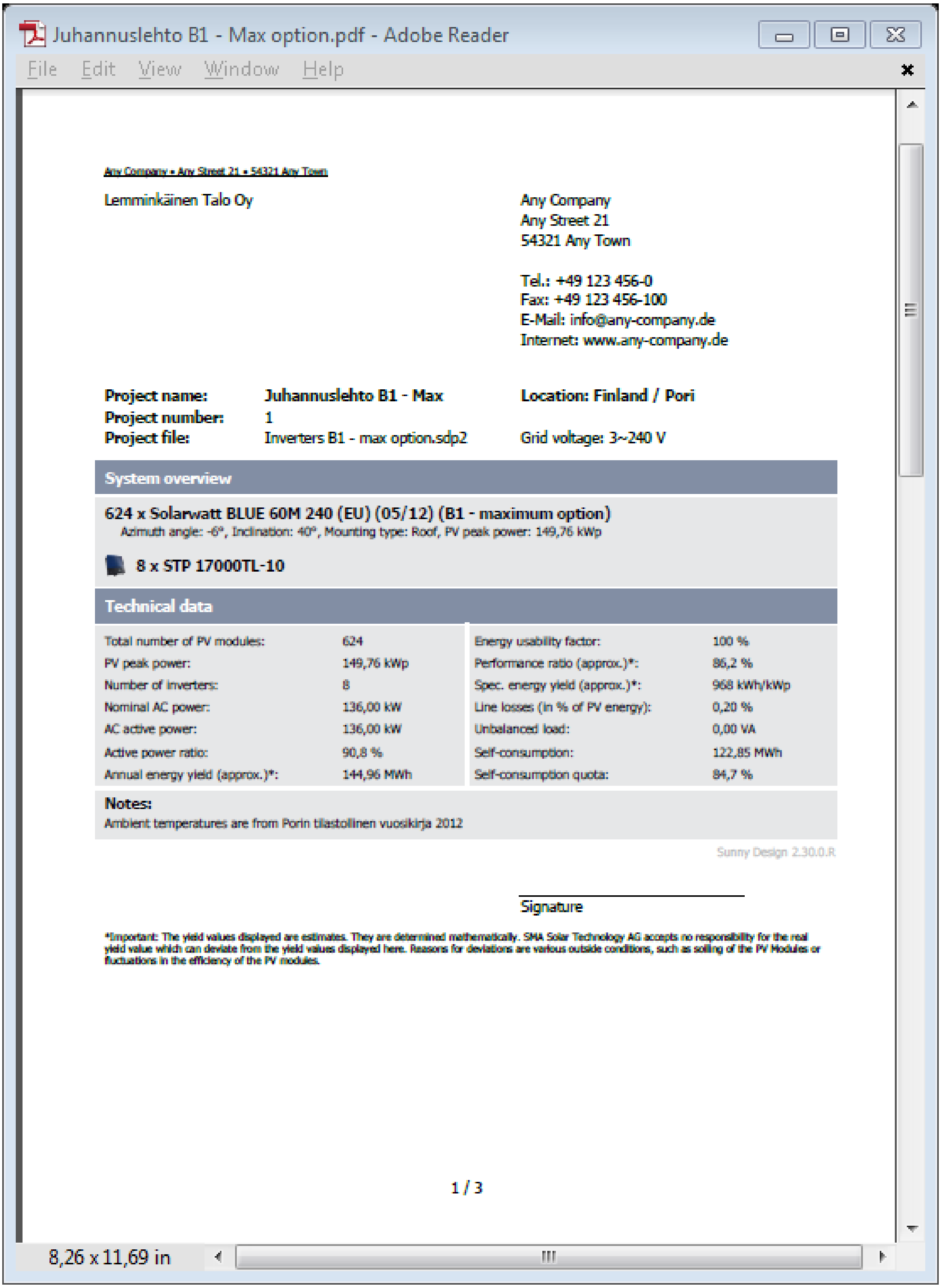
Sun altitude angle at Pori (61,486°N, 21,812°E) during the year.

In table Thursdays of each week are representing the week. Calendar year 2013 was used.

15deg in rad 0,26

	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
UTC +2	**SolTime**																																																				
3:30	3:00	-40,7	-40,0	-39,0	-37,7	-36,1	-34,4	-32,3	-30,1	-27,8	-25,3	-22,7	-20,1	-17,5	-14,9	-12,3	-9,9	-7,6	-5,5	-3,5	-1,9	-0,4	0,7	1,5	2,1	2,3	2,2	1,8	1,0	0,0	-1,3	-2,9	-4,8	-6,8	-9,0	-11,4	-13,9	-16,5	-19,2	-21,8	-24,4	-26,9	-29,3	-31,6	-33,7	-35,5	-37,2	-38,5	-39,7	-40,5	-41,0	-41,2	-41,2
4:00	3:30	-37,5	-36,8	-35,8	-34,6	-33,0	-31,3	-29,3	-27,1	-24,8	-22,4	-19,8	-17,3	-14,7	-12,1	-9,6	-7,2	-4,9	-2,9	-1,0	0,7	2,1	3,2	4,0	4,5	4,8	4,7	4,2	3,5	2,5	1,2	-0,4	-2,2	-4,2	-6,4	-8,7	-11,2	-13,8	-16,3	-18,9	-21,5	-24,0	-26,3	-28,5	-30,6	-32,4	-34,0	-35,4	-36,5	-37,3	-37,8	-38,0	-38,0
4:30	4:00	-34,1	-33,4	-32,5	-31,2	-29,7	-28,0	-26,0	-23,9	-21,6	-19,2	-16,7	-14,2	-11,6	-9,1	-6,6	-4,3	-2,0	0,0	1,9	3,5	4,9	6,0	6,8	7,3	7,5	7,4	7,0	6,3	5,3	4,0	2,5	0,7	-1,3	-3,5	-5,8	-8,2	-10,7	-13,3	-15,8	-18,3	-20,8	-23,1	-25,3	-27,3	-29,1	-30,7	-32,0	-33,1	-33,9	-34,4	-34,6	-34,6
5:00	4:30	-30,6	-29,9	-29,0	-27,7	-26,3	-24,5	-22,6	-20,5	-18,2	-15,9	-13,4	-10,9	-8,4	-5,9	-3,4	-1,1	1,1	3,1	4,9	6,5	7,9	9,0	9,8	10,3	10,5	10,4	10,0	9,3	8,3	7,0	5,5	3,8	1,8	-0,3	-2,6	-5,0	-7,5	-10,0	-12,5	-15,0	-17,4	-19,7	-21,9	-23,9	-25,7	-27,2	-28,6	-29,6	-30,4	-30,9	-31,1	-31,1
5:30	5:00	-27,1	-26,4	-25,4	-24,2	-22,7	-21,0	-19,1	-17,0	-14,7	-12,4	-9,9	-7,5	-5,0	-2,5	-0,1	2,2	4,4	6,4	8,2	9,8	11,1	12,2	13,0	13,5	13,7	13,6	13,2	12,5	11,5	10,3	8,8	7,1	5,1	3,0	0,8	-1,6	-4,1	-6,6	-9,1	-11,5	-13,9	-16,2	-18,4	-20,3	-22,1	-23,7	-25,0	-26,1	-26,9	-27,4	-27,6	-27,5
6:00	5:30	-23,5	-22,8	-21,8	-20,6	-19,1	-17,4	-15,5	-13,4	-11,2	-8,8	-6,4	-3,9	-1,4	1,0	3,4	5,7	7,8	9,8	11,6	13,2	14,5	15,5	16,3	16,8	17,0	16,9	16,5	15,8	14,9	13,7	12,2	10,5	8,6	6,5	4,2	1,9	-0,6	-3,0	-5,5	-8,0	-10,4	-12,6	-14,8	-16,8	-18,5	-20,1	-21,4	-22,5	-23,3	-23,8	-24,0	-23,9
6:30	6:00	-19,9	-19,3	-18,3	-17,0	-15,6	-13,9	-11,9	-9,9	-7,6	-5,3	-2,8	-0,4	2,1	4,6	6,9	9,2	11,4	13,3	15,1	16,6	18,0	19,0	19,8	20,3	20,5	20,4	20,0	19,3	18,4	17,1	15,7	14,0	12,1	10,0	7,8	5,4	3,0	0,5	-1,9	-4,4	-6,8	-9,1	-11,2	-13,2	-15,0	-16,5	-17,9	-18,9	-19,7	-20,2	-20,5	-20,4
7:00	6:30	-16,5	-15,8	-14,8	-13,6	-12,1	-10,3	-8,4	-6,3	-4,1	-1,7	0,7	3,2	5,7	8,1	10,5	12,8	14,9	16,9	18,7	20,2	21,5	22,6	23,3	23,8	24,0	23,9	23,5	22,9	21,9	20,7	19,2	17,6	15,7	13,6	11,4	9,0	6,6	4,1	1,6	-0,8	-3,2	-5,5	-7,7	-9,7	-11,5	-13,1	-14,4	-15,5	-16,3	-16,8	-17,0	-16,9
7:30	7:00	-13,1	-12,4	-11,4	-10,2	-8,7	-6,9	-5,0	-2,9	-0,6	1,8	4,2	6,7	9,2	11,7	14,1	16,4	18,5	20,5	22,2	23,8	25,1	26,1	26,9	27,4	27,6	27,5	27,1	26,4	25,5	24,3	22,8	21,1	19,2	17,1	14,9	12,6	10,1	7,6	5,1	2,7	0,2	-2,1	-4,2	-6,3	-8,1	-9,7	-11,0	-12,1	-12,9	-13,4	-13,7	-13,6
8:00	7:30	-9,9	-9,2	-8,2	-6,9	-5,4	-3,7	-1,7	0,5	2,8	5,2	7,6	10,2	12,7	15,2	17,6	19,9	22,0	24,0	25,8	27,3	28,6	29,7	30,5	30,9	31,1	31,1	30,7	30,0	29,0	27,8	26,4	24,7	22,8	20,7	18,4	16,0	13,6	11,1	8,5	6,0	3,6	1,3	-0,9	-3,0	-4,8	-6,4	-7,8	-8,9	-9,7	-10,3	-10,5	-10,4
8:30	8:00	-7,0	-6,2	-5,2	-3,9	-2,4	-0,6	1,4	3,6	5,9	8,4	10,9	13,4	16,0	18,5	20,9	23,3	25,4	27,4	29,2	30,8	32,1	33,2	34,0	34,5	34,7	34,6	34,2	33,5	32,5	31,3	29,8	28,1	26,2	24,1	21,8	19,4	16,9	14,4	11,8	9,3	6,8	4,4	2,2	0,1	-1,7	-3,4	-4,8	-5,9	-6,7	-7,3	-7,5	-7,4
9:00	8:30	-4,2	-3,5	-2,4	-1,1	0,5	2,3	4,3	6,5	8,9	11,4	13,9	16,5	19,1	21,7	24,1	26,5	28,7	30,7	32,6	34,1	35,5	36,6	37,3	37,8	38,0	37,9	37,6	36,9	35,9	34,6	33,1	31,4	29,4	27,3	25,0	22,6	20,0	17,5	14,9	12,3	9,8	7,4	5,1	3,0	1,1	-0,6	-2,0	-3,1	-4,0	-4,5	-4,8	-4,7
9:30	9:00	-1,7	-1,0	0,1	1,4	3,0	4,9	7,0	9,2	11,6	14,1	16,7	19,4	22,0	24,6	27,1	29,5	31,7	33,8	35,7	37,3	38,6	39,7	40,5	41,0	41,2	41,1	40,7	40,0	39,1	37,8	36,3	34,5	32,5	30,3	28,0	25,5	22,9	20,3	17,7	15,0	12,5	10,1	7,7	5,6	3,7	2,0	0,5	-0,6	-1,5	-2,0	-2,3	-2,2
10:00	9:30	0,5	1,2	2,3	3,7	5,3	7,2	9,3	11,6	14,0	16,6	19,2	21,9	24,5	27,2	29,7	32,2	34,5	36,6	38,5	40,1	41,5	42,6	43,5	44,0	44,2	44,1	43,7	43,0	42,0	40,7	39,1	37,3	35,3	33,0	30,6	28,1	25,5	22,8	20,1	17,5	14,9	12,4	10,1	7,9	5,9	4,2	2,8	1,6	0,7	0,1	-0,1	0,0
10:30	10:00	2,3	3,1	4,2	5,5	7,2	9,1	11,2	13,6	16,0	18,6	21,3	24,0	26,8	29,4	32,0	34,5	36,9	39,0	40,9	42,6	44,1	45,2	46,0	46,6	46,8	46,7	46,3	45,5	44,5	43,2	41,6	39,7	37,7	35,4	32,9	30,4	27,7	25,0	22,3	19,6	17,0	14,4	12,0	9,8	7,9	6,1	4,6	3,4	2,5	2,0	1,7	1,8
11:00	10:30	3,7	4,5	5,6	7,0	8,7	10,7	12,8	15,2	17,7	20,3	23,0	25,8	28,5	31,3	33,9	36,4	38,8	41,0	43,0	44,7	46,2	47,3	48,2	48,7	49,0	48,9	48,4	47,7	46,6	45,3	43,6	41,7	39,6	37,3	34,8	32,2	29,5	26,8	24,0	21,3	18,6	16,0	13,6	11,4	9,4	7,6	6,1	4,9	4,0	3,4	3,2	3,2
11:30	11:00	4,8	5,6	6,7	8,1	9,8	11,8	14,0	16,3	18,9	21,5	24,3	27,1	29,9	32,6	35,3	37,9	40,3	42,5	44,5	46,3	47,7	48,9	49,8	50,4	50,6	50,5	50,0	49,3	48,2	46,8	45,2	43,2	41,1	38,7	36,2	33,6	30,8	28,1	25,3	22,5	19,8	17,2	14,8	12,5	10,5	8,7	7,2	6,0	5,1	4,5	4,2	4,3
12:00	11:30	5,5	6,3	7,4	8,8	10,5	12,5	14,7	17,0	19,6	22,3	25,0	27,8	30,7	33,4	36,1	38,7	41,2	43,4	45,4	47,2	48,7	49,9	50,8	51,4	51,6	51,5	51,1	50,3	49,2	47,8	46,1	44,2	42,0	39,6	37,1	34,4	31,7	28,9	26,0	23,3	20,5	17,9	15,5	13,2	11,2	9,4	7,9	6,6	5,7	5,1	4,9	4,9
12:30	12:00	5,7	6,5	7,6	9,0	10,7	12,7	14,9	17,3	19,8	22,5	25,3	28,1	30,9	33,7	36,4	39,0	41,5	43,7	45,8	47,5	49,1	50,3	51,2	51,7	52,0	51,8	51,4	50,6	49,5	48,1	46,4	44,5	42,3	39,9	37,4	34,7	31,9	29,1	26,3	23,5	20,8	18,2	15,7	13,5	11,4	9,6	8,1	6,8	5,9	5,3	5,1	5,2
13:00	12:30	5,5	6,3	7,4	8,8	10,5	12,5	14,7	17,0	19,6	22,3	25,0	27,8	30,7	33,4	36,1	38,7	41,2	43,4	45,4	47,2	48,7	49,9	50,8	51,4	51,6	51,5	51,1	50,3	49,2	47,8	46,1	44,2	42,0	39,6	37,1	34,4	31,7	28,9	26,0	23,3	20,5	17,9	15,5	13,2	11,2	9,4	7,9	6,6	5,7	5,1	4,9	4,9
13:30	13:00	4,8	5,6	6,7	8,1	9,8	11,8	14,0	16,3	18,9	21,5	24,3	27,1	29,9	32,6	35,3	37,9	40,3	42,5	44,5	46,3	47,7	48,9	49,8	50,4	50,6	50,5	50,0	49,3	48,2	46,8	45,2	43,2	41,1	38,7	36,2	33,6	30,8	28,1	25,3	22,5	19,8	17,2	14,8	12,5	10,5	8,7	7,2	6,0	5,1	4,5	4,2	4,3
14:00	13:30	3,7	4,5	5,6	7,0	8,7	10,7	12,8	15,2	17,7	20,3	23,0	25,8	28,5	31,3	33,9	36,4	38,8	41,0	43,0	44,7	46,2	47,3	48,2	48,7	49,0	48,9	48,4	47,7	46,6	45,3	43,6	41,7	39,6	37,3	34,8	32,2	29,5	26,8	24,0	21,3	18,6	16,0	13,6	11,4	9,4	7,6	6,1	4,9	4,0	3,4	3,2	3,2
14:30	14:00	2,3	3,1	4,2	5,5	7,2	9,1	11,2	13,6	16,0	18,6	21,3	24,0	26,8	29,4	32,0	34,5	36,9	39,0	40,9	42,6	44,1	45,2	46,0	46,6	46,8	46,7	46,3	45,5	44,5	43,2	41,6	39,7	37,7	35,4	32,9	30,4	27,7	25,0	22,3	19,6	17,0	14,4	12,0	9,8	7,9	6,1	4,6	3,4	2,5	2,0	1,7	1,8
15:00	14:30	0,5	1,2	2,3	3,7	5,3	7,2	9,3	11,6	14,0	16,6	19,2	21,9	24,5	27,2	29,7	32,2	34,5	36,6	38,5	40,1	41,5	42,6	43,5	44,0	44,2	44,1	43,7	43,0	42,0	40,7	39,1	37,3	35,3	33,0	30,6	28,1	25,5	22,8	20,1	17,5	14,9	12,4	10,1	7,9	5,9	4,2	2,8	1,6	0,7	0,1	-0,1	0,0
15:30	15:00	-1,7	-1,0	0,1	1,4	3,0	4,9	7,0	9,2	11,6	14,1	16,7	19,4	22,0	24,6	27,1	29,5	31,7	33,8	35,7	37,3	38,6	39,7	40,5	41,0	41,2	41,1	40,7	40,0	39,1	37,8	36,3	34,5	32,5	30,3	28,0	25,5	22,9	20,3	17,7	15,0	12,5	10,1	7,7	5,6	3,7	2,0	0,5	-0,6	-1,5	-2,0	-2,3	-2,2
16:00	15:30	-4,2	-3,5	-2,4	-1,1	0,5	2,3	4,3	6,5	8,9	11,4	13,9	16,5	19,1	21,7	24,1	26,5	28,7	30,7	32,6	34,1	35,5	36,6	37,3	37,8	38,0	37,9	37,6	36,9	35,9	34,6	33,1	31,4	29,4	27,3	25,0	22,6	20,0	17,5	14,9	12,3	9,8	7,4	5,1	3,0	1,1	-0,6	-2,0	-3,1	-4,0	-4,5	-4,8	-4,7
16:30	16:00	-7,0	-6,2	-5,2	-3,9	-2,4	-0,6	1,4	3,6	5,9	8,4	10,9	13,4	16,0	18,5	20,9	23,3	25,4	27,4	29,2	30,8	32,1	33,2	34,0	34,5	34,7	34,6	34,2	33,5	32,5	31,3	29,8	28,1	26,2	24,1	21,8	19,4	16,9	14,4	11,8	9,3	6,8	4,4	2,2	0,1	-1,7	-3,4	-4,8	-5,9	-6,7	-7,3	-7,5	-7,4
17:00	16:30	-9,9	-9,2	-8,2	-6,9	-5,4	-3,7	-1,7	0,5	2,8	5,2	7,6	10,2	12,7	15,2	17,6	19,9	22,0	24,0	25,8	27,3	28,6	29,7	30,5	30,9	31,1	31,1	30,7	30,0	29,0	27,8	26,4	24,7	22,8	20,7	18,4	16,0	13,6	11,1	8,5	6,0	3,6	1,3	-0,9	-3,0	-4,8	-6,4	-7,8	-8,9	-9,7	-10,3	-10,5	-10,4
17:30	17:00	-13,1	-12,4	-11,4	-10,2	-8,7	-6,9	-5,0	-2,9	-0,6	1,8	4,2	6,7	9,2	11,7	14,1	16,4	18,5	20,5	22,2	23,8	25,1	26,1	26,9	27,4	27,6	27,5	27,1	26,4	25,5	24,3	22,8	21,1	19,2	17,1	14,9	12,6	10,1	7,6	5,1	2,7	0,2	-2,1	-4,2	-6,3	-8,1	-9,7	-11,0	-12,1	-12,9	-13,4	-13,7	-13,6
18:00	17:30	-16,5	-15,8	-14,8	-13,6	-12,1	-10,3	-8,4	-6,3	-4,1	-1,7	0,7	3,2	5,7	8,1	10,5	12,8	14,9	16,9	18,7	20,2	21,5	22,6	23,3	23,8	24,0	23,9	23,5	22,9	21,9	20,7	19,2	17,6	15,7	13,6	11,4	9,0	6,6	4,1	1,6	-0,8	-3,2	-5,5	-7,7	-9,7	-11,5	-13,1	-14,4	-15,5	-16,3	-16,8	-17,0	-16,9
18:30	18:00	-19,9	-19,3	-18,3	-17,0	-15,6	-13,9	-11,9	-9,9	-7,6	-5,3	-2,8	-0,4	2,1	4,6	6,9	9,2	11,4	13,3	15,1	16,6	18,0	19,0	19,8	20,3	20,5	20,4	20,0	19,3	18,4	17,1	15,7	14,0	12,1	10,0	7,8	5,4	3,0	0,5	-1,9	-4,4	-6,8	-9,1	-11,2	-13,2	-15,0	-16,5	-17,9	-18,9	-19,7	-20,2	-20,5	-20,4
19:00	18:30	-23,5	-22,8	-21,8	-20,6	-19,1	-17,4	-15,5	-13,4	-11,2	-8,8	-6,4	-3,9	-1,4	1,0	3,4	5,7	7,8	9,8	11,6	13,2	14,5	15,5	16,3	16,8	17,0	16,9	16,5	15,8	14,9	13,7	12,2	10,5	8,6	6,5	4,2	1,9	-0,6	-3,0	-5,5	-8,0	-10,4	-12,6	-14,8	-16,8	-18,5	-20,1	-21,4	-22,5	-23,3	-23,8	-24,0	-23,9
19:30	19:00	-27,1	-26,4	-25,4	-24,2	-22,7	-21,0	-19,1	-17,0	-14,7	-12,4	-9,9	-7,5	-5,0	-2,5	-0,1	2,2	4,4	6,4	8,2	9,8	11,1	12,2	13,0	13,5	13,7	13,6	13,2	12,5	11,5	10,3	8,8	7,1	5,1	3,0	0,8	-1,6	-4,1	-6,6	-9,1	-11,5	-13,9	-16,2	-18,4	-20,3	-22,1	-23,7	-25,0	-26,1	-26,9	-27,4	-27,6	-27,5
20:00	19:30	-30,6	-29,9	-29,0	-27,7	-26,3	-24,5	-22,6	-20,5	-18,2	-15,9	-13,4	-10,9	-8,4	-5,9	-3,4	-1,1	1,1	3,1	4,9	6,5	7,9	9,0	9,8	10,3	10,5	10,4	10,0	9,3	8,3	7,0	5,5	3,8	1,8	-0,3	-2,6	-5,0	-7,5	-10,0	-12,5	-15,0	-17,4	-19,7	-21,9	-23,9	-25,7	-27,2	-28,6	-29,6	-30,4	-30,9	-31,1	-31,1
20:30	20:00	-34,1	-33,4	-32,5	-31,2	-29,7	-28,0	-26,0	-23,9	-21,6	-19,2	-16,7	-14,2	-11,6	-9,1	-6,6	-4,3	-2,0	0,0	1,9	3,5	4,9	6,0	6,8	7,3	7,5	7,4	7,0	6,3	5,3	4,0	2,5	0,7	-1,3	-3,5	-5,8	-8,2	-10,7	-13,3	-15,8	-18,3	-20,8	-23,1	-25,3	-27,3	-29,1	-30,7	-32,0	-33,1	-33,9	-34,4	-34,6	-34,6
21:00	20:30	-37,5	-36,8	-35,8	-34,6	-33,0	-31,3	-29,3	-27,1	-24,8	-22,4	-19,8	-17,3	-14,7	-12,1	-9,6	-7,2	-4,9	-2,9	-1,0	0,7	2,1	3,2	4,0	4,5	4,8	4,7	4,2	3,5	2,5	1,2	-0,4	-2,2	-4,2	-6,4	-8,7	-11,2	-13,8	-16,3	-18,9	-21,5	-24,0	-26,3	-28,5	-30,6	-32,4	-34,0	-35,4	-36,5	-37,3	-37,8	-38,0	-38,0
21:30	21:00	-40,7	-40,0	-39,0	-37,7	-36,1	-34,4	-32,3	-30,1	-27,8	-25,3	-22,7	-20,1	-17,5	-14,9	-12,3	-9,9	-7,6	-5,5	-3,5	-1,9	-0,4	0,7	1,5	2,1	2,3	2,2	1,8	1,0	0,0	-1,3	-2,9	-4,8	-6,8	-9,0	-11,4	-13,9	-16,5	-19,2	-21,8	-24,4	-26,9	-29,3	-31,6	-33,7	-35,5	-37,2	-38,5	-39,7	-40,5	-41,0	-41,2	-41,2
22:00	21:30	-43,6	-42,9	-41,9	-40,6	-39,0	-37,1	-35,1	-32,9	-30,5	-27,9	-25,3	-22,6	-20,0	-17,3	-14,7	-12,2	-9,9	-7,8	-5,8	-4,1	-2,7	-1,5	-0,6	-0,1	0,1	0,0	-0,4	-1,2	-2,2	-3,6	-5,2	-7,0	-9,1	-11,4	-13,8	-16,4	-19,0	-21,7	-24,4	-27,0	-29,6	-32,0	-34,3	-36,4	-38,3	-40,0	-41,4	-42,6	-43,4	-44,0	-44,2	-44,1

APPENDIX 2: SMA Sunny design PV system dimensioning results



Any Company • Any Street 21 • 54321 Any Town

Lemminkäinen Talo Oy

Any Company
Any Street 21
54321 Any Town

Tel.: +49 123 456-0
Fax: +49 123 456-100
E-Mail: info@any-company.de
Internet: www.any-company.de

Project name: Juhannuslehto B1 - Max
Project number: 1
Project file: Inverters B1 - max option.sdp2

Location: Finland / Pori
Grid voltage: 3~240 V

System overview

624 x Solarwatt BLUE 60M 240 (EU) (05/12) (B1 - maximum option)
Azimuth angle: -6°, Inclination: 40°, Mounting type: Roof, PV peak power: 149,76 kWp

8 x STP 17000TL-10

Technical data

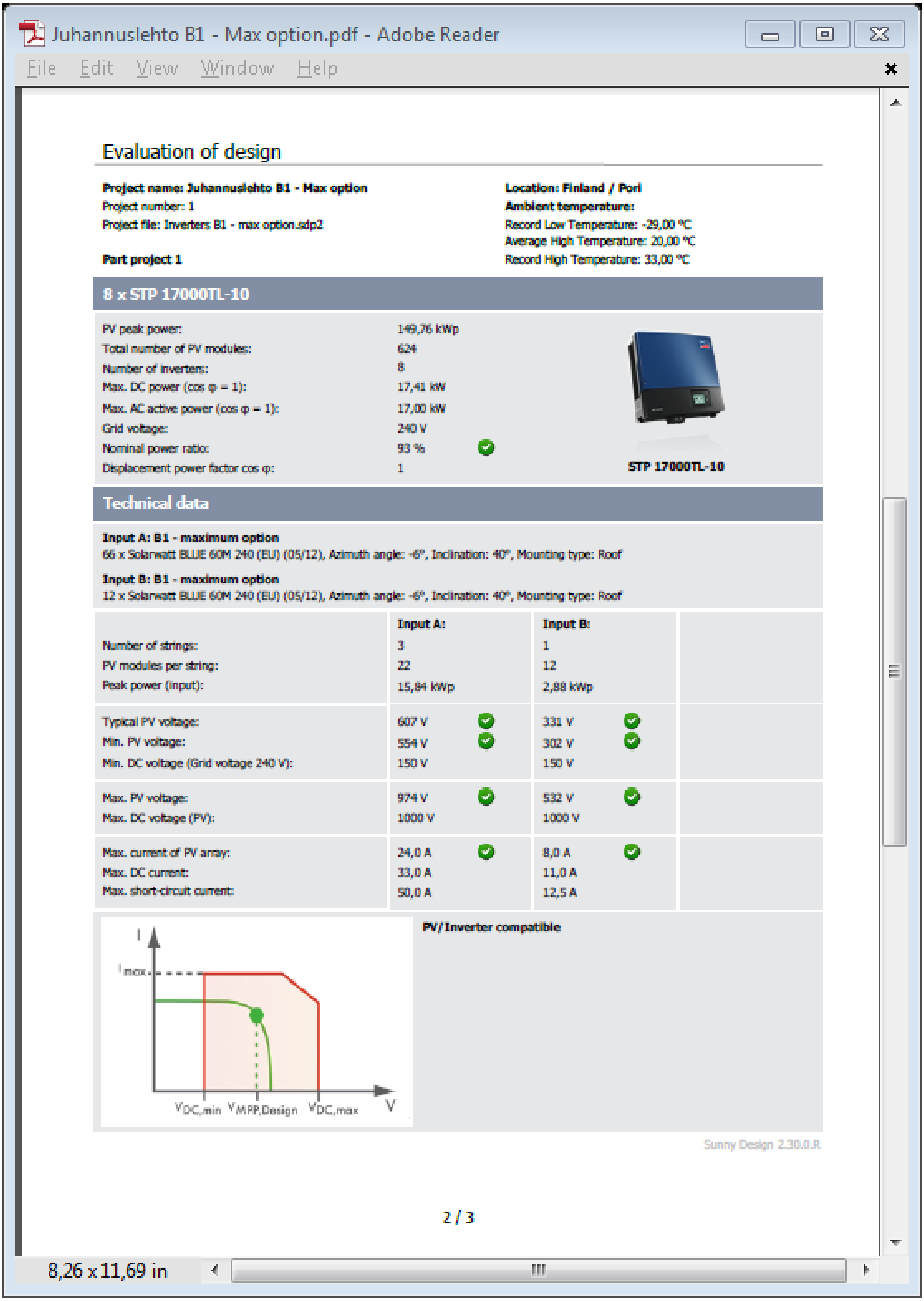
Total number of PV modules:	624	Energy usability factor:	100 %
PV peak power:	149,76 kWp	Performance ratio (approx.)*:	86,2 %
Number of inverters:	8	Spec. energy yield (approx.)*:	968 kWh/kWp
Nominal AC power:	136,00 kW	Line losses (in % of PV energy):	0,20 %
AC active power:	136,00 kW	Unbalanced load:	0,00 VA
Active power ratio:	90,8 %	Self-consumption:	122,85 MWh
Annual energy yield (approx.)*:	144,96 MWh	Self-consumption quota:	84,7 %

Notes:
Ambient temperatures are from Porin tilastollinen vuosikirja 2012

Sunny Design 2.30.0.R

Signature

*Important: The yield values displayed are estimates. They are determined mathematically. SMA Solar Technology AG accepts no responsibility for the real yield value which can deviate from the yield values displayed here. Reasons for deviations are various outside conditions, such as soiling of the PV Modules or fluctuations in the efficiency of the PV modules.



Evaluation of design

Project name: Juhannuslehto B1 - Max option
Project number: 1
Project file: Inverters B1 - max option.sdp2

Part project 1

Location: Finland / Pori
Ambient temperature:
Record Low Temperature: -29,00 °C
Average High Temperature: 20,00 °C
Record High Temperature: 33,00 °C

8 x STP 17000TL-10

PV peak power:	149,76 kWp	
Total number of PV modules:	624	
Number of inverters:	8	
Max. DC power (cos φ = 1):	17,41 kW	
Max. AC active power (cos φ = 1):	17,00 kW	
Grid voltage:	240 V	
Nominal power ratio:	93 %	✓
Displacement power factor cos φ:	1	

STP 17000TL-10

Technical data

Input A: B1 - maximum option
66 x Solarwatt BLUE 60M 240 (EU) (05/12), Azimuth angle: -6°, Inclination: 40°, Mounting type: Roof

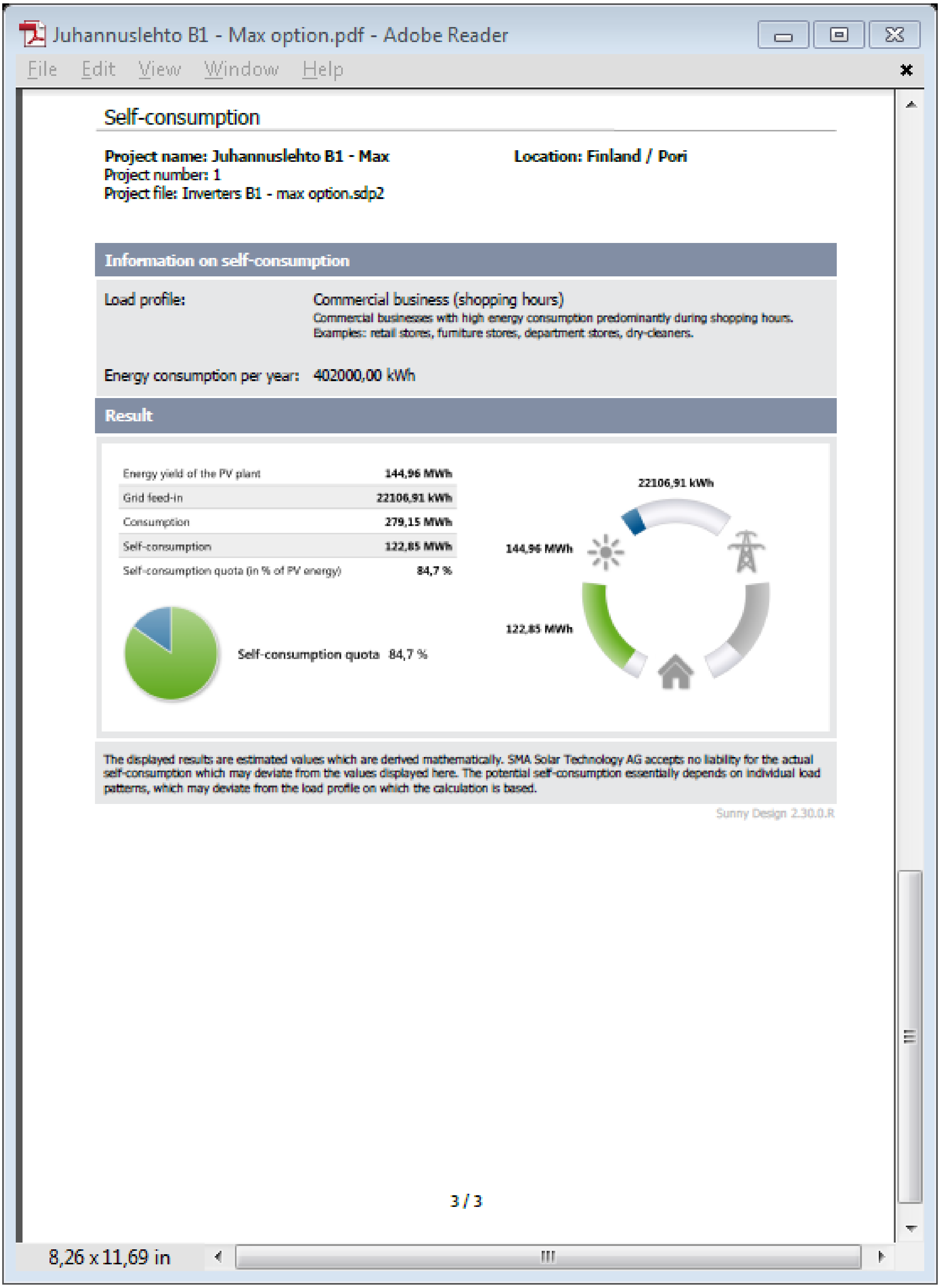
Input B: B1 - maximum option
12 x Solarwatt BLUE 60M 240 (EU) (05/12), Azimuth angle: -6°, Inclination: 40°, Mounting type: Roof

	Input A:		**Input B:**	
Number of strings:	3		1	
PV modules per string:	22		12	
Peak power (input):	15,84 kWp		2,88 kWp	
Typical PV voltage:	607 V	✓	331 V	✓
Min. PV voltage:	554 V	✓	302 V	✓
Min. DC voltage (Grid voltage 240 V):	150 V		150 V	
Max. PV voltage:	974 V	✓	532 V	✓
Max. DC voltage (PV):	1000 V		1000 V	
Max. current of PV array:	24,0 A	✓	8,0 A	✓
Max. DC current:	33,0 A		11,0 A	
Max. short-circuit current:	50,0 A		12,5 A	

PV/Inverter compatible

Sunny Design 2.30.0.R

2 / 3



Self-consumption

Project name: Juhannuslehto B1 - Max
Project number: 1
Project file: Inverters B1 - max option.sdp2

Location: Finland / Pori

Information on self-consumption

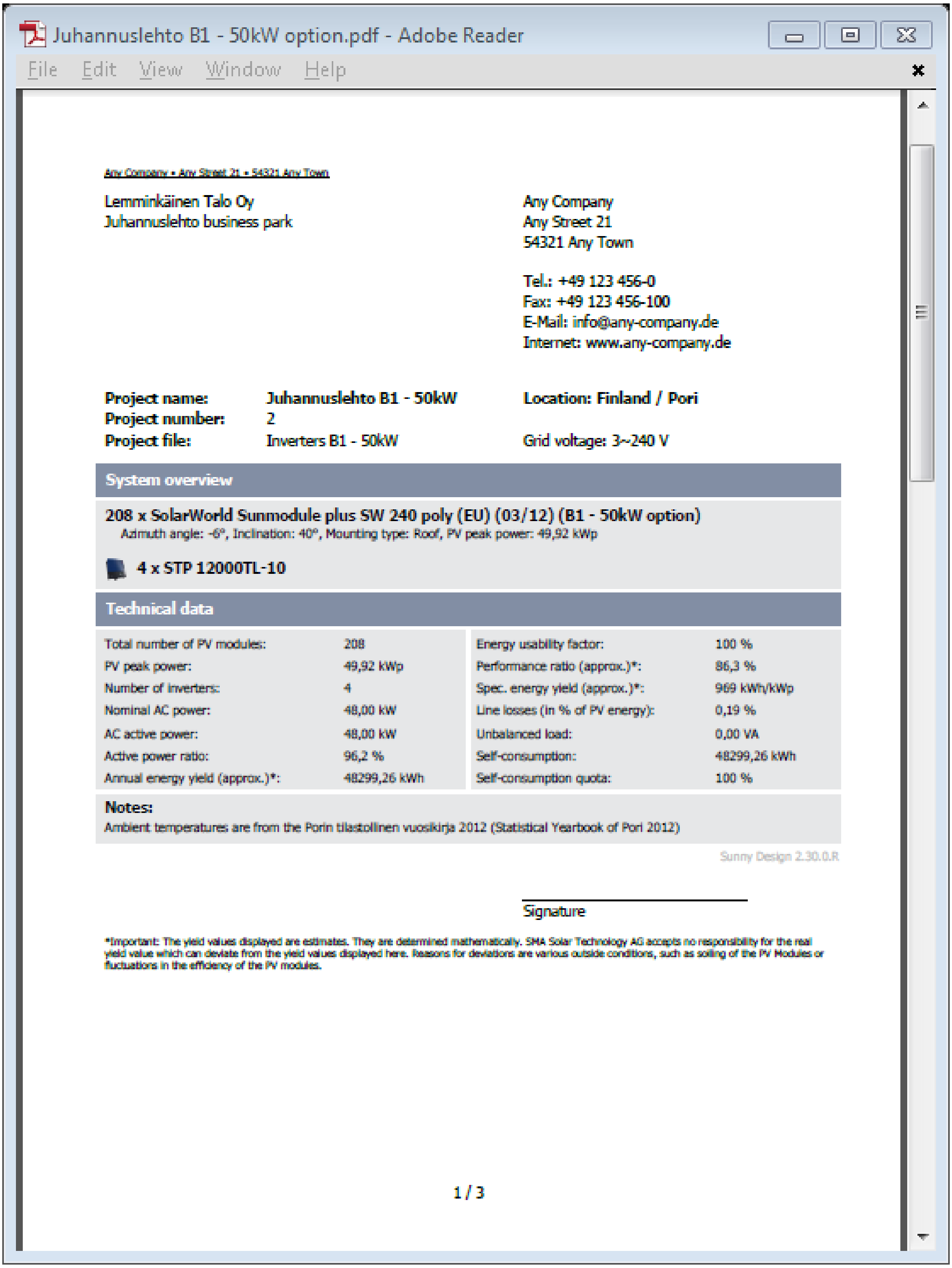
Load profile:	Commercial business (shopping hours) Commercial businesses with high energy consumption predominantly during shopping hours. Examples: retail stores, furniture stores, department stores, dry-cleaners.
Energy consumption per year:	402000,00 kWh

Result

Energy yield of the PV plant	**144,96 MWh**
Grid feed-in	**22106,91 kWh**
Consumption	**279,15 MWh**
Self-consumption	**122,85 MWh**
Self-consumption quota (in % of PV energy)	**84,7 %**

The displayed results are estimated values which are derived mathematically. SMA Solar Technology AG accepts no liability for the actual self-consumption which may deviate from the values displayed here. The potential self-consumption essentially depends on individual load patterns, which may deviate from the load profile on which the calculation is based.

Sunny Design 2.30.0.R



Any Company • Any Street 21 • 54321 Any Town

Lemminkäinen Talo Oy
Juhannuslehto business park

Any Company
Any Street 21
54321 Any Town

Tel.: +49 123 456-0
Fax: +49 123 456-100
E-Mail: info@any-company.de
Internet: www.any-company.de

Project name:	**Juhannuslehto B1 - 50kW**	**Location: Finland / Pori**
Project number:	2	
Project file:	Inverters B1 - 50kW	Grid voltage: 3~240 V

System overview

208 x SolarWorld Sunmodule plus SW 240 poly (EU) (03/12) (B1 - 50kW option)
Azimuth angle: -6°, Inclination: 40°, Mounting type: Roof, PV peak power: 49,92 kWp

4 x STP 12000TL-10

Technical data

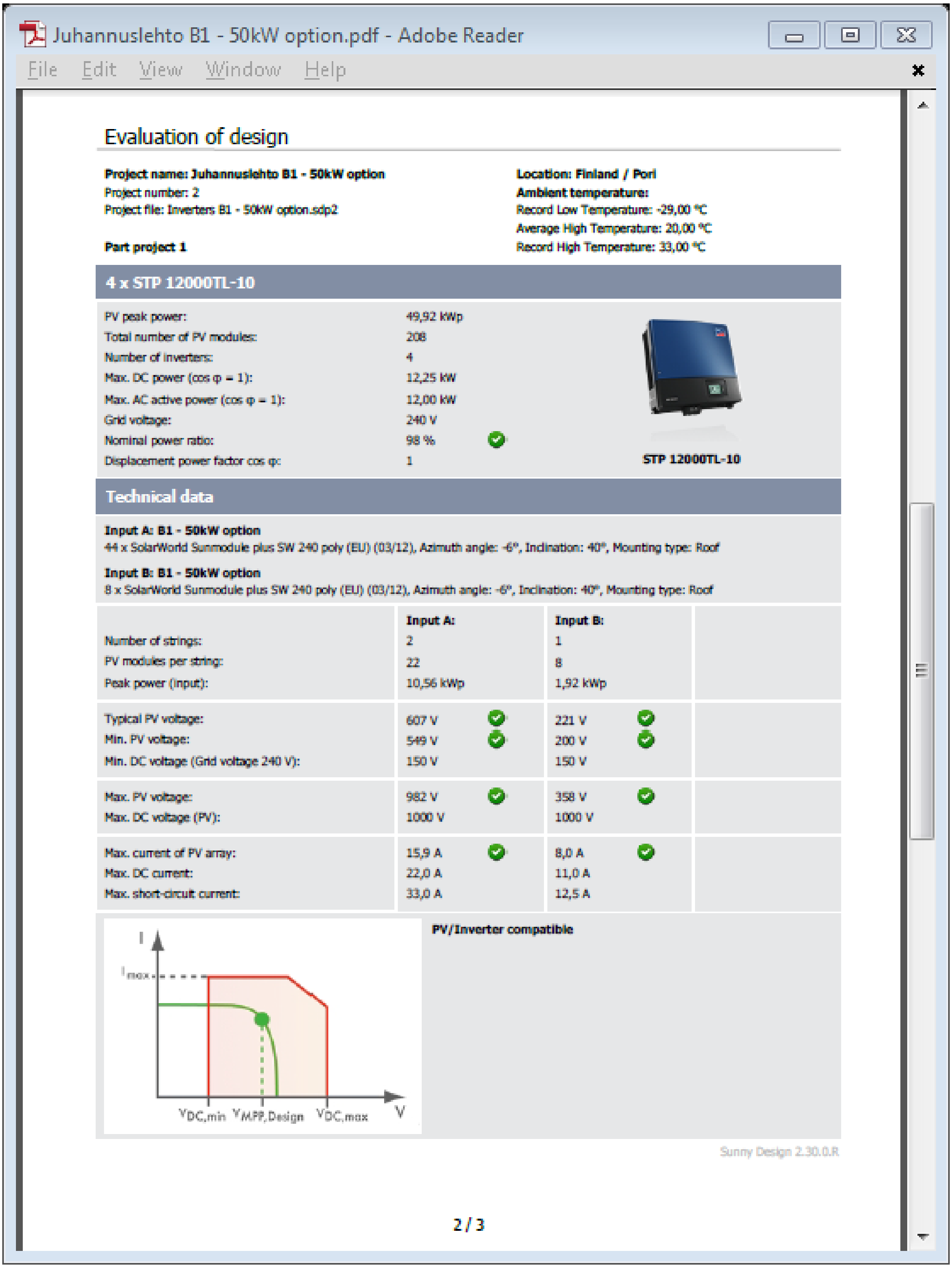
Total number of PV modules:	208	Energy usability factor:	100 %
PV peak power:	49,92 kWp	Performance ratio (approx.)*:	86,3 %
Number of inverters:	4	Spec. energy yield (approx.)*:	969 kWh/kWp
Nominal AC power:	48,00 kW	Line losses (in % of PV energy):	0,19 %
AC active power:	48,00 kW	Unbalanced load:	0,00 VA
Active power ratio:	96,2 %	Self-consumption:	48299,26 kWh
Annual energy yield (approx.)*:	48299,26 kWh	Self-consumption quota:	100 %

Notes:
Ambient temperatures are from the Porin tilastollinen vuosikirja 2012 (Statistical Yearbook of Pori 2012)

Sunny Design 2.30.0.R

Signature

*Important: The yield values displayed are estimates. They are determined mathematically. SMA Solar Technology AG accepts no responsibility for the real yield value which can deviate from the yield values displayed here. Reasons for deviations are various outside conditions, such as soiling of the PV Modules or fluctuations in the efficiency of the PV modules.



Evaluation of design

Project name: Juhannuslehto B1 - 50kW option
Project number: 2
Project file: Inverters B1 - 50kW option.sdp2

Part project 1

Location: Finland / Pori
Ambient temperature:
Record Low Temperature: -29,00 °C
Average High Temperature: 20,00 °C
Record High Temperature: 33,00 °C

4 x STP 12000TL-10

PV peak power:	49,92 kWp	
Total number of PV modules:	208	
Number of inverters:	4	
Max. DC power (cos φ = 1):	12,25 kW	
Max. AC active power (cos φ = 1):	12,00 kW	
Grid voltage:	240 V	
Nominal power ratio:	98 %	✓
Displacement power factor cos φ:	1	

STP 12000TL-10

Technical data

Input A: B1 - 50kW option
44 x SolarWorld Sunmodule plus SW 240 poly (EU) (03/12), Azimuth angle: -6°, Inclination: 40°, Mounting type: Roof

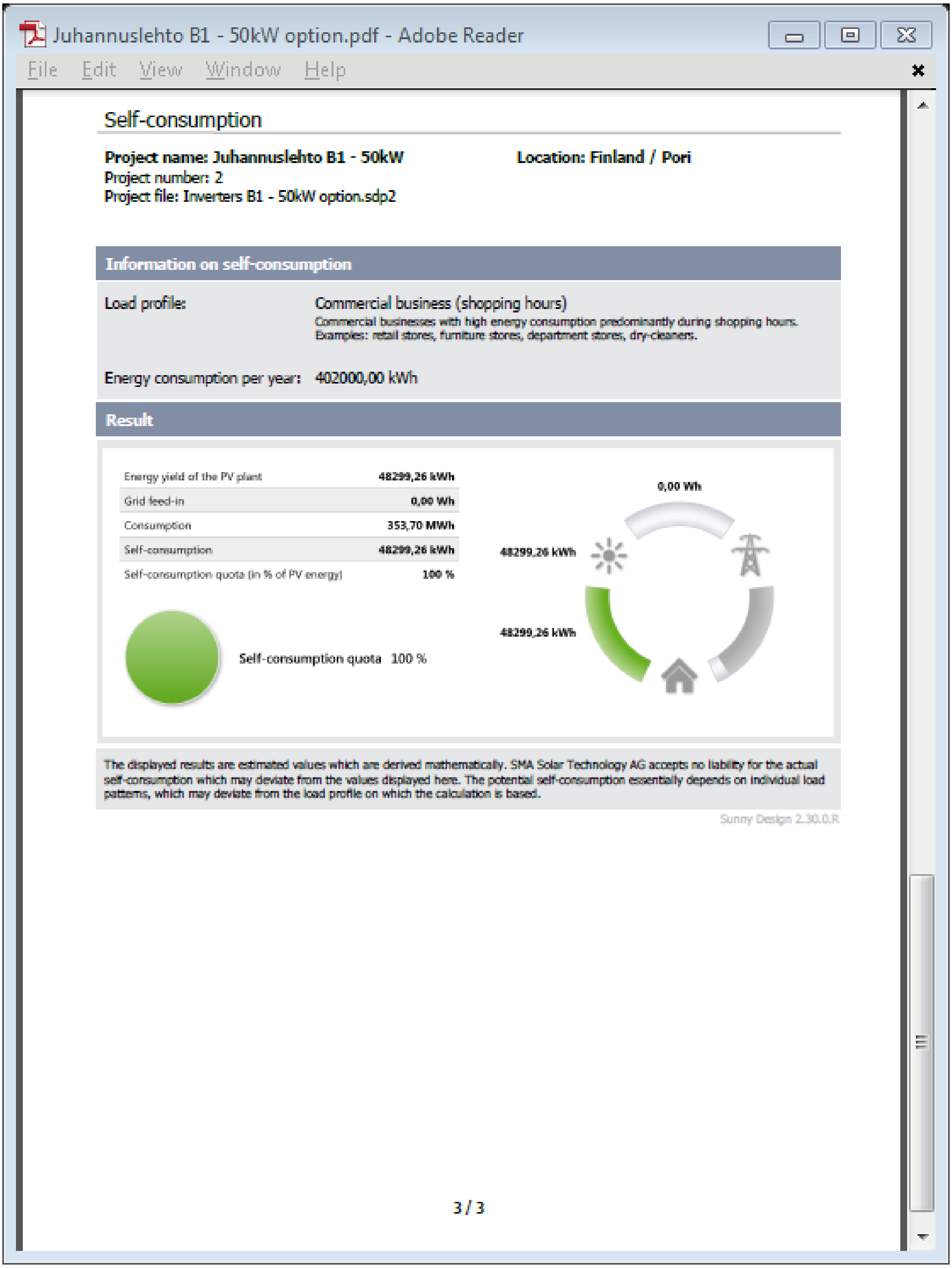
Input B: B1 - 50kW option
8 x SolarWorld Sunmodule plus SW 240 poly (EU) (03/12), Azimuth angle: -6°, Inclination: 40°, Mounting type: Roof

	Input A:		**Input B:**		
Number of strings:	2		1		
PV modules per string:	22		8		
Peak power (input):	10,56 kWp		1,92 kWp		
Typical PV voltage:	607 V	✓	221 V	✓	
Min. PV voltage:	549 V	✓	200 V	✓	
Min. DC voltage (Grid voltage 240 V):	150 V		150 V		
Max. PV voltage:	982 V	✓	358 V	✓	
Max. DC voltage (PV):	1000 V		1000 V		
Max. current of PV array:	15,9 A	✓	8,0 A	✓	
Max. DC current:	22,0 A		11,0 A		
Max. short-circuit current:	33,0 A		12,5 A		

PV/Inverter compatible

Sunny Design 2.30.0.R

2 / 3



Self-consumption

Project name: Juhannuslehto B1 - 50kW
Project number: 2
Project file: Inverters B1 - 50kW option.sdp2

Location: Finland / Pori

Information on self-consumption

Load profile:	Commercial business (shopping hours) Commercial businesses with high energy consumption predominantly during shopping hours. Examples: retail stores, furniture stores, department stores, dry-cleaners.
Energy consumption per year:	402000,00 kWh

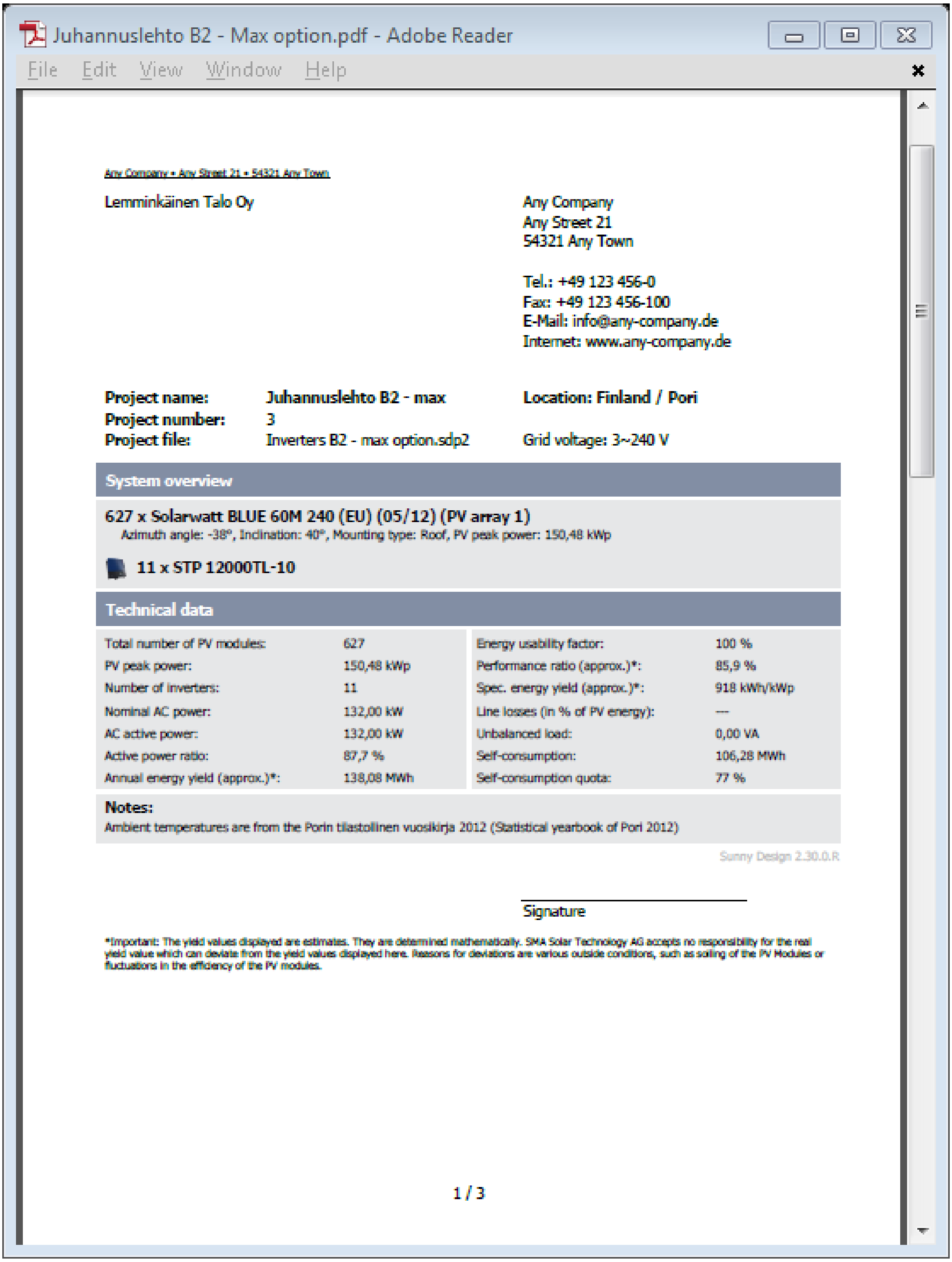
Result

Energy yield of the PV plant	**48299,26 kWh**
Grid feed-in	**0,00 Wh**
Consumption	**353,70 MWh**
Self-consumption	**48299,26 kWh**
Self-consumption quota (in % of PV energy)	**100 %**

Self-consumption quota 100 %

The displayed results are estimated values which are derived mathematically. SMA Solar Technology AG accepts no liability for the actual self-consumption which may deviate from the values displayed here. The potential self-consumption essentially depends on individual load patterns, which may deviate from the load profile on which the calculation is based.

Sunny Design 2.30.0.R



Any Company • Any Street 21 • 54321 Any Town

Lemminkäinen Talo Oy

Any Company
Any Street 21
54321 Any Town

Tel.: +49 123 456-0
Fax: +49 123 456-100
E-Mail: info@any-company.de
Internet: www.any-company.de

Project name: **Juhannuslehto B2 - max**
Project number: 3
Project file: Inverters B2 - max option.sdp2

Location: Finland / Pori

Grid voltage: 3~240 V

System overview

627 x Solarwatt BLUE 60M 240 (EU) (05/12) (PV array 1)
Azimuth angle: -38°, Inclination: 40°, Mounting type: Roof, PV peak power: 150,48 kWp

11 x STP 12000TL-10

Technical data

Total number of PV modules:	627	Energy usability factor:	100 %
PV peak power:	150,48 kWp	Performance ratio (approx.)*:	85,9 %
Number of inverters:	11	Spec. energy yield (approx.)*:	918 kWh/kWp
Nominal AC power:	132,00 kW	Line losses (in % of PV energy):	---
AC active power:	132,00 kW	Unbalanced load:	0,00 VA
Active power ratio:	87,7 %	Self-consumption:	106,28 MWh
Annual energy yield (approx.)*:	138,08 MWh	Self-consumption quota:	77 %

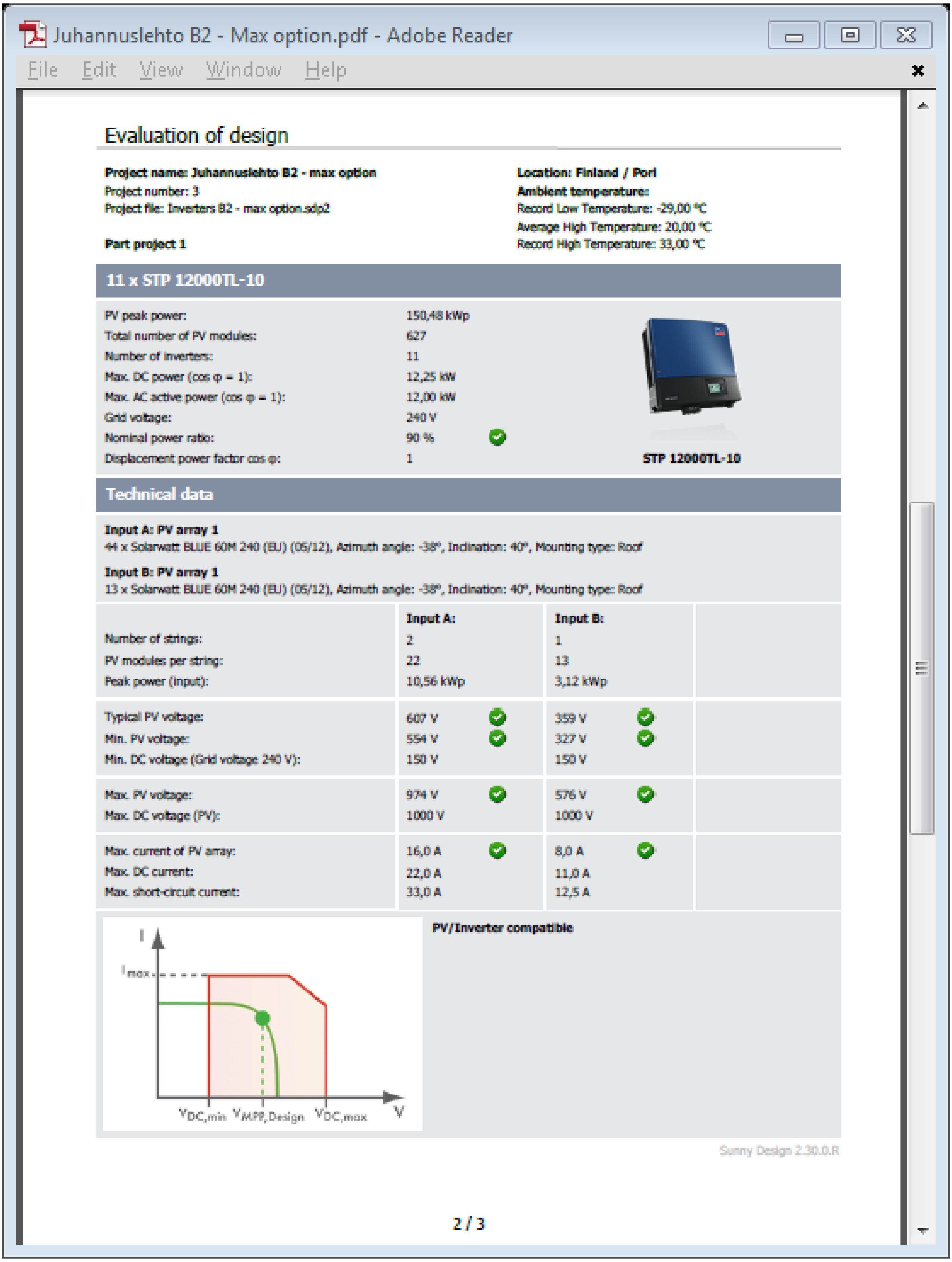
Notes:
Ambient temperatures are from the Porin tilastollinen vuosikirja 2012 (Statistical yearbook of Pori 2012)

Sunny Design 2.30.0.R

Signature

*Important: The yield values displayed are estimates. They are determined mathematically. SMA Solar Technology AG accepts no responsibility for the real yield value which can deviate from the yield values displayed here. Reasons for deviations are various outside conditions, such as soiling of the PV Modules or fluctuations in the efficiency of the PV modules.

1 / 3



Evaluation of design

Project name: Juhannuslehto B2 - max option
Project number: 3
Project file: Inverters B2 - max option.sdp2

Part project 1

Location: Finland / Pori
Ambient temperature:
Record Low Temperature: -29,00 °C
Average High Temperature: 20,00 °C
Record High Temperature: 33,00 °C

11 x STP 12000TL-10

PV peak power:	150,48 kWp	
Total number of PV modules:	627	
Number of inverters:	11	
Max. DC power (cos φ = 1):	12,25 kW	
Max. AC active power (cos φ = 1):	12,00 kW	
Grid voltage:	240 V	
Nominal power ratio:	90 %	✓
Displacement power factor cos φ:	1	

STP 12000TL-10

Technical data

Input A: PV array 1
44 x Solarwatt BLUE 60M 240 (EU) (05/12), Azimuth angle: -38°, Inclination: 40°, Mounting type: Roof

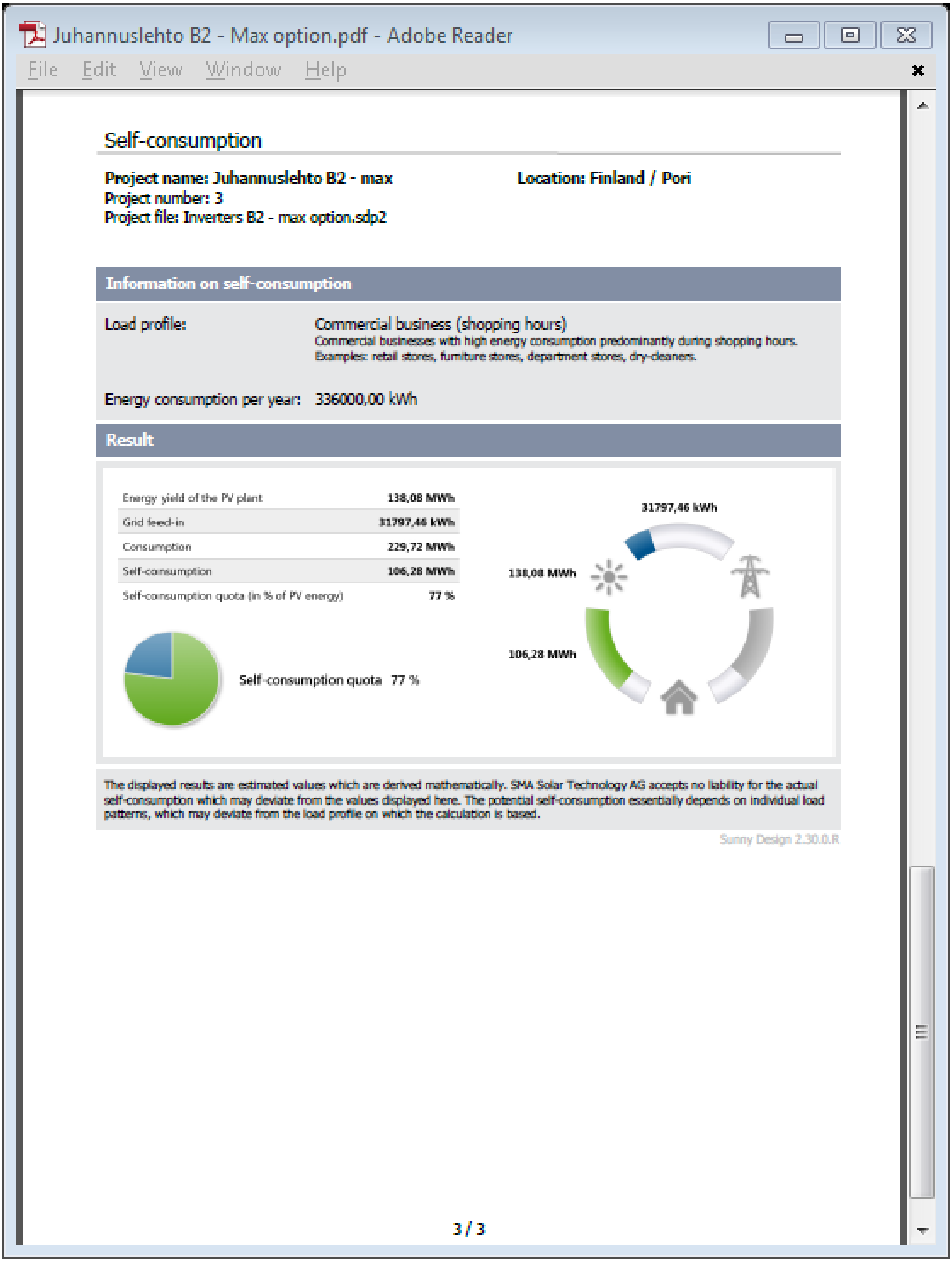
Input B: PV array 1
13 x Solarwatt BLUE 60M 240 (EU) (05/12), Azimuth angle: -38°, Inclination: 40°, Mounting type: Roof

	Input A:		**Input B:**	
Number of strings:	2		1	
PV modules per string:	22		13	
Peak power (input):	10,56 kWp		3,12 kWp	
Typical PV voltage:	607 V	✓	359 V	✓
Min. PV voltage:	554 V	✓	327 V	✓
Min. DC voltage (Grid voltage 240 V):	150 V		150 V	
Max. PV voltage:	974 V	✓	576 V	✓
Max. DC voltage (PV):	1000 V		1000 V	
Max. current of PV array:	16,0 A	✓	8,0 A	✓
Max. DC current:	22,0 A		11,0 A	
Max. short-circuit current:	33,0 A		12,5 A	

PV/Inverter compatible

Sunny Design 2.30.0.R

2 / 3



Self-consumption

Project name: Juhannuslehto B2 - max
Project number: 3
Project file: Inverters B2 - max option.sdp2

Location: Finland / Pori

Information on self-consumption

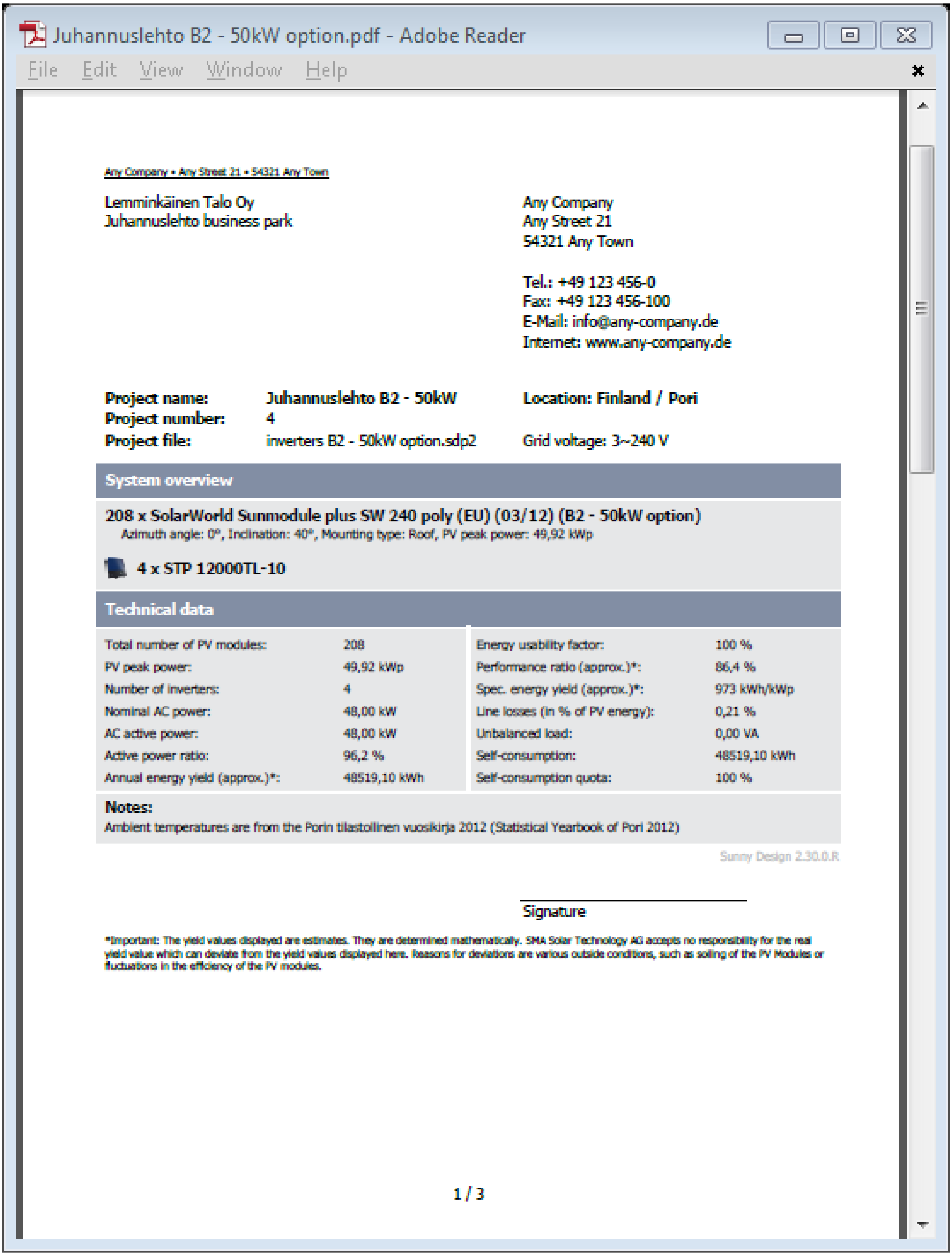
Load profile:	Commercial business (shopping hours) Commercial businesses with high energy consumption predominantly during shopping hours. Examples: retail stores, furniture stores, department stores, dry-cleaners.
Energy consumption per year:	336000,00 kWh

Result

Energy yield of the PV plant	**138,08 MWh**
Grid feed-in	**31797,46 kWh**
Consumption	**229,72 MWh**
Self-consumption	**106,28 MWh**
Self-consumption quota (in % of PV energy)	**77 %**

The displayed results are estimated values which are derived mathematically. SMA Solar Technology AG accepts no liability for the actual self-consumption which may deviate from the values displayed here. The potential self-consumption essentially depends on individual load patterns, which may deviate from the load profile on which the calculation is based.

Sunny Design 2.30.0.R



Any Company • Any Street 21 • 54321 Any Town

Lemminkäinen Talo Oy
Juhannuslehto business park

Any Company
Any Street 21
54321 Any Town

Tel.: +49 123 456-0
Fax: +49 123 456-100
E-Mail: info@any-company.de
Internet: www.any-company.de

Project name: **Juhannuslehto B2 - 50kW**
Project number: 4
Project file: inverters B2 - 50kW option.sdp2

Location: Finland / Pori
Grid voltage: 3~240 V

System overview

208 x SolarWorld Sunmodule plus SW 240 poly (EU) (03/12) (B2 - 50kW option)

Azimuth angle: 0°, Inclination: 40°, Mounting type: Roof, PV peak power: 49,92 kWp

4 x STP 12000TL-10

Technical data

Total number of PV modules:	208	Energy usability factor:	100 %
PV peak power:	49,92 kWp	Performance ratio (approx.)*:	86,4 %
Number of inverters:	4	Spec. energy yield (approx.)*:	973 kWh/kWp
Nominal AC power:	48,00 kW	Line losses (in % of PV energy):	0,21 %
AC active power:	48,00 kW	Unbalanced load:	0,00 VA
Active power ratio:	96,2 %	Self-consumption:	48519,10 kWh
Annual energy yield (approx.)*:	48519,10 kWh	Self-consumption quota:	100 %

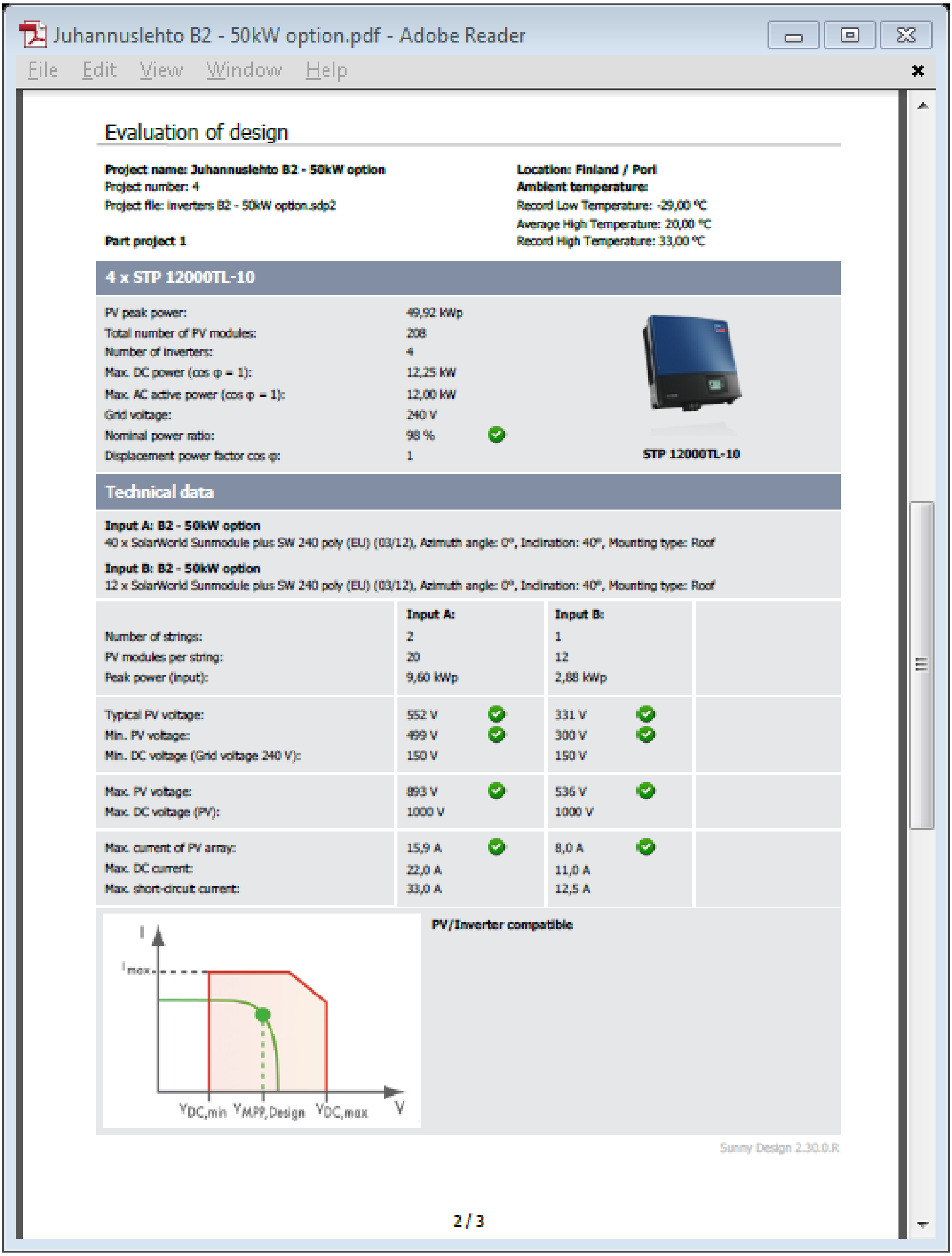
Notes:
Ambient temperatures are from the Porin tilastollinen vuosikirja 2012 (Statistical Yearbook of Pori 2012)

Sunny Design 2.30.0.R

Signature

*Important: The yield values displayed are estimates. They are determined mathematically. SMA Solar Technology AG accepts no responsibility for the real yield value which can deviate from the yield values displayed here. Reasons for deviations are various outside conditions, such as soiling of the PV Modules or fluctuations in the efficiency of the PV modules.

1 / 3



Evaluation of design

Project name: Juhannuslehto B2 - 50kW option
Project number: 4
Project file: inverters B2 - 50kW option.sdp2

Part project 1

Location: Finland / Pori
Ambient temperature:
Record Low Temperature: -29,00 °C
Average High Temperature: 20,00 °C
Record High Temperature: 33,00 °C

4 x STP 12000TL-10

PV peak power:	49,92 kWp	
Total number of PV modules:	208	
Number of inverters:	4	
Max. DC power (cos φ = 1):	12,25 kW	
Max. AC active power (cos φ = 1):	12,00 kW	
Grid voltage:	240 V	
Nominal power ratio:	98 %	✓
Displacement power factor cos φ:	1	

STP 12000TL-10

Technical data

Input A: B2 - 50kW option
40 x SolarWorld Sunmodule plus SW 240 poly (EU) (03/12), Azimuth angle: 0°, Inclination: 40°, Mounting type: Roof

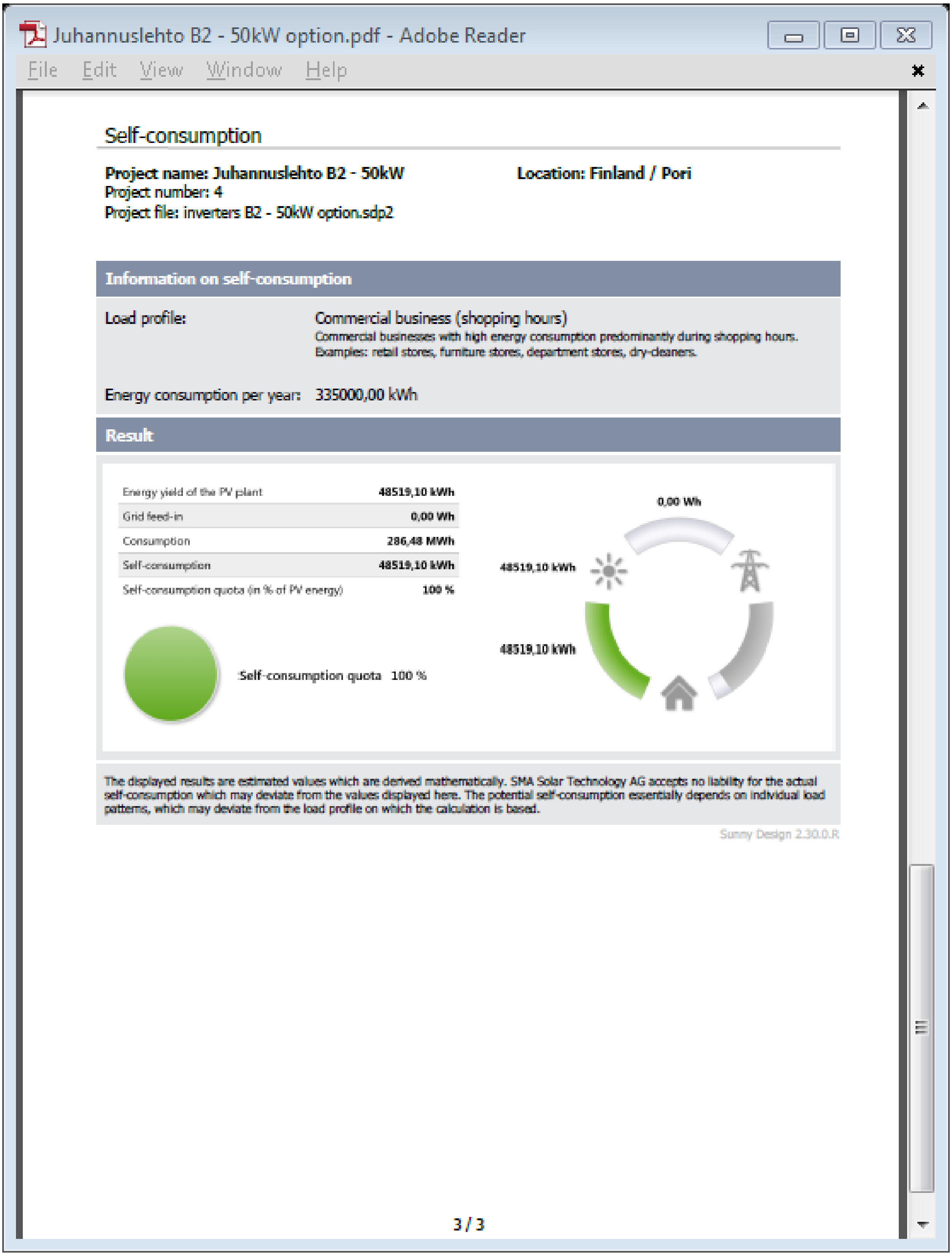
Input B: B2 - 50kW option
12 x SolarWorld Sunmodule plus SW 240 poly (EU) (03/12), Azimuth angle: 0°, Inclination: 40°, Mounting type: Roof

	Input A:		**Input B:**	
Number of strings:	2		1	
PV modules per string:	20		12	
Peak power (input):	9,60 kWp		2,88 kWp	
Typical PV voltage:	552 V	✓	331 V	✓
Min. PV voltage:	499 V	✓	300 V	✓
Min. DC voltage (Grid voltage 240 V):	150 V		150 V	
Max. PV voltage:	893 V	✓	536 V	✓
Max. DC voltage (PV):	1000 V		1000 V	
Max. current of PV array:	15,9 A	✓	8,0 A	✓
Max. DC current:	22,0 A		11,0 A	
Max. short-circuit current:	33,0 A		12,5 A	

PV/Inverter compatible

Sunny Design 2.30.0.R

2 / 3



Self-consumption

Project name: Juhannuslehto B2 - 50kW
Project number: 4
Project file: inverters B2 - 50kW option.sdp2

Location: Finland / Pori

Information on self-consumption

Load profile: Commercial business (shopping hours)
Commercial businesses with high energy consumption predominantly during shopping hours.
Examples: retail stores, furniture stores, department stores, dry-cleaners.

Energy consumption per year: 335000,00 kWh

Result

Energy yield of the PV plant	**48519,10 kWh**
Grid feed-in	**0,00 Wh**
Consumption	**286,48 MWh**
Self-consumption	**48519,10 kWh**
Self-consumption quota (in % of PV energy)	**100 %**

Self-consumption quota 100 %

The displayed results are estimated values which are derived mathematically. SMA Solar Technology AG accepts no liability for the actual self-consumption which may deviate from the values displayed here. The potential self-consumption essentially depends on individual load patterns, which may deviate from the load profile on which the calculation is based.

Sunny Design 2.30.0.R