Contract number ENER/FP7/260039/BEEMUP

BEEM-UP

Building Energy Efficiency for Massive market UPtake

Integrated Project

EeB-ENERGY-2010.8.1-2
Demonstration of Energy Efficiency through Retrofitting of Buildings

Deliverable D4.2: Specification of electricity generation potential

Due date of deliverable: 2011/05
Actual submission date: 2012/05/15

Start of the project: 2011/01/01 **Duration:** 48 months

Organisation name and lead contractor: ITA (Task4.2 leader) / SKANSKA / SP

Revision: Final

Project co-funded by the European Commission within the Seventh Framework Programme		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Deliverable description

This deliverable report belongs to work package *WP4. Technology Innovation and Tailoring for Replication*, inside in the task *T4.2. Energy generation: Optimisation of local electricity generation systems*.

It´s considered as Report with a public level dissemination.

The overall objective of this report is to provide a comprehensive approach to net energy balance of the building, identifying the actual loads and photovoltaic power generation.

Chapter 1 describes the objectives of the report.

Chapter 2 includes a review of the various renewable energy sources available locally.

Chapter 3 discusses the actual loads of Alingsas, differentiating between types of loads installed by analyzing the actual values collected for 2011, and graphically showing consumption profiles in different temporary basis.

Chapter 4 presents several pre-dimensioning aspects of the installation such as: solar radiation data (comparating solar radiation data collected from various sources), an estimate of the space available for installing PV cell panels and the energy generated, different PV cell panel technologies, and simulation software for the design of PV solar installations.

Chapter 5 shows the results obtained from the simulations performed with the PV*SOL Expert Pro v5.5 software[1]. The energy balance calculation between the actual load and the source of energy is presented. It is based on simulations from energy production-generation and system topologies. Finally, possible improvements that maximize or optimize energy production are suggested.

Chapter 6 presents the main findings from the report.

The Annexes list the actual consumption data collected in tables and graphs in a time basis. Also added the meteorological data obtained from the NASA-SSE source for the region of Alingsas[2].

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Chapter 1 Introduction

1.1 Objectives

The main goal of this report is to provide a comprehensive approach to electrical network of the building. It identifies the real electrical energy demanded and estimates the renewal energy produced.

All the analysis in this report is focused on the pilot site Alingsas-Brogården. It is therefore advisable to first make a brief introduction to describe the site and buildings for such a study.

1.2 Site presentation: The residential area Alingsas-Brogården

The residential area Alingsas-Brogården were built in 70´s, belonging to Million Home Program.

This area is composed by 16 buildings, grouped by blocks of 2 or 4 buildings, forming small subgroups with interior garden, among other common elements.

Brogården is located closely to the city centre and its facilities, but at the same time is surrounded by nature. Moreover, it has a relevant cultural and historical value.

In total there are around 300 flats and the buildings are constructed from 2 up to 4 floors each. All flats have outside access, either balcony or patio.

The 16 buildings are named by letters A to Q, as shown in the following chart:

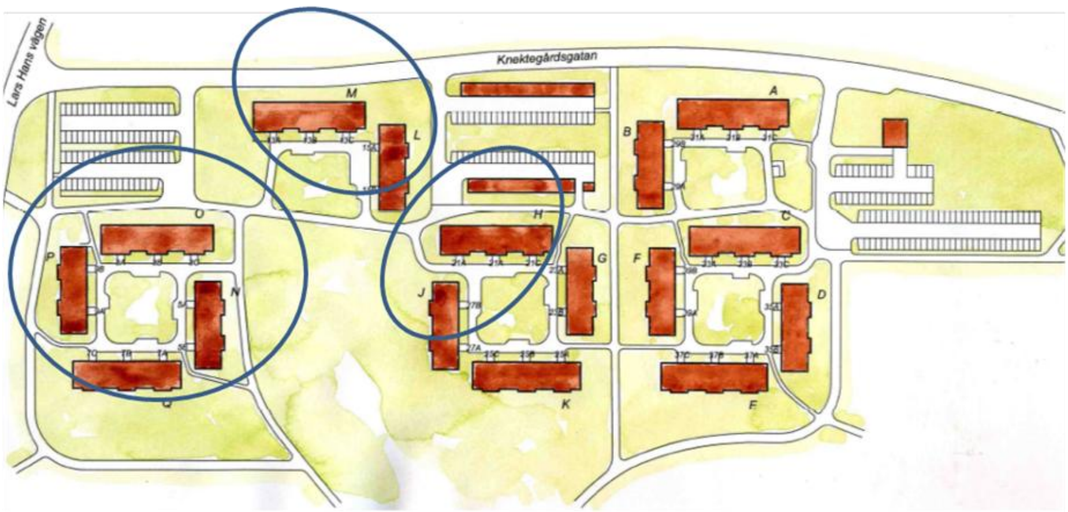


Fig. 1.1. Situation plane over the eight buildings at Brogården included in BEEM_UP project (© SKANSKA Sverige AB)

The 8 buildings which are initially included in the BEEM_UP project are showed on picture above (marked with blue circles).

Skanska, who is in charge of the retrofitting project in Alingsas, has decided to carry out the works on several sub-groups of buildings in order to facilitate the rehabilitation of the buildings and tenants living in them. They have decided to start with the AB and CDEF groups and finished with NOPQ groups.

For this reason, Skanska has decided to apply the analysis and possible future integration of renewable energy sources to the latter group of buildings. Thus, all calculations and estimations in this report are referred to this group of buildings (NOPQ), both in terms of the load measurements and the calculation of solar energy generated.

1.3 Preliminary work

An important starting point of this report was to know the results obtained in a previous work made by Lin Liljefors (Skanska Sverige AB) in 2010.[3] (Bachelor Thesis in Physics, Sustainable Energy: "*Locally Produced Renewable Electricity for Heating at Brogården*"). A brief summary of the main findings of this work is presented.

Today we can see very energy efficiently built or renovated houses, and at the same time the very low energy demand for heating makes it tempting to use the very simple and cheap heating system of electrical heating batteries. The Bachelor Thesis discusses the sustainability in choosing electrical heating instead of district heating in the continued renovation of Brogården in Alingsås to very energy efficient buildings, in combination with local production of renewable electricity. The thesis tackles the issue from the perspectives of regulations, economy and environment, in addition to evaluating what methods for electricity production are available/suitable at Brogården. It is throughout the thesis focused on the potential effects on the massive market, according to the goals of the BEEM UP project. This summary will briefly present the conclusions of the thesis. (Note that some figures on funding, costs, energy calculations etc. might have changed since 2010.).

The energy consumption for space heating at Brogården the heating season 09-10 was according to the calculations in this thesis 22 % higher that the theoretical calculation for house D, and 56 % higher for house E, after normal year climate correcting. The heating demand in house E seem to be lower than for house D in the winter, but higher in the spring. The overall high heating demand in the houses in the spring was surprising. The methods for correcting by normal year climate might be misleading for passive houses, and this might have exerted an influence on the results.

There is a clear correlation between high heating demands and low outdoor temperatures, and no evidence for weather dependent short time displacement of heating demand has been found.

The total energy demand for space heating in the eight BEEM UP houses is estimated to approx. 485 000 kWh/year (from measured data in earlier houses). The electricity needed for fans and common area is estimated to approx. 85 000 kWh/year (from theoretical analyses).

A comparison of the power load in the Swedish power grid with the measured heating demand at Brogården at an hourly basis is made in the thesis. The comparison shows that the heating demand peaks tend to occur simultaneously with peaks in the grid power load, both locally and nationally. At these peaks the power grid is especially strained, and the Swedish peak load reserve is activated in fossil power plants, with increasing CO2-emissions as a result. The environmental effects of the electricity demand are therefore very much connected to the power load demand, and not only to the yearly demand. The conclusion is that a massive increase of use of electricity heating in Sweden will lead to an increase of the usage of the Swedish peak load reserve, and therefore have a negative effect on the environment, compared to the bio energy in the district heating system.

The thesis shows that solar cells are the only suitable method for local electricity production at Brogården today, as well as for most of the similar areas in Sweden. It might but be difficult to live up to the Swedish building regulations if the heating is provided by electricity, since the energy regulations are much stricter for electrically heated buildings that for others. The solar electricity is mainly produced during summer but needed in the winter, and according to the regulations one can only count for the solar electricity used simultaneously as produced, and therefore the surplus production during very sunny days cannot be accounted for.

It is not either economically sustainable to change from district heating to electrical heating. The local electricity production would not take place simultaneously with the demand, and it is today not profitable to sell the excess electricity during production peaks. This means that the energy for heating will still have to be paid for, and since the price for electricity is much higher than district heat the possibilities to lower the yearly energy cost would be insignificant. The installation costs for an electrical heating system in combination with an electricity producing system would be much higher than the costs for installing district heat in the buildings, so no savings would be possible there either.

The conclusion of the thesis is that it is not feasible to change from district to electrical heating even if it is combined with local electricity production. It falls on a combination of regulations, economy and environment. Following table shows the results of four different scenarios.

Scenario	Yearly demand	Yearly electricity production	Regulations	Economy	Environment
1 (el.)	485 000 kWh	0 kWh	-	-	-
2 (el.)	485 000 kWh	485 000 kWh	+-	-	-
3 (el.)	485 000 kWh	245 000 kWh	+-	-	-
4 (dh.)	85 000 kWh	85 000 kWh	+	+	+

Table 1.1. Sustainability analysis of different scenarios. el. = electrical heating, dh. = district heating

It would but be sustainable to build a solar cell system at Brogården for covering e.g. the electricity demand for fans and common area (see scenario 4 in table above). In this way regulations are followed, the possibilities to live up to the demands for a passive house are increasing, and the houses will become more environmentally friendly. This could be done by approx 800 m2 of crystalline cells on the roof, corresponding to a kWp of approx. 118 kW. If it is possible to get 55 % state funding for the system, the total price towards customer would be around 2 000 000 SEK, and the POT 25 years with 5 % bank rate and an yearly electricity price increase of 5 %.

Comment: Since the thesis was written the solar cell market has experienced extreme changes, and the price picture today differs a lot from 2010. See BEEM UP delivery report 4.5 for more up-to-date numbers.

Chapter 2 Review of renewable energy sources

This chapter briefly analyses the most typical renewable energy sources, which are photovoltaic solar and wind power, and their application at Brogården site.

For this analysis, the local weather conditions have been considered as an important factor to take decisions, but not the only one. The weather parameters considered are the horizontal solar irradiation energy and the average wind speed.

2.1 Photovoltaic solar power

The **horizontal solar irradiation value (Gh)** is the most important parameter in the evaluation of the PV installation feasibility. This value is normally measured as the daily average in a monthly basis (in kWh/m^2/day). It means the quantity of solar energy received on an horizontal surface in Alingsas for a day.

This parameter can be got from different official sites, as the next table shows:

HORIZONTAL SOLAR IRRADIATION (Gh)	Daily Average per Month												Daily Average per Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
NASA-SSE[2]	0.50	1.18	2.39	3.74	5.09	5.38	5.21	4.30	2.84	1.40	0.68	0.37	**2.76**
Meteonorm v6.1[4]	0.35	0.89	1.87	3.5	4.93	5.37	5.29	4.03	2.57	1.22	0.53	0.26	**2.57**
PVGIS-ESRA[5]	0.35	0.87	2.30	3.90	5.00	5.36	4.76	3.78	2.62	1.18	0.43	0.27	**2.58**
RETScreen[6]	0.50	1.18	2.39	3.74	5.09	5.38	5.21	4.30	2.84	1.40	0.68	0.37	**2.77**

Table 2.1. Horizontal solar irradiation data from different sources (in kWh/m^2/day)

The maximum difference among them is around 7%, so it can be assumed that the horizontal solar irradiation has a value of **2.57 kWh/m^2/day**.

A quick calculation for knowing the possible energy production in Alingsas is showed below (supposed over an 300 m^2 area and a PV cell panel efficiency around 10%):

Daily horizontal solar irradiation **=** **2.57 kWh/m^2/day**

Yearly horizontal solar irradiation **~** **938 kWh/m^2/year**

Yearly horizontal solar irradiation (on a area 300 m^2) **~ 281 MWh/y**

Yearly energy production (η_{PV} = 10%) **~ 28 MWh/y**

This produced energy is a significant quantity in relation to the building load. Of course, it must be taken into account the true azimuth and inclination angles of the PV cell panels installed on surfaces, the real PV panel efficiency and the global system efficiency.

In chapter 4 it will be analyzed in more detail how many square meters are really available on each surface, but it is sure that they will be more than 300 m^2 in total for the group NOPQ.

There is another parameter to consider which is the components of the solar radiation. Figure 2.1 shows the evolution of horizontal solar irradiation throughout the year and its two components:

- Diffuse radiation
- Direct radiation

The diffuse radiation is the energy received by sunlight reflected in atmosphere (mainly in clouds), while the direct radiation is the energy that emanates directly from the sun's disc an is not reflected anywhere before it reaches the surface.

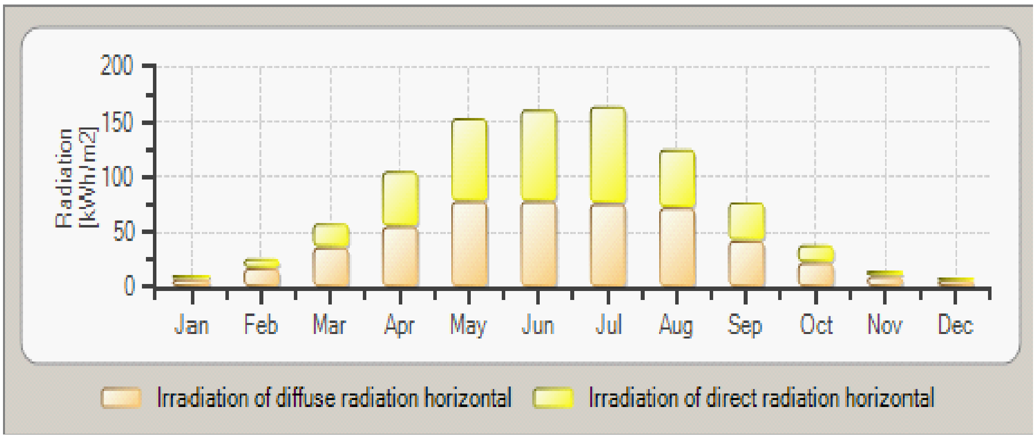


Fig. 2.1. Solar irradiation components distribution (© Data source METEONORM [Version 6.1])

From the figure above it can be seen that both irradiations contribute in a similar percentage to the total energy received. This situation is frequent in most of countries of Northern Europe.

Other important factor to consider in a solar cell installation is the possibility of getting state funding, which is an important help to lower the investment economic cost. In the case of Brogården, an application for funding was made in spring 2011. These kind of funding have some limitations related to the investment cost. In chapter 5.6 an economic analysis is made including more detailed data about funding.

Moreover, there is the possibility to sell the energy overproduction to the local electricity company. The conditions to do this can vary from one company to another and furthermore the grid owner must be considered as well in the process, but in general this situation is allowed, which is a very interesting issue.

At last, another significative aspect to be in favour with the implementation of this technology is the environmental and sociological impact in the society, because people normally agree with this kind of technology, which represents a symbol of progress in defense of the planet.

2.2 Wind power

Nowadays the number of wind power systems on the market is high, so trying to analyze all the alternatives is a really difficult task.

However, most of these systems are based on a fundamental meteorological parameter which is the wind speed.

Table 2.2 shows the values for average wind speed at Alingsas area. This data has been got from different private or public sources, throughout the year. This parameter refers to the wind speed at 10 meters above the ground´s level. These values are monthly averages in m/s.

AVERAGE WIND SPEED	Daily Average per Month												Daily Average per Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
NASA-SSE	3.97	3.53	3.68	3.57	3.59	3.48	3.44	3.36	3.79	3.91	3.92	3.91	**3.68**
Meteonorm v6.1	4.6	5.1	4.3	4.1	4.0	4.1	3.7	3.6	4.0	4.4	4.4	4.4	**4.2**
PVGIS-ESRA	-	-	-	-	-	-	-	-	-	-	-	-	**-**
RETScreen	5.1	5.0	4.8	4.4	4.3	4.1	3.9	3.9	4.3	4.7	4.7	4.8	**4.5**

Table 2.2. Average wind speed in Alingsas from several sources (in m/s)

According to this table, the average wind speed in Alingsas is around **4.2 m/s**. Assuming that any wind power installation requires an average wind speed per year higher than 5 m/s to be economical sustainable, it is possible to conclude from this table that this type of renewal energy does not fit into the environmental condition of the Alingsas area. Moreover, from the aesthetic point of view, this technology is much more impressive to the eyes and ears of the tenants, so the wind power installations may have serious limitations.

Remark!

The conclusion of this chapter is that the best option for generating local electricity in Alingsas is at the moment by PV cell panels. On the other hand, wind power systems will not be considered in the present study.

Chapter 3 Load identification

Before evaluating the profiles of the loads is important to remark two things:

1. Correct identification of the load profiles of the buildings has to be completed in order to get the real consumption of each building from the mains. It has been decided to obtain and analysis the actual consumption data from the first group of buildings (CDEF), which are already rehabilitated and occupied. These data will be extended to NOPQ groups of buildings because they are structurally and constructively similar.
2. The measurement period was from January to September. All the buildings were not completed and inhabited until April. Therefore, the measurements were only considered during the summer time. The energy and power consumption for winter time has been estimated applying a correction factor of 1.2. This is explained in more detail in Annex A.1.

Remark!

In consequence, it can be assumed that this report analyses the real consumption data for buildings NOPQ during 2011.

3.1 Load classes

Electric loads found in these buildings are composed of various systems: Pumps for running the air and water heating systems, ventilation systems, lighting systems for indoor and outdoor common areas, laundry rooms, parking, elevators, and devices domestic use.

The central heating and hot water services cover districts areas. The accounting of electricity consumption takes place outside the building blocks, which greatly complicates the analysis of individual building blocks. Therefore, they have not been included in the present analysis. Moreover, Bachelor Thesis work conducted in 2010 by Lin Liljefors demonstrated the unsustainability of replacing the district heating and hot water system by electric radiators.[3]

The electricity consumption from the use of appliances and household devices by tenants is not measured in the real consumption measurements compiled at Brogården site. In order to simplify the analysis, this type of loads haven´t been included in the calculations. However, they are interesting to take into account in the future or in other projects as they represent a significant and increasing share of the total power consumption.

Consequently, the loads which have been measured and included in this analysis are:

1. Residential loads (internal ventilation system and indoor lighting)
2. Laundry rooms located in building O
3. Lightning from garbage house, outdoor yard and parking lot
4. Elevator located in building Q

The total real consumption of the four loads above is included in the data tables in Annex A.1. In the Chapter 3.2. these data are analyzed for extracting the yearly, monthly and daily profiles.

In addition to these data tables, the energy consumption of some of the loads has been estimated based on manual recording at Brogården site and estimations. These values are:

- **Laundry rooms**: 1000 kWh/month per laundry room (there are two laundry rooms on building O)
- **Outdoor electricity** (Lightning for garbage house, outdoor yard, parking lot): 1200 kWh/month (all on building O)
- **Elevator**: 83 kWh/month (there is one elevator on building Q)

Based on previous data, an estimation of the energy consumption per each House could be similar to the next values:

House N	**=>**	**12%**
House O	**=>**	**51%**
House P	**=>**	**12%**
House Q	**=>**	**25%**

3.2 Load profiles

This section presents and analyzes the energy consumption curves in different temporary basis (yearly, monthly, daily).

3.2.1 Yearly profile

Figure 3.1 shows the real values (marked in blue) of the energy consumption for a year. These values have been fitted by fourth-order statistical function, which it is also shown in the figure (marked in red). A high order regression curved has been chosen as preferred option to fit the measured values. This type of fitting curve is equivalent to calculating the tendency curve to the points given by the equation:

$$y = b + c_1x + c_2x^2 + c_3x^3 + .. + c_6x^6$$

where b y c_1 .. c_6 are constant values calculated for each curve.

The goal of this function is to show more clearly the average value of the original curve. This curve will be used as input data in the simulation model developed in the present study. Next table and figure show the total energy consumption (kWh) of the building group for a year. More details of these values are shown in Annex A.1:

MONTH	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	TOTAL ENERGY
kWh/month	11156	9791	10693	8665	9024	8427	8911	9142	8997	10449	10398	10970	116.623

The next chart shows the evolution over the year of energy consumption in kWh/day:

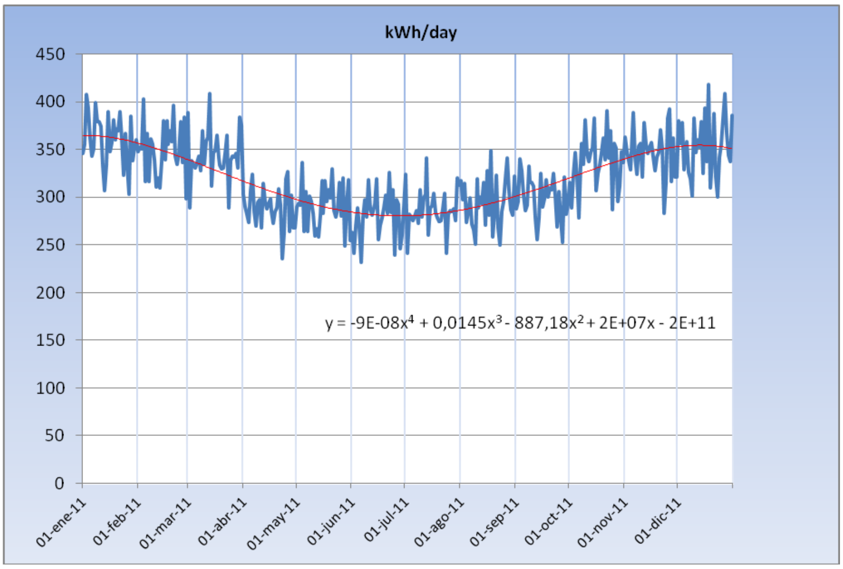


Fig. 3.1. Energy consumption in 2011

The red curve represents the basic and continuing use of the building. The real measurements have fluctuations due to external factors such as changing weather conditions or common loads usage by the tenants. The curve shows that the average energy consumption increases during the winter time season and decreases during summer time.

During a day, the variation of the energy consumption keeps similar in any month. There is a difference around 90 kWh/day between nearby peaks and valleys of the same day. This reduces the complexity of the control system of building energy flows.

The closely spaced peaks have been observed. They may be generated by the energy consumption of common areas (laundry rooms, elevator). They are random but they can vary from one day or week. (Text removed)

The energy consumption per House is shown below:

House N (12%)	**=>**	**~ 14 MWh/y**
House O (51%)	**=>**	**~ 59 MWh/y**
House P (12%)	**=>**	**~ 14 MWh/y**
House Q (25%)	**=>**	**~ 29 MWh/y**
TOTAL (4 Houses)	**=>**	**~ 116 MWh/y**

They have been calculated based on the energy weights estimated in previous section and the total consumption. These values are used in the simulation model presented in chapter 5.

Remark!

These energy consumption values and the prior annual profile will be considered as input data for defining the yearly load requeriment in the simulation software on Chapter 5.

3.2.2 Monthly profile

The average monthly profile of the energy consumption in Brogården block is shown in figure 3.2. It has been extracted from the monthly profiles (January to December), which can be observed in Annexes, Fig.A.1 and A.2.

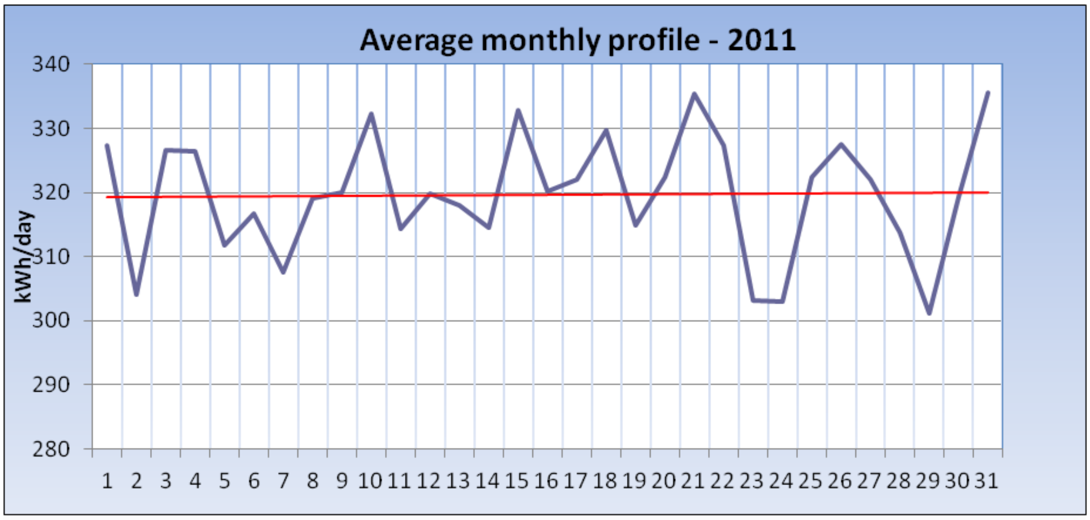


Fig. 3.2. Average monthly profile

All monthly curves are more or less similar. There are a lot of peaks and valleys around the core value of the consumption. The average energy consumption in winter time is well above 300 kWh/day (even more than 350 kWh/day), whereas in summer time is close to 300 kWh/day. As a result, the average energy consumption per month is around 320 kWh/day (red line in graph above).

Moreover, the average energy consumption during cold months remains flatter than the hot months. They do not exceed more than 50 kWh/day of maximum difference within each month.

The energy consumption variability between days over the same week is around +-5.5% (35 kWh/day in the worst case), which is not very high. So, for assessing the need for a energy storage system or calculating the installation size, it would be more appropriate to use an hourly profile of the consumption, showing the consumption differences between in the daytime and nighttime.

This is an important question because the energy produced can only be consumed at the same time (or close to), unless an energy storage system is implemented in the installation. The dimensions of the energy storage device as well as system energy dynamic have a direct impact in the cost of the installation and thus the total investment cost.

Remark!

As the behaviour looks like a bit random, the monthly profile considered to input in the simulation software will be a flat curve on the average value (red line).

3.2.3 Daily profile

Table 3.1 shows the energy consumption distribution along a day. It shows the average hourly values every month for a year. More details of these profiles are shown in Annex A.1.

TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	kWh/day
JANUARY	13	13	13	13	13	13	14	17	14	15	17	15	15	15	15	17	19	17	17	19	17	14	13	13	360
FEBRUARY	12	12	12	12	11	11	13	14	14	15	17	16	17	17	15	16	21	18	16	17	16	13	12	12	349
MARCH	11	12	12	12	11	10	13	15	13	15	17	16	16	16	15	16	20	17	18	18	17	13	12	12	347
APRIL	10	10	10	10	10	10	11	13	12	12	14	12	14	15	14	14	17	15	13	12	11	11	10	10	290
MAY	10	10	10	10	9	9	10	11	11	13	14	13	14	14	13	14	17	15	14	14	14	11	10	10	290
JUNE	9	9	10	9	8	8	10	12	11	12	14	13	13	14	13	14	16	14	14	14	13	11	10	10	281
JULY	10	10	10	10	9	8	11	13	11	12	14	13	13	14	13	13	16	15	15	15	14	11	10	10	290
AUGUST	10	10	10	10	10	9	11	14	12	12	13	13	13	15	13	14	17	14	14	14	14	11	10	10	293
SEPTEMBER	11	11	10	11	11	11	12	14	12	12	14	13	14	13	13	14	16	14	14	16	15	12	11	10	304
OCTOBER	11	11	11	11	10	10	12	14	14	14	16	15	16	17	15	17	19	17	17	17	16	14	12	12	338
NOVEMBER	12	12	12	12	12	12	13	15	14	15	17	15	16	18	17	17	20	17	15	15	13	13	12	12	346
DECEMBER	12	12	12	12	12	11	14	17	15	15	16	15	16	18	16	17	20	17	16	17	17	14	12	12	355
AVERAGE 2011 (kW)	11	11	11	11	10	10	12	14	13	14	15	14	15	16	14	15	18	16	15	16	15	12	11	11	320
AVERAGE Summertime	10	10	10	10	10	9	11	13	12	12	14	13	14	14	13	14	17	15	14	14	14	11	10	10	291
AVERAGE Wintertime	12	12	12	12	11	11	13	15	14	15	17	15	16	17	16	17	20	17	16	17	16	14	12	12	349

Table 3.1. Average hourly energy consumption

Figure 3.3 shows the average daily profile for a year. From 7:00 on there is an increase in consumption matching with the human activity. During the day there are five consumption peaks at 8:00, 11:00, 14:00, 17:00 and 20:00.

The highest peak of consumption is produced at 17:00. The valley time matches night time sleeping, whereas the peak fits the timing during the afternoon, which is always the highest consumption period of the day.

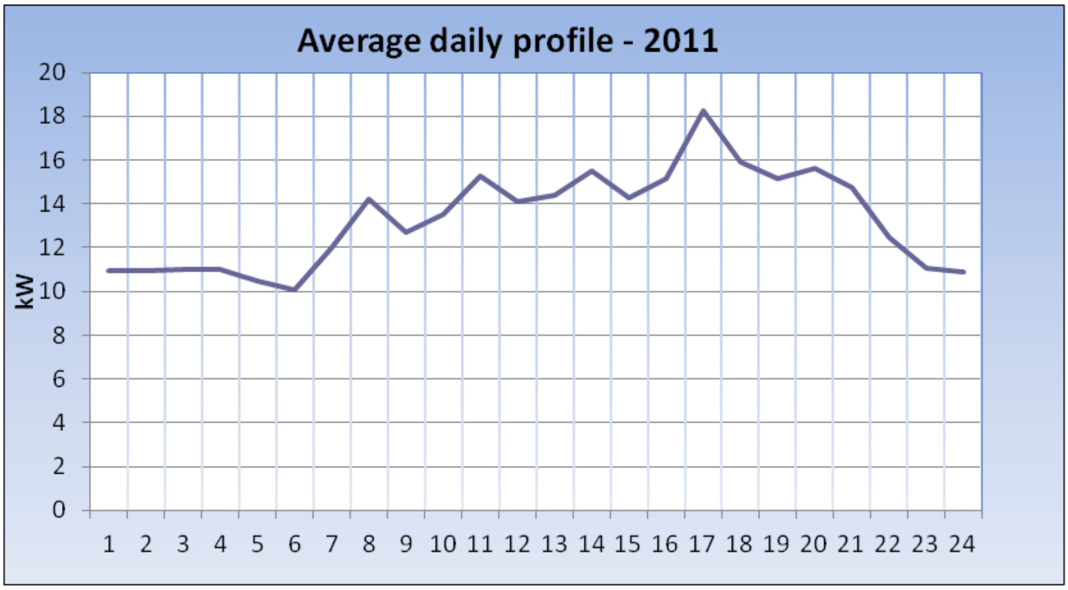


Fig. 3.3. Average daily profile

Remark!
This daily profile will be imported as input data in the simulation software on Chapter 5.

Chapter 4 PV solar system presizing

The photovoltaic electric production forecast and assessments of the energy balance of the system require a preliminary data processing in order to obtain the appropriate input data for these calculations. The most important data and components required for this analysis are:

- Solar radiation data for Alingsas using one of the official sources
- Available space area for solar cell panels (included geometric and topographical features)
- Solar cell panel model

The selected solar cell panel model is not definitive but it is necessary to establish an initial reference and allow further comparisons with other models. For example, one of the most relevant parameters to compare should be their corresponding efficiencies.

All this information is used as input data in the photovoltaic energy production simulation software.

Remark!
All this information will be used as input data in the photovoltaic energy production simulation software on Chapter 5.

4.1 Solar irradiation data sources: Compilation and verification

The weather conditions of the site is one of the main factors to take into account when assessing the possibility of generating electricity from renewable energy sources. For that purpose, it is essential to have reliable and accurate weather data.

Solar radiation, wind and other data have been collected and compared from several independent sources. This procedure has produced many parameters which conduct to reliable decisions.

There are many databases on atmospheric data. Each of them has its particular methods of calculation, application areas, types of data provided, terms of use and availability. There are sources that support worldwide areas, whereas others database are limited to specific regions, continents or countries. Also, some of them include only data for calculations of solar energy while others in addition generate data for wind energy. The data source differ also from one application to other; they could be got from ground weather stations or satellites and they could be expressed on different time basis (hourly, monthly or annual). The most frequently used variables are:

- **Gh**: Horizontal solar irradiation (in $kWh/m^2/day$). The monthly average amount of the total solar radiation incident on a horizontal surface at the earth surface
- **Dh**: Monthly averaged diffuse radiation incident on a horizontal surface (in $kWh/m^2/day$)
- **Ta**: Air temperature at ground level (in ºC)
- **WindVel**: Wind velocity (in m/s), normally given at different heights

Next table shows a compilation of the most important official sources of weather data worldwide:

DATABASE	REGION	VALUES	SOURCE	PERIOD	VARIABLES	AVAILABILITY
Meteonorm	Worldwide	Monthly	1700 terrain stations. Interpolations	1995-2005 averages	Gh, Ta, WindVel, Others	Software
Meteonorm	Worldwide	Hourly	Synthetic generation	1995-2005 averages	Gh, Dh, Ta, WindVel	Software
Satellight	Europe	Hourly	Meteosat Any pixel about 5x7 km^2	1996-2000	Gh	Web free
Helioclim (SoDa)	Europe	Hourly	Meteosat	From 2004	Gh	Web restricted
NASA-SSE	Worldwide	Monthly	Satellites (111x111 km^2 cells)	1983-1993 averages	Gh, Ta	Web free
WRDC	Worldwide	Hourly Daily Monthly	1195 stations	1964-1993	Gh	Web free
PVGIS-ESRA	Europe	Monthly	566 stations interp. 1x1 km^2	1981-1990 averages	Gh, Ta, Others	Web free
Helioclim-1 (SoDa)	Europe	Monthly	Meteosat 50x50 km^2	1985-2005	Gh	Web restricted
RETScreen	Worldwide	Monthly	Compil. 20 sources including WRDC-NASA	1961-1990 averages	Gh, Ta, WindVel	Software, free
SolarGIS	Europe	Hourly	Meteosat 4x5 km^2	From 1994	Gh, Dh, Ta	Web, paid access

Table 4.1. Meteorological data sources

The collected and compared data sources are:

- NASA-SSE: Official information supplied for the NASA´s sponsorized web: http://eosweb.larc.nasa.gov/sse/. This worldwide source is free, only registering in the web page.

- Meteonorm: Software for sale, it´s one of the most confident sources: http://meteonorm.com/

- PVGIS-ESRA: Free source with available data for Europe from the web page: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php. Moreover, it allows to calculate PV solar energy production simulations in an easy and very quick way.

- RETScreen: This free web page is supported by Canada´s Goverment supplying worldwide atmospheric data and software to calculate renewable energy installations: http://www.retscreen.net/es/home.php

The most significant atmospheric parameters considered for the analysis are shown below.

4.1.1 Horizontal solar irradiation (Gh)

This parameter has already been described in Chapter 2.1. The Table 2.1. shows the values compiled by several data sources.

As complementary information, Figure 4.1 below shows the astronomic sunshine duration, counting from sunrise to sunset, and the real sunshine duration taking into account the clouds over Alingsas.

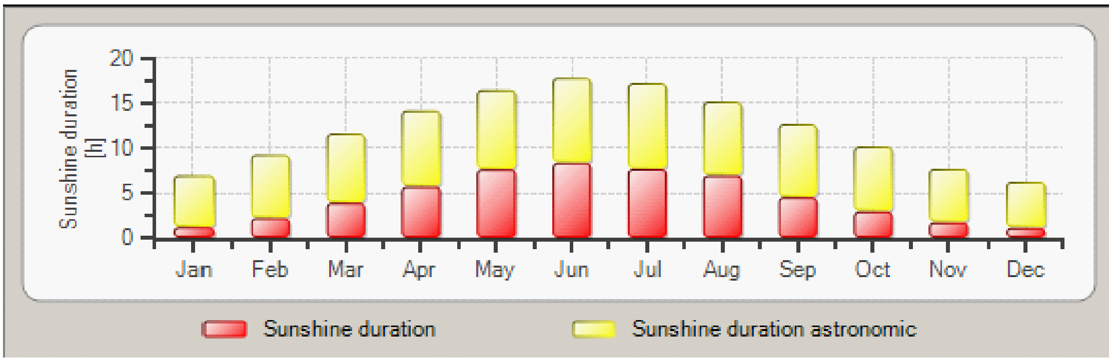


Fig. 4.1. Sunshine durations comparison in Alingsas (© Data source METEONORM [Version 6.1])

4.1.2 Air temperature (Ta)

This parameter is normally measured as the daily average in a monthly time basis (in ºC).

Next table compiles this parameter from several sources:

AIR TEMPERATURE (Ta)	Daily Average per Month												Daily Average per Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
NASA-SSE	-2.45	-1.71	1.08	5.84	11.7	15.5	17.6	16.9	12.0	7.22	1.72	-1.39	**7.07**
Meteonorm v6.1	-2.3	-1.3	0.6	5.7	10.1	13.5	15.9	16.3	12.1	7.1	2.5	-1.2	**6.6**
PVGIS-ESRA	-0.8	-0.2	1.2	5.9	10.6	14.4	16.8	16.9	13.0	8.3	3.7	0.3	**7.5**
RETScreen	-2.5	-1.7	1.1	5.8	11.8	15.5	17.7	17.0	12.0	7.2	1.7	-1.4	**7.1**

Table 4.2. Air temperature values in Alingsas (in °C)

The maximum difference between them is around 13%.

Figure 4.2 shows the evolution of the monthly average temperature, indicating the extreme temperatures (maximum and minimum), and the range of average temperature.

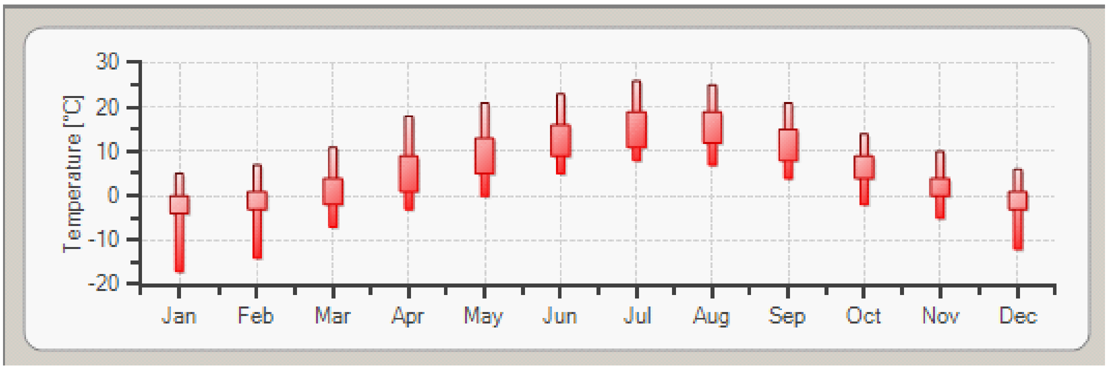


Fig. 4.2. Air temperature values in Alingsas (© Data source METEONORM [Version 6.1])

4.1.3 Air relative humidity (Hr)

The influence of this parameter is already taken into account by the horizontal solar irradiation parameter, which includes the effect of the atmosphere in the received energy.

This parameter refers to the quantity of relative humidity in the air at the ground level, it´s measured in %. This data is monthly average value. Table 4.3 compiles this parameter from several sources:

AIR RELATIVE HUMIDITY (Hr)	Daily Average per Month												Daily Average per Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
NASA-SSE	82.5	79.1	74.4	69.5	62.2	63	64.2	66.4	70.6	77.7	83	84	**73**
Meteonorm v6.1	99	89	77	71	70	73	75	74	79	86	92	95	**82**
PVGIS-ESRA	-	-	-	-	-	-	-	-	-	-	-	-	**-**
RETScreen	87.7	84.5	78.3	73.1	69.8	73.5	74	77.1	80.8	84.6	86.9	87.9	**79.8**

Table 4.3. Air relative humidity values in Alingsas (in %)

The maximum difference between them is around 11%. Figure 4.3 shows the quantity of precipitation (rain, snow, ..) along the year and the number of days with precipitation.

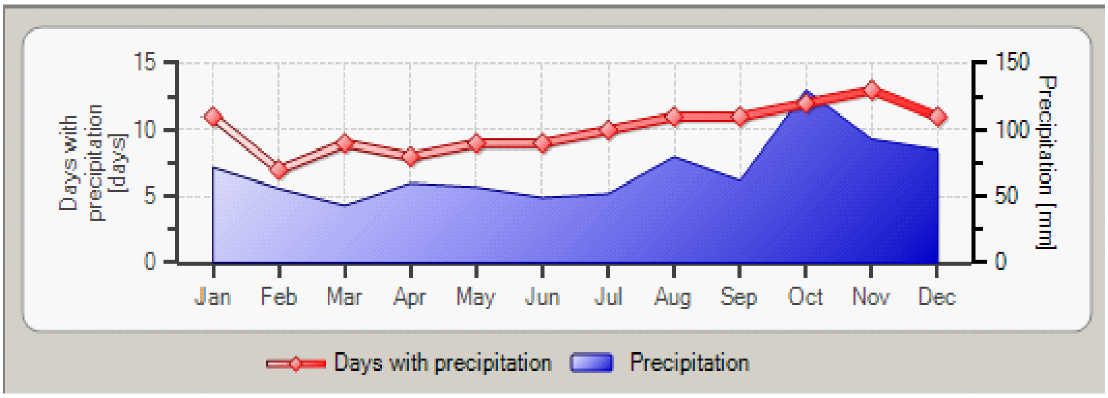


Fig. 4.3. Precipitation values in Alingsas (© Data source METEONORM [Version 6.1])

Remark!

From here on Meteonorm data will be the reference source for all calculations, simulations and estimates on Chapter 5.

4.2 Available surfaces for PV cell panels installation

The analysis will consider only the group of buildings NOPQ. They are arranged in a square structure. They are oriented 15 degrees westwards (note that speaking of PV solar power in Northern hemisphere the reference direction is South = 0º). Therefore, the orientations of the various surfaces are one of the next four angles (-165° E, -75° E, 15° W, 105° W), where 0º azimuth is pointing to South and positive angles are oriented towards the West and negative ones to the East.

The available locations of solar cell panels in each building are:

- Roofs
- Balconies
- Facades

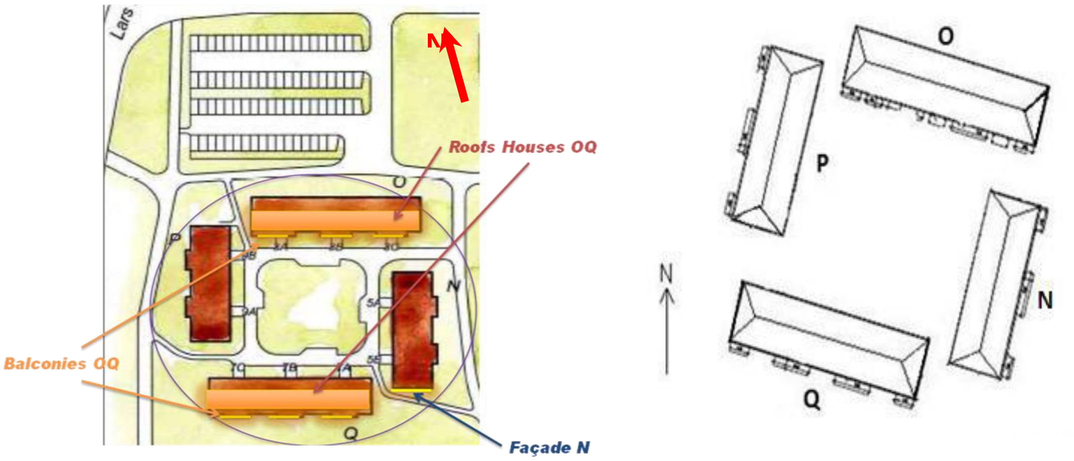


Fig. 4.5. Top view of buildings group NOPQ (© SKANSKA Sverige AB)

4.2.1 Roofs

Each building consists of a sloping roof on four sides, two large longitudinal sides and other two small ones at the ends of each building.

The longitudinal sides of each roof have a 14º slope and the ending sides have a 20º slope.

Tables 4.5 to 4.8 below show the different roof areas, approximately calculated from the drawings in the construction documents. It must be noted that these roofs contains some roof ladders, ducts, fire-gas fans, snow guards and roof caps that might be an obstacle when mounting the solar cell panels. The roof areas for solar cell panels are calculated taking into account the limited space, but fine calculation will be required for final panel implementations.

Comment!

For more detailed calculations the available roof areas should be more accurately calculated, taking into account all the objects located on each roof.

4.2.2 Balconies

All buildings have balconies. The number varies from one building to another, although the dimensions of each balcony are very similar. All of them are always placed on one side of the building.

The orientation of the balconies is different depending on the building (-75° E, 15° W, 105° W), but all balconies have the same inclination 90°, ie, are vertical.

Given the particular location of the balconies, it may be necessary to study in more detail the specific mounting issues on them.

It has to be noted that the ground floor balconies are at ground´s level, so from the point of view of safety, for example in terms of accidental breakage, it would be better not to mount on them.

The PV cell panels would be widely visible in the area, giving a positive feeling for most of people living there.

Integrating PV cell panels in balconies can mean to substitute the original constructive material, which is very cheap, so in that case the economic saving is minor.

4.2.3 Facades

Each building has two side walls with space available to place solar cell panels.

The orientation of the facades is different depending on the building (four directions are possible), but all facades have the same inclination 90°, ie, are vertical.

There are several elements in some facades, such as windows, which decrease the available space for solar cell panels.

It has to be noted that the facades begin at ground´s level, so from the point of view of safety, it would be better not to mount there.

The PV cell panels would be widely visible in the area, giving a positive feeling for most of people living there.

Integrating PV cell panels in facades can mean to substitute the original constructive material, which is quite expensive, so in that case the economic saving could be important.

Comment!

The windows distribution could be redefined in order to cover a lower part of each façade. Moreover, there is the alternative of using blinds where a full PV cell panel cannot be used.

4.2.4 Surfaces pre-sizing

Four tables below show every available surface, its orientation and inclination angles, solar radiation, its efficiency with respect to the optimal inclination one.

The optimal surface at Alingsas site is given by the 0° S orientation (azimuth) and 41° inclination (tilt), which provides a solar radiation of 1.140 kWh/m^2y, which represents a 100% efficiency.

The energy efficiency is inversely proportional to the economic cost of the investment (€/kWh), ie, low efficiency means a high cost of production while in the other end a high efficiency means a low cost.

The amount of energy produced by each surface is another important parameter. For this purpose, free software PVGIS has been used, which allows to get a first and quick calculation of produced energy by each surface.

Comment!

The energy production values given in the tables below are merely indicative. Values closer to reality will be calculated and shown again in Chapter 5.

The differences between these production values and the real ones are because of many parameters such as: the real useful area of each surface, the type of installation performed, the connection between panels, the installation wiring losses, the component performance losses, the shadows of other objects ..

On the other hand, there are other aspects to take into account which can represent benefits like, for example, the environmental and sociological impact in the society.

House N

Table 4.5 summarizes the energy production and efficiency of the different surface areas of the house N. It shows the main parameters for each surface in House N:

HOUSE N	Area (m^2)	Azimuth	Slope	Solar radiation ($kWh/m^2/year$)	Energy efficiency (%)	Energy production (kWh/year)	Code
Eastern Roof	269	-75ºE	14º	964	**85**	11500	**S1**
Western Roof	228	105ºW	14º	903	**79**	9040	**S2**
Northern Roof	27	-165ºE	20º	760	**67**	886	**S3**
Southern Roof	27	15ºW	20º	1070	**94**	1290	**S4**
Balconies	55	-75º E	90º	687	**60**	1690	**S5**
Northern Facade	95	-165ºE	90º	290	**25**	1200	**S6**
Southern Facade	77	15ºW	90º	828	**73**	2850	**S7**

Table 4.5. House N available surfaces

From the energy efficiency point of view, Table 4.5 shows that the best surface for locating solar cell panels is the Southern Roof (94%). Unfortunately this surface has an small area (27 m^2).

The Eastern and Western Roofs are good options (85% and 79% respectively) and both of them have a big available area (497 m^2 in total).

The Southern Facade is also a good option to take into account (73%). Even the Northern Roof and Balconies can get an interesting energy efficiency (67% and 60% respectively).

Only the Northern Facade has a really small energy efficiency (25%).

House O

Table 4.6 summarizes the energy production and efficiency of the different surface areas of the house O. It shows the main parameters for each surface in House O:

HOUSE O	Area (m^2)	Azimuth	Slope	Solar radiation ($kWh/m^2/year$)	Energy efficiency (%)	Energy production (kWh/year)	Code
Southern Roof	200	15ºW	14º	1040	**91**	9270	**S8**
Northern Roof	250	-165ºE	14º	816	**72**	8900	**S11**
Eastern Roof	20	-75ºE	20º	971	**85**	865	**S9**
Western Roof	20	105ºW	20º	887	**78**	785	**S10**
Balconies	70	15ºW	90º	828	**73**	2580	**S7**
Eastern Facade	88	-75º E	90º	687	**60**	2700	**S5**
Western Facade	88	105ºW	90º	547	**48**	2140	**S12**

Table 4.6. House O available surfaces

From the energy efficiency point of view, Table 4.6 shows that the best surface for locating solar cell panels is the Southern Roof (91%). In addition, this surface has a big available area (200 m^2).

The Eastern and Western Roofs are good options (85% and 78% respectively), but the available area is only 40 m^2 in total.

The Balconies and Northern Roof are also good options to take into account (73% and 72% respectively). Even the Eastern Facade can get an interesting energy efficiency (60%).

Only the Western Facade has a relatively small energy efficiency (48%).

House P

Table 4.7 summarizes the energy production and efficiency of the different surface areas of the house P. It shows the main parameters for each surface in House P:

HOUSE P	Area (m^2)	Azimuth	Slope	Solar radiation ($kWh/m^2/year$)	Energy efficiency (%)	Energy production (kWh/year)	Code
Eastern Roof	256	-75ºE	14º	964	**85**	10900	**S1**
Western Roof	269	105ºW	14º	903	**79**	10700	**S2**
Northern Roof	27	-165ºE	20º	760	**67**	886	**S3**
Southern Roof	27	15ºW	20º	1070	**94**	1290	**S4**
Balconies	55	105ºW	90º	547	**48**	1340	**S12**
Northern Facade	97	-165ºE	90º	290	**25**	1230	**S6**
Southern Facade	104	15ºW	90º	828	**73**	3830	**S7**

Table 4.7. House P available surfaces

From the energy efficiency point of view, Table 4.7 shows that the best surface for locating solar cell panels is the Southern Roof (94%). Unfortunately this surface has an small area (27 m^2).

The Eastern and Western Roofs are good options (85% and 79% respectively) and both of them have a big available area (525 m^2 in total).

The Southern Facade is also a good option to take into account (73%). Even the Northern Roof can get an interesting energy efficiency (67%). Balconies can only reach a energy efficiency around 48%.

Only the Northern Facade has a really small energy efficiency (25%).

House Q

Table 4.8 summarizes the energy production and efficiency of the different surface areas of the house Q. It shows the main parameters for each surface in House Q:

HOUSE Q	Area (m^2)	Azimuth	Slope	Solar radiation ($kWh/m^2/year$)	Energy efficiency (%)	Energy production (kWh/year)	Code
Southern Roof	275	15ºW	14º	1040	**91**	12700	**S8**
Northern Roof	0	-165ºE	14º	816	**72**	0	**S11**
Eastern Roof	20	-75ºE	20º	971	**85**	872	**S9**
Western Roof	20	105ºW	20º	887	**78**	791	**S10**
Balconies	105	15ºW	90º	828	**73**	3870	**S7**
Eastern Facade	118	-75º E	90º	687	**60**	3620	**S5**
Western Facade	128	105ºW	90º	547	**48**	3110	**S12**

Table 4.8. House Q available surfaces

From the energy efficiency point of view, Table 4.8 shows that the best surface for locating solar cell panels is the Southern Roof (91%). In addition, this surface has a big available area (275 m^2).

The Eastern and Western Roofs are good options (85% and 78% respectively), but the available area is only 40 m^2 in total.

The Balconies and the Northern Roof are also good options to take into account (73% and 72% respectively). Even the Eastern Facade can get an interesting energy efficiency (60%).

The Western Facade can only reach a energy efficiency around 48%.

It is import to remark that the available surface on the Northern Roof is zero, because of the large number of objects located in this area.

Remark!

Taking all these surfaces into account the total PV solar power production could be around **111 MWh/year** for the four buildings group (NOPQ houses).

These parameters will be better analized and new results will be showed in next chapter 5.

4.3 PV solar cell panel selection

This chapter includes a brief review of the technology evolution applied to PV solar cell panels. It also includes the Skanska´s selection about the PV panels models to apply at Brogården site and finally, the main characteristics of the selected model to input in the software simulations.

PV solar cell panels consist of a cells set which produce electricity from the incident sunlight over them. The standard parameter to clasify their power is named Peak Power that means the maximum delivered power under specific standarized conditions:

- Solar irradiation = **1,000 W/m^2**
- Cell temperature = **25 ºC**

Only as a reference, a general classification of standard PV panels can be split according to the table below (it doesn´t include the state-of-the-art technologies):

STRUCTURE TYPE	EFFICIENCY	PHYSICAL CHARACTERISTICS	MANUFACTURE PROCESS
Monocrystalline	15–18 %	It presents a homogeneous blue colour. The cell connections are individual and visible	It is obtained from pure silicon which is melting and joining with boron particles
Policrystalline	12-14 %	The surface is structured by crystals and contains different blue shades	Similar to the monocrystalline process but lowering the number of crystallization phases
Amorphous	< 10 %	It presents a homogeneous brown colour. The cell connections are not visible	It is formed as a thin film and over a plastic or glass substratum

Table 4.9. PV panels classification

The monocrystalline structures are composed by sections of a single silicon crystal with a circular or octagonal shape. The policrystalline ones are composed by small crystallized particles. However, in the amorphous ones the silicon has not been crystallized.

The greater crystalls are the higher their efficiency is, but also their weight, width and cost. The efficiency of the amorphous type might not reach 10%, but its cost and weight is really inferior.

The first generation of PV cells consisted of a single big surface crystal. Just a single diode p-n layer was able to generate electrical energy from light sources similar to the sunlight beams. In 2007 this technology was the dominant one on the commercial production reaching up to 86 %.

The second generation is based in the use of very slim semiconductor deposits (Thin-Film technology). They have been divided in two classes, one for the spatial market with very high efficiencies (28-30 %) and costs, and another for the rest of markets with reduced efficiencies (7-9 %) and costs.

For this kind of technology a number of different semiconductor materials are being investigated for massive production. Between these materials they can be mentioned microcrystalline silicon, cadmium compounds and other chemical elements compounds.

An advantage of the Thin-Film technology is its reduced mass, which is very convenient for panels mounted over weak or flexible materials, even over the textile materials.

The third generation of PV cells are very different from the latter technologies, because of they are not based on the traditional p-n union, but they are based in photoelectrochemical cells, polymeric solar cells, nanocrystals solar cells and other kind of solar cells under ongoing investigation.

On the other hand, there is a relatively new technology that improves the energy efficiency lowering the silicon amount. This technology is named **Concentrating Solar Power (CSP)**, it was originated by avoiding the silicon dependence and fully exploiting the solar resource.

Some of these technologies use lenses to rise the solar power received by the cell. Other ones concentrate the sun energy through a mirror system over some high efficiency cells to get a optimal energy performance.

The CSP technology is seen like one of the most efficient options in order to produce low cost energy in high solar irradiation regions, as they can be mediterranean countries in Europe.

For knowing in more detail the specific application at Brogården of these kind of technologies, the reader can consult the Bachelor Thesis in Physics, Sustainable Energy: "*Locally Produced Renewable Electricity for Heating at Brogården*", this work was made by Lin Liljefors (Skanska Sverige AB) in 2010.[3]

Skanska has carried out a previous study for analysing what is the better PV solar cell panel to integrate at Brogården site.

From this study, in collaboration with the manufacturer Schüco International KG, Skanska has selected several models of PV solar cell panels for facades, balconies and roofs, which are on table below:[7]

SURFACE	PANEL MODEL	PEAK POWER	SIZE
Roofs	Schüco Thin-Film MPE AL 01 (or the new micro-crystalline Thin-Film MPE BL 01)	90 – 95 Wp (100 – 130 Wp)	1,300 x 1,100 mm.
Balconies	Schüco Thin-Film PV Standard Module	85 Wp	1,300 x 1,100 mm.
Facades	Schüco SCC 60 Cold Facade with Prosol Thin-Film	85 Wp	1,300 x 1,100 mm.

Table 4.10. Skanska´s selection about PV solar cell panels at Brogården[7]

Selected solar panel characterization

To simplify the calculations only one model has been selected for all surfaces (roofs, balconies and facades). The selected model is **Schüco Thin-Film PV module MPE 90 AL 01**, which has a **6,3 %** efficiency.

Its main parameters and values can be seen in figure 4.6 below, taken directly from the simulation software database considered on Chapter 5.

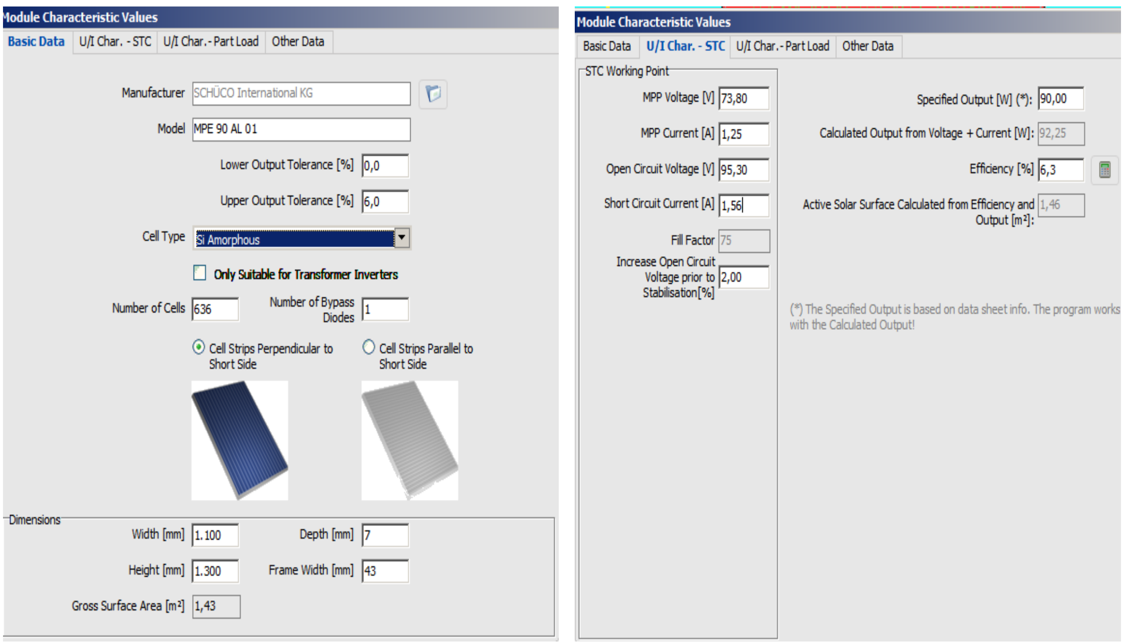


Fig. 4.6. Main parameters of PV solar cell panel selected (Screenshot done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Figure 4.7 shows the characteristic curves for the current and power parameters against voltage.

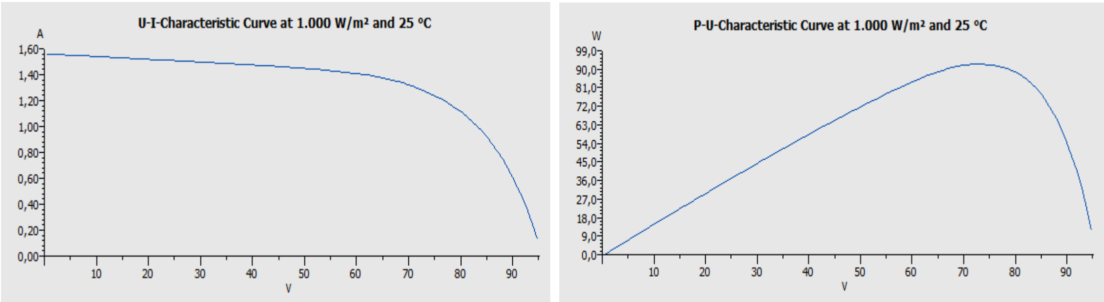


Fig. 4.7. Current vs Voltage and Power vs Voltage characteristic curves (Screenshot done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Figure 4.8 shows the characteristic curve of the relative efficiency depending on the environment temperature. It can be noted that as the temperature arises the efficiency decreases.

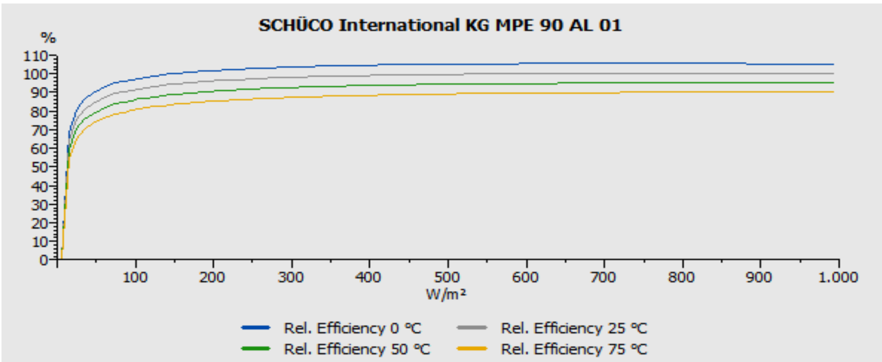


Fig. 4.8. Relative efficiency characteristic curve (Screenshot done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Finally, the figure 4.9 shows other parameters related to the dynamic behaviour depending on the work temperature of the module.

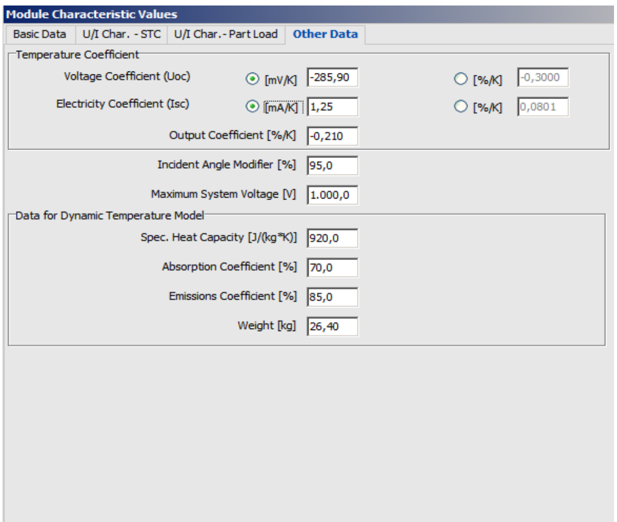


Fig. 4.9. Other parameters (Screenshot done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

4.4 Simulation softwares for photovoltaic systems design

A simulation software is highly recommended to carry out a detailed analysis and design of a solar cell power system because of the large number of parameters that have to be considered during the design process (solar radiation parameters, available surface area for installation, topographic situation, solar cell panel models, other component models, connection and installation topologies, etc..).

It helps to calculate in great detail the losses of the facility, the energy produced in real time throughout the year, the energy balance between consumption and production, to estimate the financial investment of the facility, to compare different topologies of installation, to test the sensitivity of the system to the variation of a component.

There is a great variety of photovoltaic systems design and simulation software available in the market. Short summary of some of them are presented below.

4.4.1 RETScreen 4 software

RETScreen 4 is a software tool for analysing and designing clean energy projects based in Excel sheets that helps to project managers to take decisions about technical and economic feasibility of renewable energy projects, with the objective of improving the energy efficiency of the global system.

It can be used worldwide, is free of charge and is available in multiple languages. The software includes several databases about products, climates and economic costs and also includes different tutorials and case studies for helping to the designer.

RETScreen International is managed under the leadership and ongoing economic support of the Natural Resources Canada's (NRCan), CanmetENERGY. This software tool has been developed by a number of goverment and industry experts and academic professionals.

For more information about this software or this organization enter on next link: http://www.retscreen.net/ang/centre.php

4.4.2 PVGIS online tool

The PVGIS acronym means PhotoVoltaic Geographical Information System. It refers to a free software created to give a geographical assessment of solar resource and performance of photovoltaic technology.

This software is public domain and has been developed by IET (Institute for Energy and Transport, belonging to Joint Research Centre (JRC) of the European Commission).[8]

One of the software functions is to use climatologic data for Europe to calculate a solar radiation database. For this task, the laboratory has created a simulation algorithm to get different components of the solar radiation, like beam, diffuse and reflected components, taking into account other surrounding aspects like shadowing effect due to nearby terrain.

Furthermore, the PVGIS software gives the user the capability to calculate different parameters for designing a solar system. For example, in base of the coordinates (latitude and longitude) of a location and other typical parameters like the azimuth angle, the inclination, the PV technology used, the PV mounting option and so on the software can calculate the energy production throughout the year in a monthly basis. Moreover, the software can give many other parameters, like air temperature or solar irradiation in different time basis.

It is a very quick way of getting a first estimation of energy production at a specific location and conditions.

For more information about this software or this organization enter on next link: http://re.jrc.ec.europa.eu/pvgis/

4.4.3 HOMER v2.68ß software[9]

HOMER is a free simulation software that lets the user to design and optimize a hybrid system composed by renewable energy sources, diesel generators, energy storage equipments and a variety of loads.

It is valid both for grid-connected or off-grid power systems, so it can be applied for remote and stand-alone installations.

The user can input a really high quantity of parameters, from equipment efficiencies and behaviours to electricity tariffs distributed in hourly ranges.

Furthermore, HOMER's optimization and sensitivity analysis algorithms allow the user to evaluate the economic and technical feasibility of a large number of technology options and to account for uncertainty in technology costs, energy resource availability, and other variables.

Power sources:

- ✓ solar photovoltaic (PV)
- ✓ wind turbine
- ✓ run-of-river hydro power
- ✓ generator: diesel, gasoline, biogas, alternative and custom fuels, cofired
- ✓ electric utility grid
- ✓ microturbine
- ✓ fuel cell

Storage:

- ✓ battery bank
- ✓ hydrogen
- ✓ flow batteries
- ✓ flywheels

Loads:

- ✓ daily profiles with seasonal variation
- ✓ deferrable (water pumping, refrigeration)
- ✓ thermal (space heating, crop drying)
- ✓ efficiency measures

For more information about this software or this organization enter on next link: http://www.homerenergy.com/

4.4.4 PV*SOL Expert Pro v5.5 software

This licensed software is a dynamic simulation program with 3D visualization and detailed shading analysis. It can define and simulate tridimensional objects like buildings in a really high realism.

Its functionalities are enormous, the list below compiles some of them:

- ✓ The integrated MeteoSyn tool provides with climate data records from 8,000 weather stations around the world and can interpolate climate data for any location from them
- ✓ In the extensive module and inverter databases (around 7,600 modules and 1,700 inverters which are continuously updated)
- ✓ Simulation of shading in 10 minute intervals
- ✓ Yield simulation takes account of the precise shading ratio for each module
- ✓ Easy to use configuration of modules with inverters
- ✓ Automatic and manual PV module roof coverage, taking account of restricted areas
- ✓ Animated visualization of the course of shade for any point in time
- ✓ Visualization of the annual direct irradiation reduction for each point of the PV area
- ✓ Mounted systems can be planned in 3D mode - even on the ground
- ✓ Adaptation of the system to the roof architecture
- ✓ Optimization of row distances and installation angle
- ✓ Configuration across rows
- ✓ Joint configuration of multiple PV areas
- ✓ Manual configuration in 3D visualization
- ✓ Optimization of PV module coverage and configuration corresponding to the shading situation
- ✓ Multiple buildings and dormers can be covered with PV modules
- ✓ Saw tooth roofs can be visualized and covered with PV modules
- ✓ Reactive power supply

For more information about this software or this organization enter on next link: http://www.valentin-software.com/

4.4.5 PVSYST v5.56 software[10]

PVSyst is a licensed software tool designed to study, size and optimize any energy renewable system. It is a complete software which is able to import meteo data from many different sources, as well as personal data, for example.

The software PVSyst is a tool that allows to analyze accurately different configurations and evaluate its results in order to identify the best solution.

This engineer-oriented part is aiming to perform a thorough system design using detailed hourly simulations. This software lets to the user:

- ✓ A large database of PV components, location and meteorological sites.
- ✓ Definition of the plane orientation (with possibility of tracking planes, double-orientation or shed/sun-shields mounting).
- ✓ An expert system to facilitate the PV system layout definition.
- ✓ Detailed parameters allowing fine effects analysis, including thermal behaviour, wiring and mismatch losses, real module quality loss, incidence angle losses.
- ✓ Horizon definition for "far shading" calculations.
- ✓ A detailed economic evaluation performed using real component prices, additional costs and investment conditions, in any currency.
- ✓ Condensed result forms which summarise all system parameter and the most significant result plots and tables for one given simulation. These forms are readily available on the printer, or can be inserted in documents through the clipboard.
- ✓ Other detailed results available for several dozens of simulation variables, which may be displayed in monthly, daily or hourly tables or graphs, printed or transferred to other software.
- ✓ The 3-D CAO tool allows the user to draw the geometry of the complete system. It computes a shading factor for beam component as a function of the sun's position. The shading for the diffuse is taken into account using an integral of the shading factor over the sky portion "seen" by the array. It is also possible to partition the array in order to evaluate the electric losses due to the string layout.
- ✓ Animation over a whole chosen day clarifies the shading impact of a given situation.

For more information about this software or this organization enter on next link: http://www.pvsyst.com/

Remark!

PV*SOL Expert Pro v5.5 is the selected software to carry out the simulations and calculations executed in Chapter 5 and included on this report.

Chapter 5 Energy balance: Consumption vs Production

With the help of PV*SOL Expert Pro v5.5 software a series of simulations of electricity production from different configurations of photovoltaic panels have been carried out. Possible combinations can be endless, so that it is recommendable to set a range of starting conditions to be able to show detailed results.

The calculations have been made independently for each building with the idea of getting a more flexible system, so each building could implement a different configuration, if needed. But, this question has been recently revised and new calculations, taking the four Houses as only one load, will be made and include in the Deliverable D4.5.

Another important issue is related to **the topology of the Swedish power grid**. Currently, the sale of surplus power to the grid is allowed, but optional to any electricicity company. The grid owner must allow usage of their grid for trading the overproduction on the free market.

This means that the optimal solution for Brogården site will probably be a topology similar to Net Metering case, in which the overproduction can be sold and a energy storage system is not needed.

The Net Metering topology would allow a simpler design, more efficient and with lower investment costs than the other topologies.

But, the aim of this report is to show different alternatives for producing energy from PV solar cell panels to help other future sites inside the BEEM_UP project. This is the reason for including on calculations a topology with energy storage system and a topology without overproduction.

So, there are three main alternatives: Either producing without overproduction or producing using an energy storage system or producing with overproduction and selling it to the electricity company (similar to Net Metering case).

With the idea of comparing the results between energy storage system and Net Metering cases, a monthly period has been selected. But any other time period could have been selected.

Next topologies have been analyzed:

- When there is **no overproduction at any time of the year** (energy storage system is not needed)
- When **maximum production equals the minimum monthly demand** (in June), for a topology based on energy storage system
- When **maximum production equals the minimum monthly demand** (in June), for a topology based on Net Metering case

Monthly adjustment procedure consists of selecting the month of lower demand and higher production, which is the month of June. But this only an example, not the optimal case.

Finally, the economic criterion for the cost of investment and the amortization period is a crucial factor in this type of PV systems. Therefore, this report includes **a simple economic analysis** which can give a slight idea of the investment cost.

All data provided in this report are purely an estimate and should never be considered definitive or binding.

5.1 House N

5.1.1 Maximum production without overproduction

The system is dimensioned so that the surplus PV energy at any time is virtually zero, thereby an energy storage system is not needed.

For this idea the least consumption month and the highest PV solar power production must be taken into account, which results in June as the selected month.

Moreover, as the condition is to avoid overproduction at any time, this means that the time resolution for the calculation must be set in an hourly basis.

In this case, the GERES system design will be very simple, due to the fact that the installation will be the simplest and cheapest one.

Next picture shows the solar cell panels layout on the Eastern roof of building N:

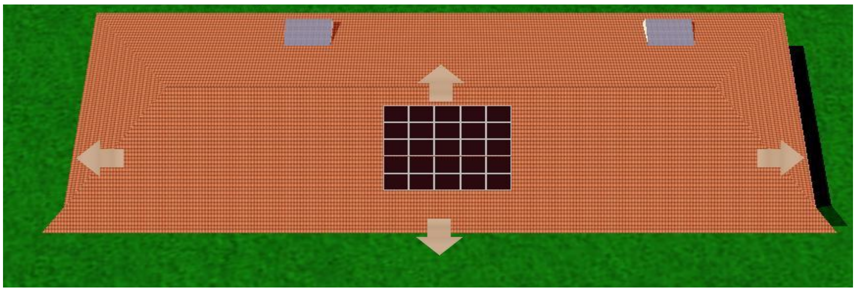


Fig. 5.1. Solar cell panel layout on House N (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The basic topology for this installation is shown on next picture:

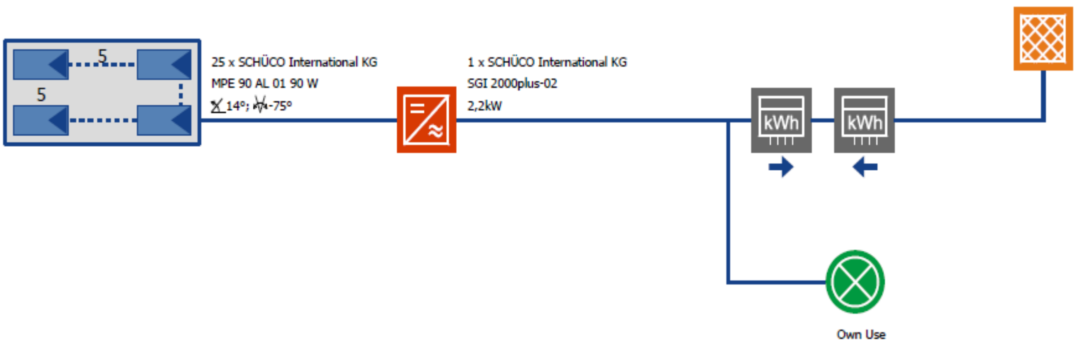


Fig. 5.2. Topology scheme without any storage system on House N (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Two counters can be found. One measures the input energy from the grid, and the other measures the output energy delivered to the grid (in this case is zero).

One of the possible configurations consists of a 25 panel array, composed by 5 strings with 5 panels each one. This array is connected to a 2.2 kW inverter. The panel model selected is **Schüco MPE 90 AL 01**.

The main parameters of this system are compiled on next table:

Location:	Alingsas_Brogarden - NOPQ	
Climate Data Record:	Alingsas_Brogarden - NOPQ (1981-2000)	
PV Output:	2,25	kWp
Gross/Active PV Surface Area:	35,75 / 36,61	m²
PV Array Irradiation:	33.719	kWh
Energy Produced by PV Array (AC):	1.772,5	kWh
Energy to Grid:	17,9	kWh
Consumption Requirement:	14.006	kWh
Direct Use of PV Energy:	1.754,7	kWh
Energy from Grid:	12.267,5	kWh
Yield Reduction Due to Shading:	1	%
Solar Fraction:	12,5	%
System Efficiency:	5,2	%
Performance Ratio:	84,7	%
Inverter Efficiency:	92,8	%
PV Array Efficiency:	5,6	%
Specific Annual Yield:	780,6	kWh/kWp
CO2 Emissions Avoided:	1.083	kg/a

Table 5.1. Main parameters system calculated for the scheme without any storage system on House N (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The total installed power is 2.25 kWp, over an usable area around 36 m^2. All energy values on this table are on an annual basis.

This building demands 14 MWh/y, and the PV system generates 1.8 MWh/y, which is a small part of the demand. But, the interesting parameter is the Energy to Grid, whose value is really small 18 MWh/y. This means that the PV system doesn´t produce surplus energy throughout the year.

The amount of energy which must be supplied from the grid is 12 MWh/y.

Next table shows the system parameters in more detail, specifying the array modules and components and the simulation results for total system related to the energy balance.

These data reveal a solar fraction of 12.5 % with respect to the demanded energy. The system efficiency is around 5.2 %.

One of the most important parameters is the Specific Annual Yield, 781 kWh/kWp, which gives an idea of the energy and economic performance of the installation. This value represents the amount of energy the system can generate for each installed PV kWp.

Array 1: System 1

Output:	2,25 kW	Ground Reflection:(Annual Average)	13,4 %
Gross/Active Solar Surface Area:	35,8 m² / 36,6 m²	Output Losses due to...	
PV Module	25 x	deviation from AM 1.5:	1,0 %
Manufacturer:	SCHÜCO International KG	deviation from Manufacturer's Specification:	2,0 %
Model:	MPE 90 AL 01	in Diodes:	0,5 %
Nominal Output:	90 W	due to Pollution:	0,0 %
Power Rating Deviation:	0 %	**Inverter**	1 x
Efficiency (STC):	6,3 %	Manufacturer:	SCHÜCO International KG
No. of Modules in Series:	5	Model:	SGI 2000plus-02
MPP Voltage (STC):	369 V	Output:	2,20 kW
Orientation:	-75,0 °	European Efficiency:	95,7 %
Inclination:	14,0 °	No. of MPP Trackers:	1
Mount:	with Ventilation	MPP Tracking:	330 V To 600 V
Shade:	Yes		

Simulation Results for Total System

Irradiation onto Horizontal:	34.313 kWh	Energy from Grid:	12.268 kWh
PV Array Irradiation:	33.719 kWh	Own Use:	16,2 kWh
Irradiation minus Reflection:	32.095 kWh	Energy Produced by PV Array:	1.892 kWh
Irradiation without Shade:	34.883 kWh	Solar Fraction:	12,5 %
Energy from Inverter (AC):	1.773 kWh	System Efficiency:	5,2 %
Energy to Grid:	18 kWh	Performance Ratio:	84,7 %
Consumption Requirement:	14.006 kWh	Final Yield:	2,1 h/d
Direct Use of PV Energy:	1.755 kWh	Specific Annual Yield:	781 kWh/kWp
Array Efficiency:	5,6 %		

Table 5.2. Main parameters components and simulation results for the scheme without any storage system on House N (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next pictures show the energy balance in different time periods. The first one shows the values throughout the year:

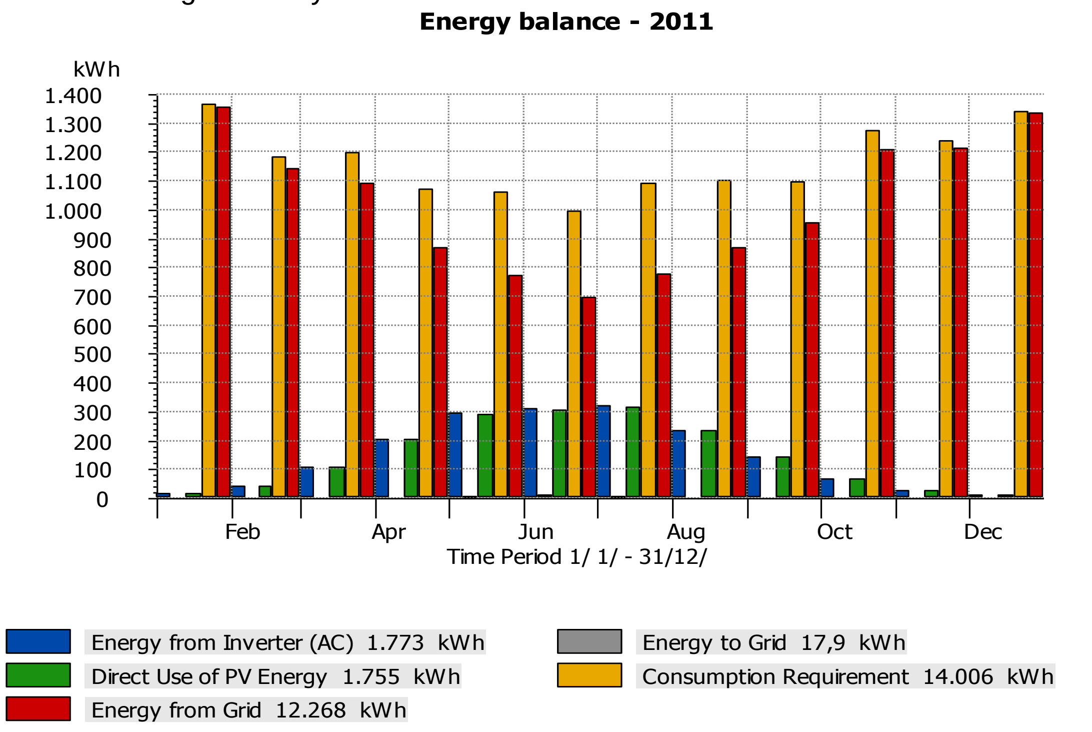


Fig. 5.3. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The second one shows the values corresponding to June, as this is the selected month for the energy flow balance:

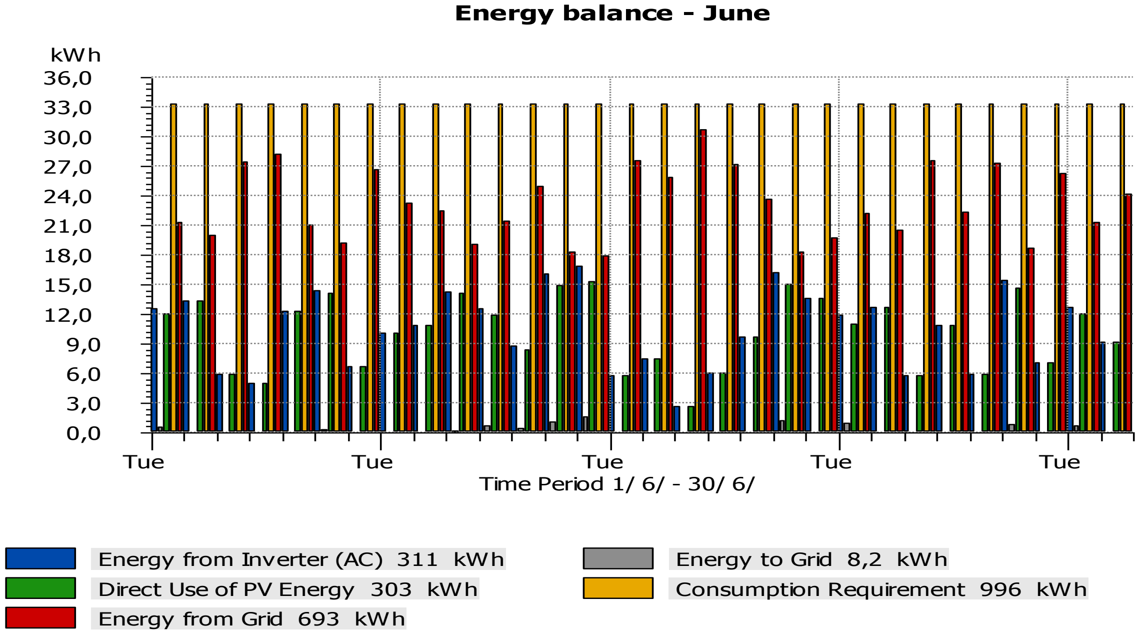


Fig. 5.4. Energy balance in June (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

It can be verified that the Energy to Grid value is almost zero, 8.2 kWh. On the third picture the worst day of this month is displayed, regarding the most producing energy day:

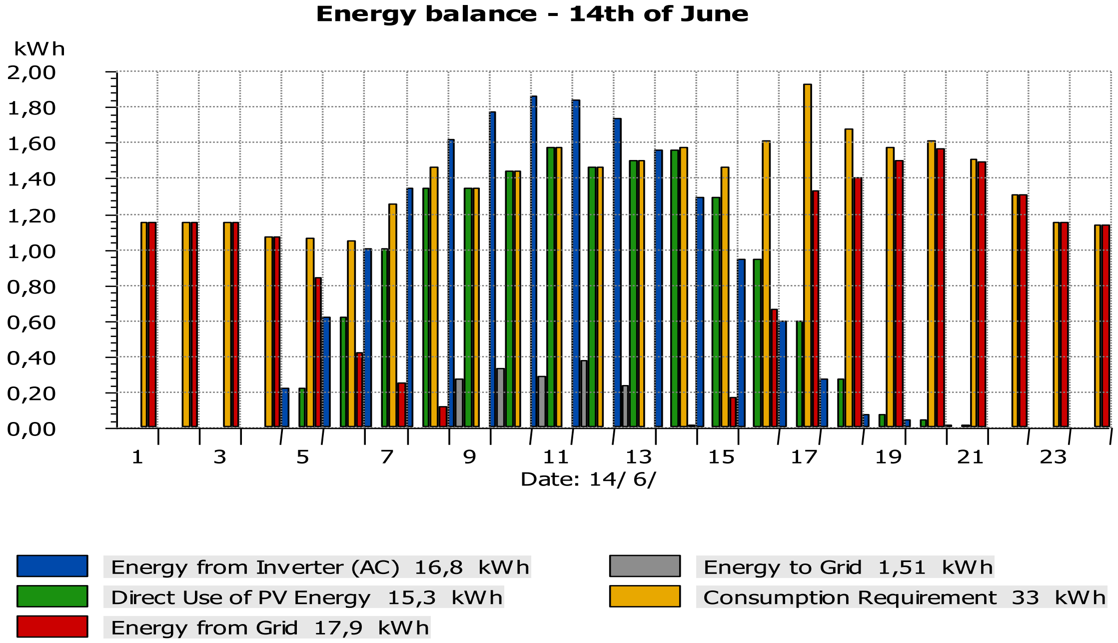


Fig. 5.5. Energy balance in 14th of June (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Even in this case, the Energy to Grid value is only 1.5 kWh/day, so this value is negligible.

5.1.2 June consumption balanced with June production (storage case)

In this case, the electrical grid topology doesn´t buy the overproduced energy, so the system needs to store this surplus energy produced by the PV solar cell panels.

The system is sized in such a way that the produced solar power in June equals the demanded energy. This means an energy storage system is required since every day there will be surplus production and not satisfied demand in real time.

For this idea the least consuming month and the highest solar power production must be considered, resulting in June as the selected month. Moreover, as the condition is to avoid overproduction for a month, a monthly-based time resolution for the calculation is required.

In this case, the GERES system design could bring about a very complex installation. The daily overproduced energy must be stored on batteries during the day and it must be used later during the night. So, the batteries must be charged and discharged every day.

The solar cell panels layout is located on the Eastern roof of the building. Next picture shows the topology scheme of the installation.

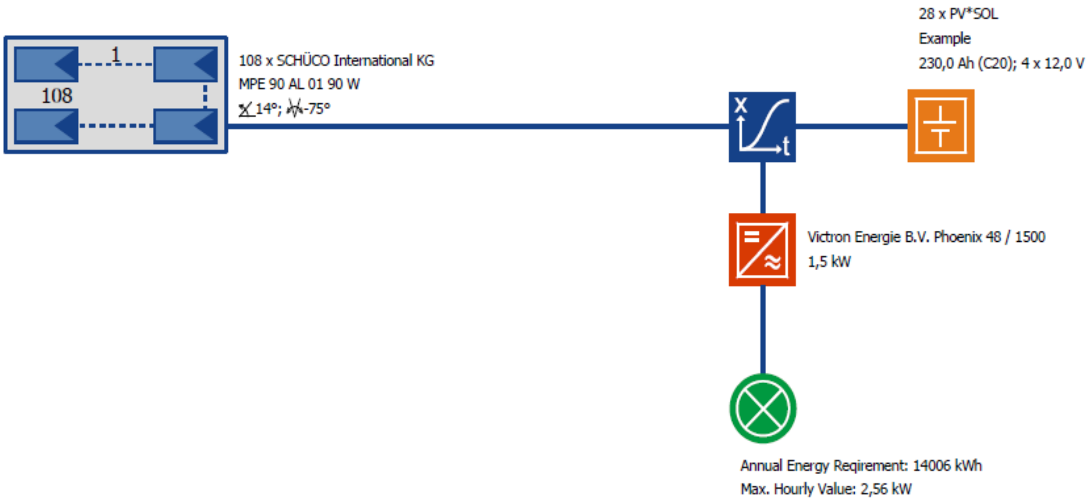


Fig. 5.6. Topology scheme with storage system on House N (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

A **108** panel array could be a possible configuration. This array is connected to one battery regulator, the battery bus and the 1.5 kW inverter. The selected panel model is **Schüco MPE 90 AL 01**.

The battery bus consists of 28 batteries of 230 Ah, 12 V each one. So, the battery bus can store up to **77.28 kWh**.

The main parameters of this system are compiled on next table:

Location:	Alingsas_Brogarden - NOPQ	
Climate Data Record:	Alingsas_Brogarden - NOPQ (1981-2000)	
PV Output:	9,72	kWp
Gross/Active PV Surface Area:	154,44 / 158,14	m²
PV Array Irradiation:	150.696	kWh
Energy Produced by PV Array:	6.300,3	kWh
Consumption Requirement:	14.006	kWh
Consumption Covered by Solar Energy:	5.277,4	kWh
Consumption Not Covered by System:	8.728,6	kWh
Solar Fraction:	37,7	%
Performance Ratio:	57,0	%
Specific Annual Yield:	542,9	kWh/kWp
CO2 Emissions Avoided:	3.242	kg/a
System Efficiency:	3,5	%
PV Array Efficiency:	4,2	%

Table 5.3. Main parameters system calculated for the scheme with storage system on House N (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The total installed power is 10 kWp, over an usable area around 154 m^2. All energy values on this table are on an annual basis.

This building demands 14 MWh/y, and the PV system generates 6.3 MWh/y. Taking into account the losses and efficiencies of the storage system, the final energy provided by solar production is 5.3 MWh/y.

The amount of energy which must be supplied from the grid is 8.8 MWh/y.

These data reveal a 38% solar fraction with respect to the demanded energy. The system efficiency is around 3.5 %.

One of the most important parameters is the Specific Annual Yield, 543 kWh/kWp, which gives an idea of the energy and economic performance of the installation. This value represents the amount of energy the system can generate for each installed PV kWp.

Next table shows the system parameters in more detail, specifying the array modules and components as well as the simulation results for the whole system related to the energy balance.

Array 1: Array Name			
Output:	9,72 kW	Ground Reflection:(Annual Average)	13,4 %
Gross/Active Solar Surface Area:	154,4 m² / 158,1 m²	Output Losses due to...	
PV Module	108 x	deviation from AM 1.5:	1,0 %
Manufacturer:	SCHÜCO International KG	deviation from Manufacturer's Specification:	2,0 %
Model:	MPE 90 AL 01	in Diodes:	0,5 %
Nominal Output:	90 W	due to Pollution:	0,0 %
Power Rating Deviation:	0 %		
Efficiency (STC):	6,3 %		
No. of Modules in Series:	1		
MPP Voltage (STC):	74 V		
Orientation:	-75,0 °		
Inclination:	14,0 °		
Mount:	with Ventilation		
Shade:	No		
Battery			
Manufacturer:	PV*SOL	Mean Charge Efficiency:	85,0 %
Model:	Example	Mean Discharge Efficiency:	99,0 %
Nominal Voltage:	12,0 V	Charge Controller	
C20 Capacity:	230,0 Ah	Lower Battery Discharge Threshold:	30,0 %
Self Discharge:	0,3 %/Tag		
Stand-Alone System Inverter			
Manufacturer:	Victron Energie B.V.	Nom. DC Voltage:	48,0 V
Model:	Phoenix 48 / 1500	Stand-by Consumption:	0,0 W
AC Power Rating:	1,5 kW	Efficiency at Nominal Output:	90,0 %
Nom. AC Voltage:	230,0 V		
Appliances 1 (Load Profile)			
Annual Requirement:	14.006 kWh		
Max. Hourly Value:	2,56 kW		
Weekend Consumption:	Saturday: 100 %	Sunday: 100 %	
Consumption Profile:	Alingsas - NOPQ - Average daily profile		
Holiday Periods:	None		

Simulation Results for Total System			
Irradiation onto Horizontal:	148.231 kWh	Battery Losses:	382 kWh
PV Array Irradiation:	150.696 kWh	Charge Condition at Sim. Start:	24,7 %
Irradiation minus Reflection:	140.346 kWh	Charge Condition at Sim. End:	24,7 %
Energy Produced by PV Array:	6.300 kWh	Solar Fraction:	37,7 %
Consumption Requirement:	14.006 kWh	Performance Ratio:	57,0 %
Direct Use of PV Energy:	4.016 kWh	Final Yield:	1,5 h/d
Consumption Not Covered by System:	8.729 kWh	Specific Annual Yield:	543 kWh/kWp
PV Array Surplus:	54 kWh	System Efficiency:	3,5 %
Consumption Covered by Solar Energy:	5.277 kWh	Array Efficiency:	4,2 %
Battery Discharge:	1.848 kWh	Inverter Efficiency:	90,0 %

Table 5.4. Main parameters components and simulation results for the scheme with storage system on House N (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The charging energy in batteries throughout the year is 2.2 MWh, and the battery losses are 382 kWh, which means a battery efficiency around 83%.

Next pictures show the energy balance in different time periods. The first one shows the values throughout the year:

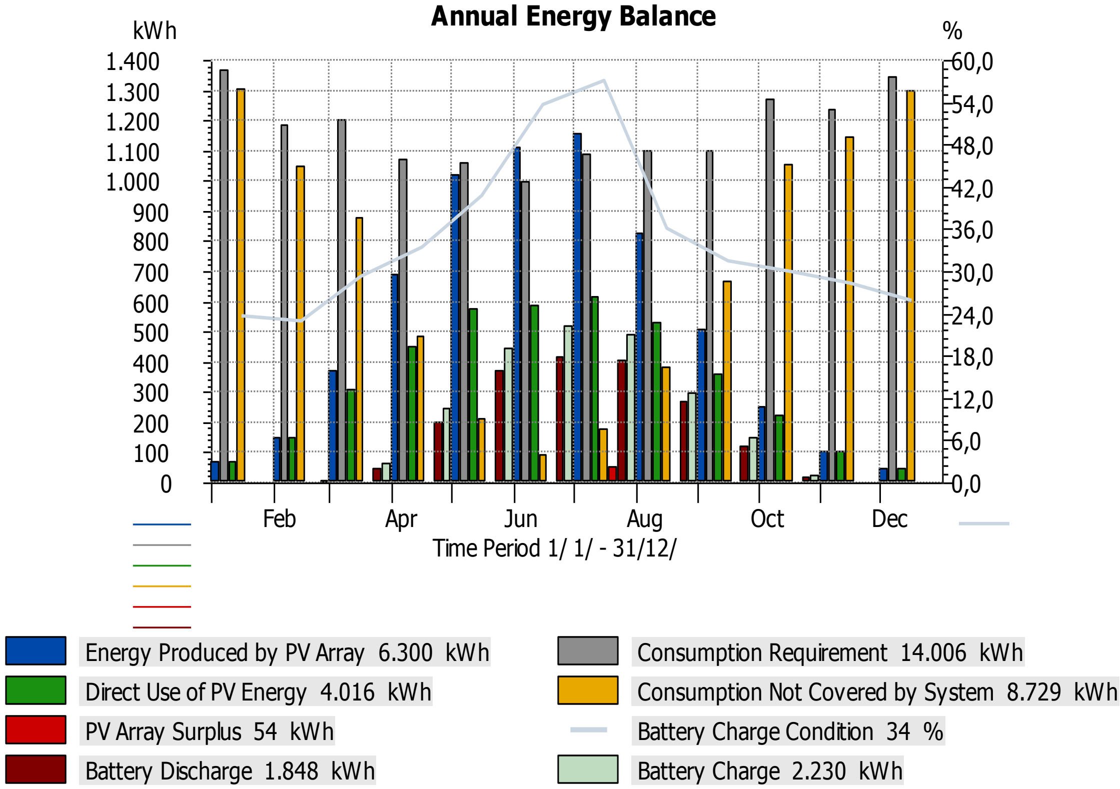


Fig. 5.7. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The second picture shows the values corresponding to June, since this is the selected month for the energy flow balance.

It can be seen that the surplus energy from PV is only 54 kWh/y, so in June this value is still lower, 2.5 kWh.

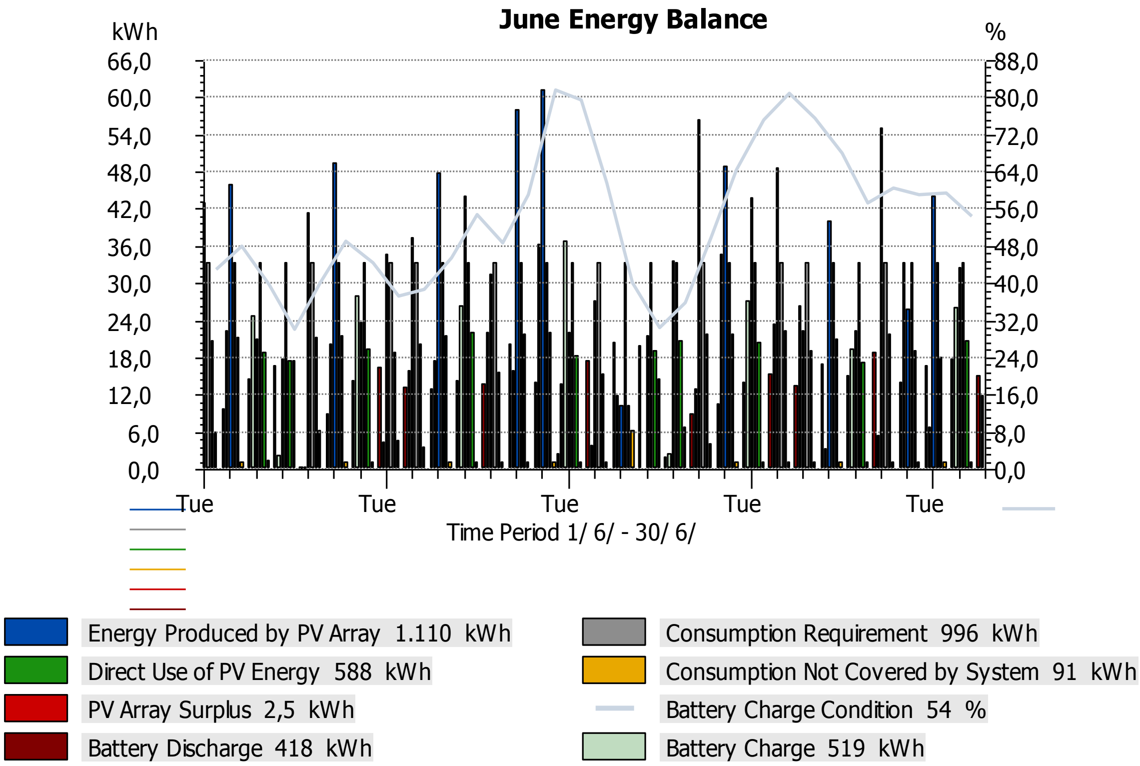


Fig. 5.8. Energy balance in June (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The energy balance in June can be verified by comparing the values of the energy produced by PV array and the consumption requirement, set around 1 MWh. Of course, the consumption not covered by system is only 91 kWh in June.

5.1.3 June consumption balanced with June production (Net Metering case)

In the Net Metering case, the electrical grid topology buys the overproduced energy. The total bought and sold energy from and to the grid is compared and compensated afterwards. In this situation the system doesn´t need to store the surplus energy produced by the PV solar cell panels. This results in a very simple, cheap and efficient installation.

As in the last case, the system is sized in such a way that the produced PV energy during June equals the demanded energy.

For this idea the least consuming month and the highest PV energy production must be taken into account, which results in June as the selected month. Moreover, as the condition is to avoid overproduction in June, a monthly-based time resolution for the calculation is required.

In this case, the GERES system design could be very simple. The daily overproduced energy must be delivered to the grid and at the same time the non-satisfied load at night must be taken from the grid.

The solar cell panels layout is located on the Eastern roof of the building.

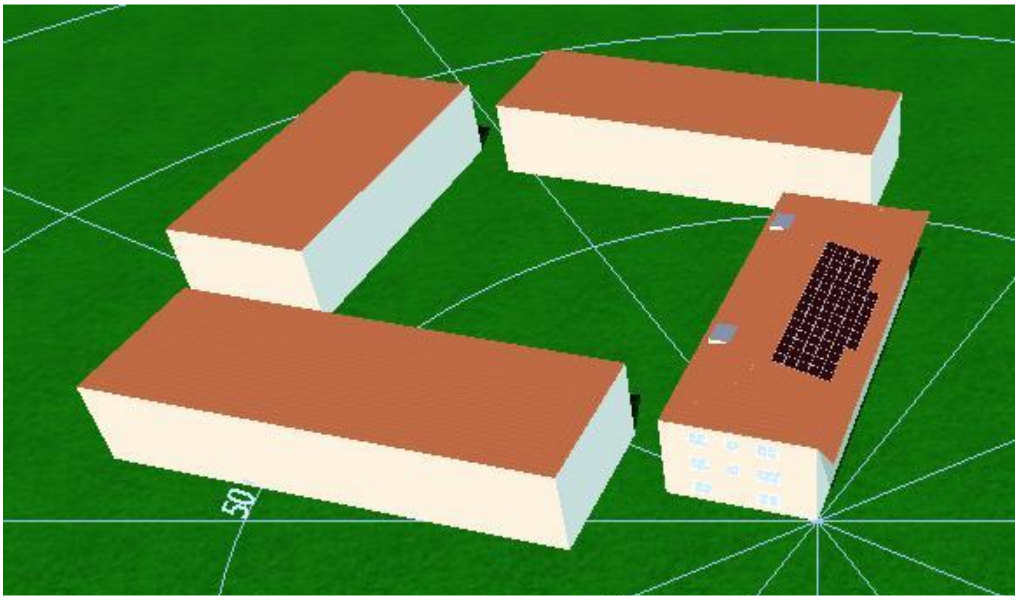


Fig. 5.9. Net Metering topology scheme on House N (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Figure 5.9 shows the corresponding layout for Net Metering case. It shows the four buildings NOPQ, from the Southern view. The buildings set is rotated 15º westwards.

The solar cell panels are located on Eastern roof because this is the most efficient surface. These are displayed in more detail on the next picture.

Fig. 5.10. Detailed view of Eastern roof on House N (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next picture shows the topology scheme of the installation:

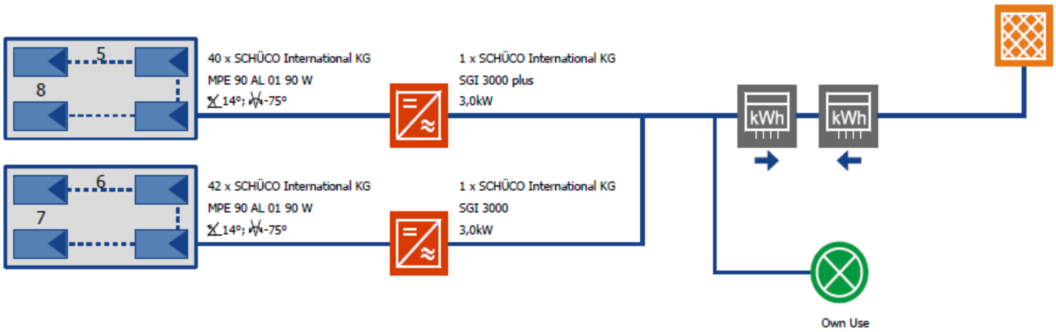


Fig. 5.11. Topology scheme in Net Metering system on House N (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Two counters can be found in the installation. One counter measures the input electrical energy to the system (energy bought from the grid), and the other one measures the energy sold to the grid by the system.

A possible configuration can be made with two arrays. One consists of 40 solar cell panels connected to a 3kW inverter. The other consist of 42 solar cell panels connected to another 3 kW inverter. The full system consists of **82** solar cell panels **Schüco MPE 90 AL 01**.

The main parameters of this system are compiled on next table:

Location:	Alingsas_Brogarden - NOPQ	
Climate Data Record:	Alingsas_Brogarden - NOPQ (1981-2000)	
PV Output:	7,38	kWp
Gross/Active PV Surface Area:	117,26 / 120,07	m²
PV Array Irradiation:	110.597	kWh
Energy Produced by PV Array (AC):	5.774,2	kWh
Energy to Grid:	2.130,6	kWh
Consumption Requirement:	14.006	kWh
Direct Use of PV Energy:	3.643,6	kWh
Energy from Grid:	10.394,8	kWh
Yield Reduction Due to Shading:	1	%
Solar Fraction:	41,0	%
System Efficiency:	5,2	%
Performance Ratio:	84,5	%
Specific Annual Yield:	778,0	kWh/kWp
CO2 Emissions Avoided:	4.105	kg/a

Table 5.5. Main parameters system calculated for Net Metering system on House N (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The total installed power is 7.4 kWp, over an usable area around 117 m^2. All energy values on this table are on an annual basis.

This building demands 14 MWh/y, and the PV system generates 5.8 MWh/y, which represents a 41% of the total load. The amount of energy delivered to the grid is 2 MWh/y and the amount of energy supplied from the grid is 10.4 MWh/y.

The system efficiency is around 5.2%, significantly higher than the one with storage system.

One of the most important parameters is the Specific Annual Yield, 778 kWh/kWp, which gives an idea of the higher energy and economic performance of this installation.

Next table shows the system parameters in more detail, specifying the array modules and components included in this installation.

Array 1: System 1			
Output:	3,60 kW	Ground Reflection:(Annual Average)	13,4 %
Gross/Active Solar Surface Area:	57,2 m² / 58,6 m²	Output Losses due to...	
PV Module	40 x	deviation from AM 1.5:	1,0 %
Manufacturer:	SCHÜCO International KG	deviation from Manufacturer's Specification:	2,0 %
Model:	MPE 90 AL 01	in Diodes:	0,5 %
Nominal Output:	90 W	due to Pollution:	0,0 %
Power Rating Deviation:	0 %	**Inverter**	1 x
Efficiency (STC):	6,3 %	Manufacturer:	SCHÜCO International KG
No. of Modules in Series:	5	Model:	SGI 3000 plus
MPP Voltage (STC):	369 V	Output:	3,00 kW
Orientation:	-75,0 °	European Efficiency:	95,8 %
Inclination:	14,0 °	No. of MPP Trackers:	1
Mount:	with Ventilation	MPP Tracking:	330 V To 600 V
Shade:	Yes		

Array 2: System 1			
Output:	3,78 kW	Ground Reflection:(Annual Average)	13,4 %
Gross/Active Solar Surface Area:	60,1 m² / 61,5 m²	Output Losses due to...	
PV Module	42 x	deviation from AM 1.5:	1,0 %
Manufacturer:	SCHÜCO International KG	deviation from Manufacturer's Specification:	2,0 %
Model:	MPE 90 AL 01	in Diodes:	0,5 %
Nominal Output:	90 W	due to Pollution:	0,0 %
Power Rating Deviation:	0 %	**Inverter**	1 x
Efficiency (STC):	6,3 %	Manufacturer:	SCHÜCO International KG
No. of Modules in Series:	6	Model:	SGI 3000
MPP Voltage (STC):	443 V	Output:	3,00 kW
Orientation:	-75,0 °	European Efficiency:	94,7 %
Inclination:	14,0 °	No. of MPP Trackers:	1
Mount:	with Ventilation	MPP Tracking:	330 V To 600 V
Shade:	Yes		

Table 5.6. Main parameters components for Net Metering system on House N (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next table shows the system parameters in more detail, specifying the simulation results for total system related to the energy balance.

Simulation Results for Total System

Irradiation onto Horizontal:	112.547 kWh	Energy from Grid:	10.395 kWh
PV Array Irradiation:	110.597 kWh	Own Use:	32,4 kWh
Irradiation minus Reflection:	105.271 kWh	Energy Produced by PV Array:	6.207 kWh
Irradiation without Shade:	114.418 kWh	Solar Fraction:	41,0 %
Energy from Inverter (AC):	5.774 kWh	System Efficiency:	5,2 %
Energy to Grid:	2.131 kWh	Performance Ratio:	84,5 %
Consumption Requirement:	14.006 kWh	Final Yield:	2,1 h/d
Direct Use of PV Energy:	3.644 kWh	Specific Annual Yield:	778 kWh/kWp

Results for Array 1: System 1

Irradiation onto Horizontal:	54.900 kWh	Energy Produced (DC):	3.027 kWh
Array Irradiation:	53.950 kWh	System Efficiency:	5,2 %
Irradiation without Shade:	55.813 kWh	Performance Ratio:	85,2 %
Energy Produced (AC):	2.842 kWh	Specific Annual Yield:	785 kWh/kWp
Own Use:	16 kWh	Array Efficiency:	5,6 %
Inverter Efficiency:	93,3 %		

Results for Array 2: System 1

Irradiation onto Horizontal:	57.646 kWh	Energy Produced (DC):	3.180 kWh
Array Irradiation:	56.647 kWh	System Efficiency:	5,1 %
Irradiation without Shade:	58.604 kWh	Performance Ratio:	83,8 %
Energy Produced (AC):	2.932 kWh	Specific Annual Yield:	771 kWh/kWp
Own Use:	16 kWh	Array Efficiency:	5,6 %
Inverter Efficiency:	91,7 %		

Table 5.7. Main simulation results for Net Metering system on House N (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next pictures show the energy balance in different time periods. The first one shows the values throughout the year:

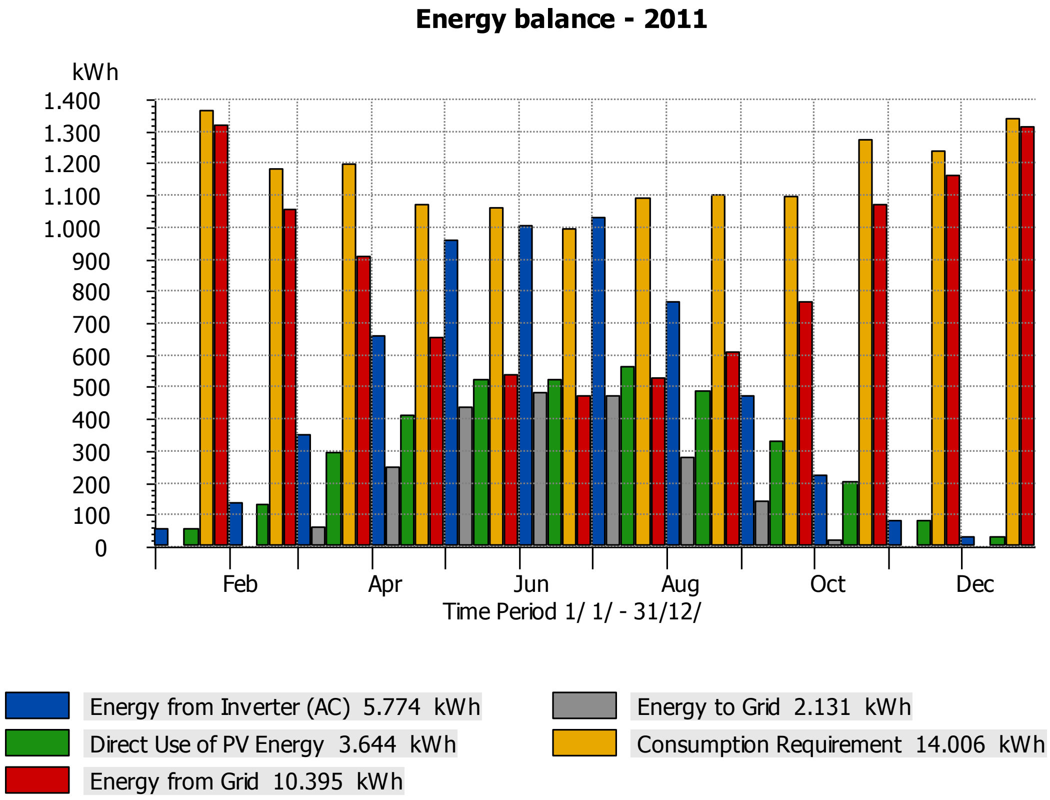


Fig. 5.12. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The second one shows the values corresponding to June, since this is the selected month for the energy flow balance.

The consumption requirement in June is 996 kWh, and the produced energy is 1 MWh. On the other hand, the energy delivered to the grid and the energy taken from the grid are balanced around 475 kWh.

Also, it can be noted that there are 15 days with overproduction and other 15 days with lack of energy, but at the end of the month the energy flow is balanced.

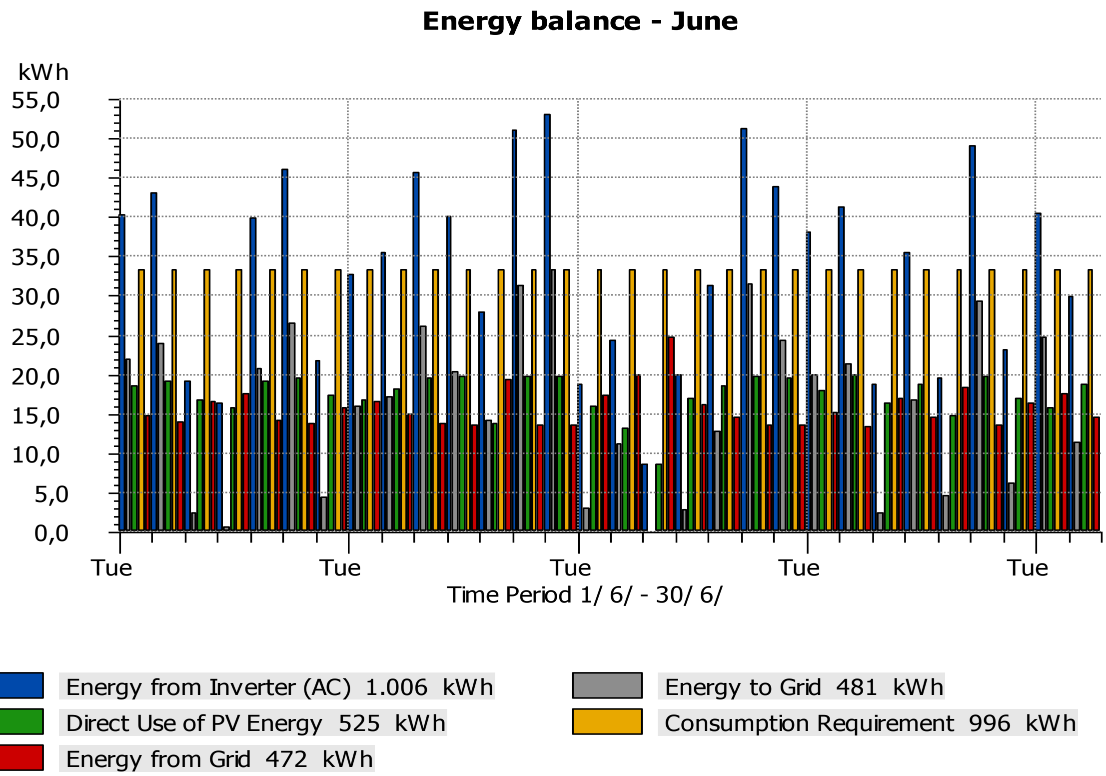


Fig. 5.13. Energy balance in June (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Remark!

In order to get the same energy requirement, the system with batteries needs 26 solar cell panels more than the Net Metering case.

5.2 House O

5.2.1 All surfaces energy production comparative

Eastern Facade (S5)

Next picture shows the location and layout of solar cell panels on this surface from a Southern-Eastern point of view. Next to this picture, the percentage of lost performance of each solar cell panel due to shading of other objects or buildings is shown.

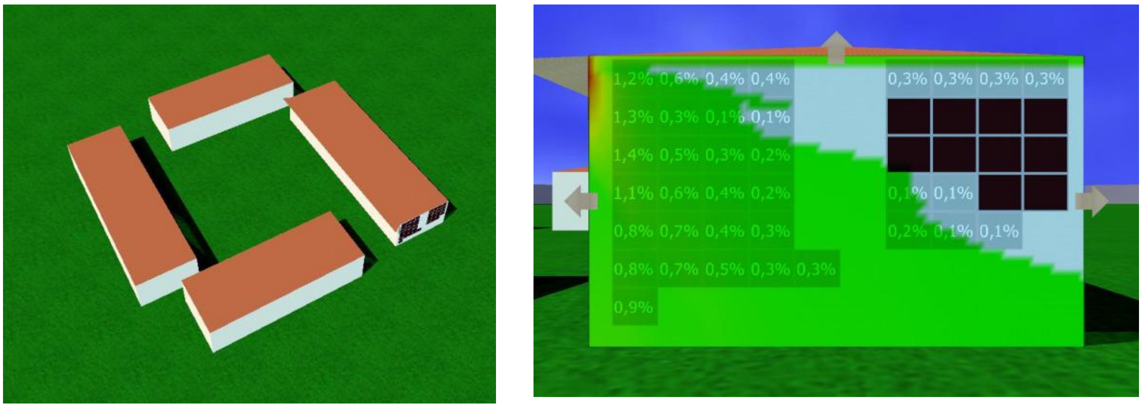


Fig. 5.14. Surface location and shading effect (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The picture below shows the main values of energy flow for this surface: the produced energy, the consumption requirement and the energy delivered from and to the grid. Due to the very small energy production, no energy surplus is obtained.

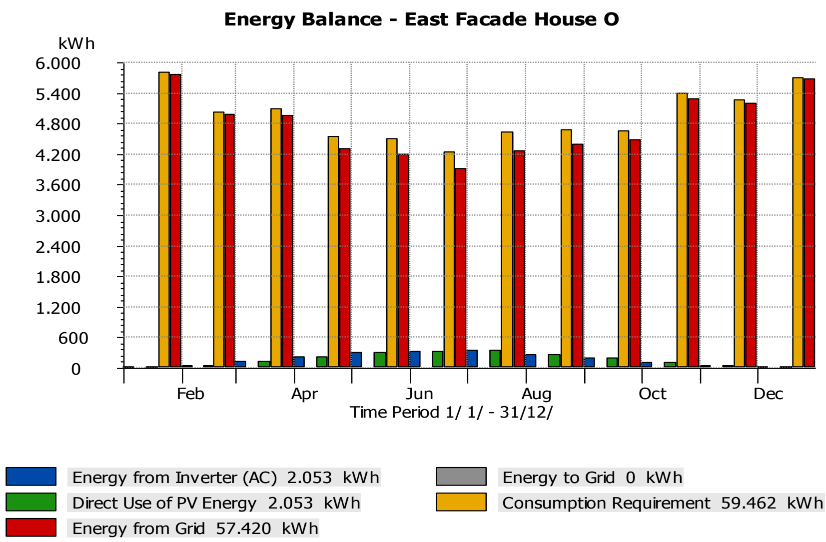


Fig. 5.15. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Southern Balconies (S7)

Next picture shows the location and layout of solar cell panels on this surface from a Southern point of view. Below this picture, the percentage of lost performance of each solar cell panel due to shading of other objects or buildings is shown.

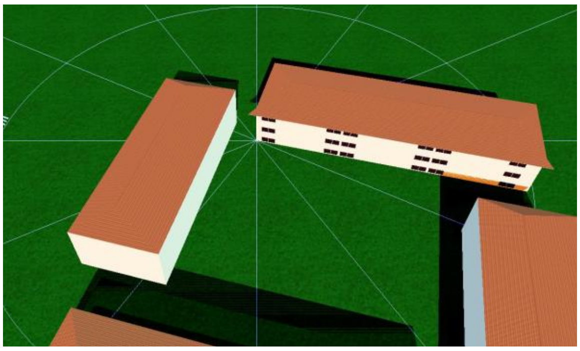


Fig. 5.16. Surface location (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

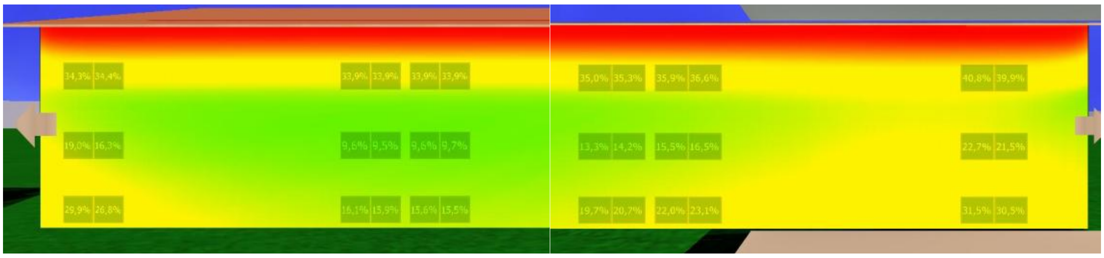


Fig. 5.17. Shading effect (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The picture below shows the main values of energy flow for this surface: the produced energy, the consumption requirement and the energy delivered from and to the grid. The losses due to shading are very important on this surface. Due to the very small energy production, no energy surplus is obtained.

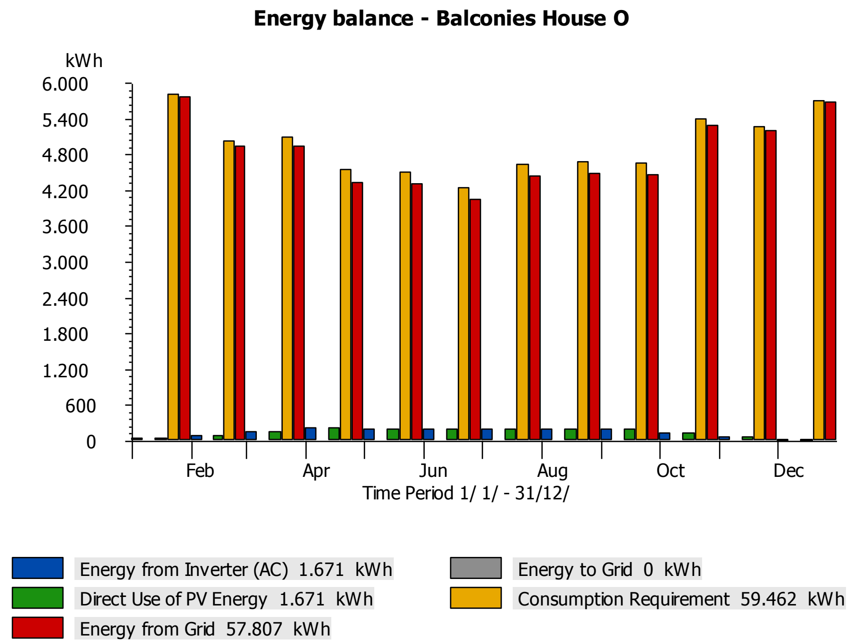


Fig. 5.18. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Southern Roof (S8)

Next picture shows the location and layout of solar cell panels on this surface from a Southern point of view. Below this picture, the percentage of lost performance of each solar cell panel due to shading of other objects or buildings is shown.

Fig. 5.19. Surface location (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

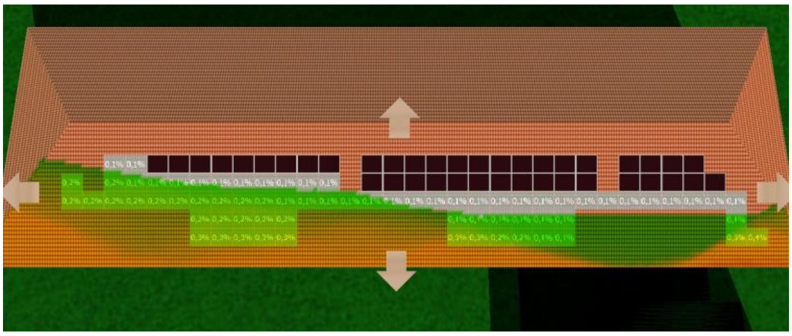


Fig. 5.20. Shading effect (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The picture below shows the main values of energy flow for this surface: the produced energy, the consumption requirement and the energy delivered from and to grid. Due to the fact that almost all the produced energy is consumed, practically no energy surplus is obtained.

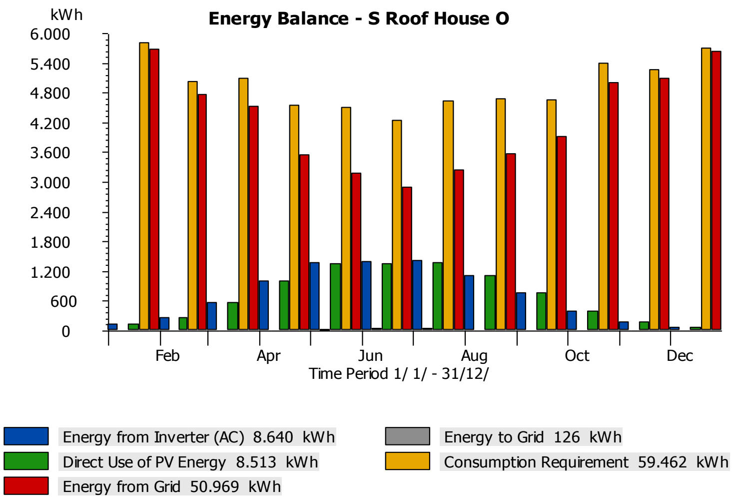


Fig. 5.21. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Eastern Roof (S9)

Next picture shows the location and layout of solar cell panels on this surface from a Southern point of view. Next to this picture, a more detailed view of this roof, which is not affected by any shadow, is shown.

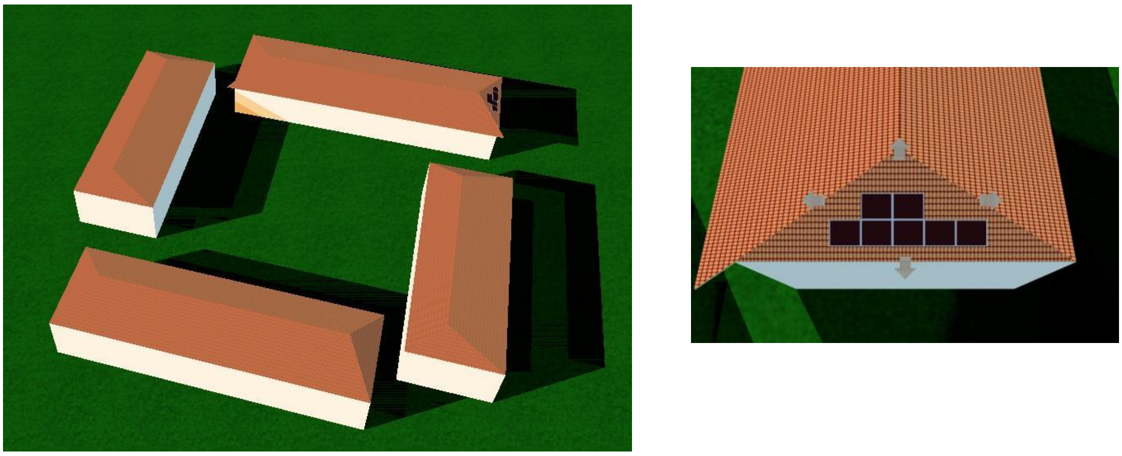


Fig. 5.22. Surface location (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The picture below shows the main values of energy flow for this surface: the produced energy, the consumption requirement and the energy delivered from and to grid. Due to the very small energy production, no energy surplus is obtained.

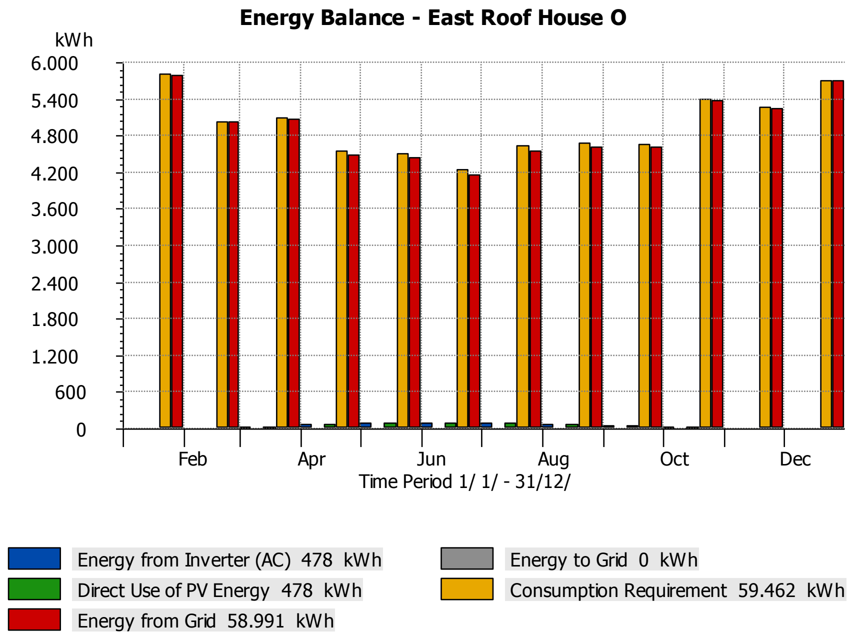
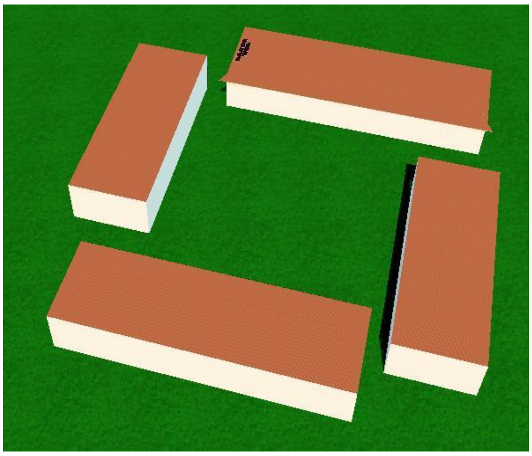


Fig. 5.23. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Western Roof (S10)

Next picture shows the location and layout of solar cell panels on this surface from a Southern point of view. Next to this picture, the percentage of lost performance of each solar cell panel due to shading of other objects or buildings is shown.



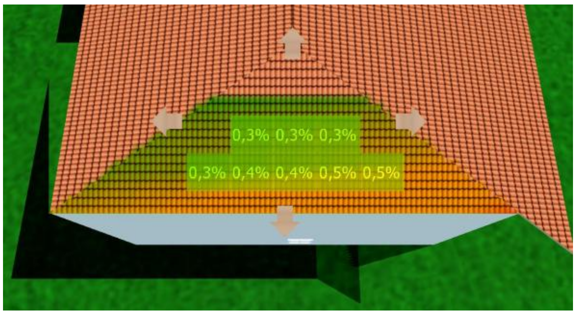


Fig. 5.24. Surface location and shading effect (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The picture below shows the main values of energy flow for this surface: the produced energy, the consumption requirement and the energy delivered from and to grid. Due to the very small energy production, no energy surplus is obtained.

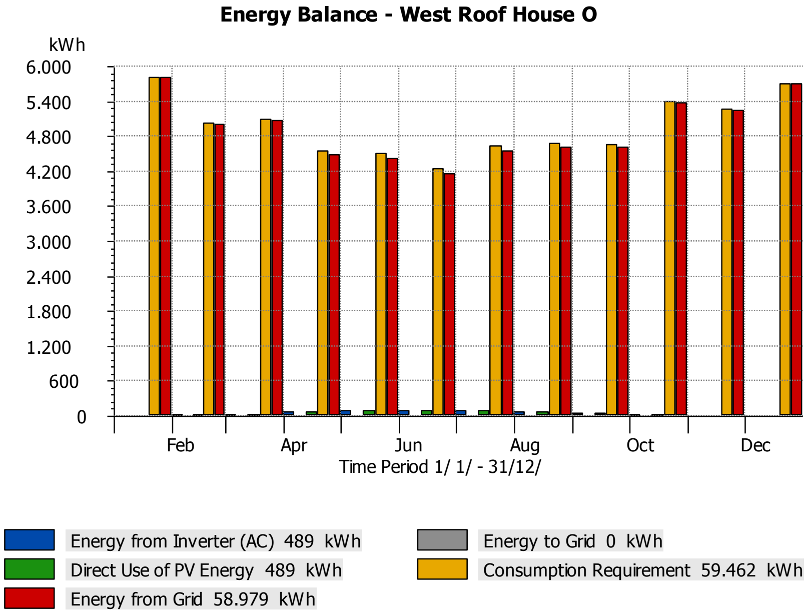
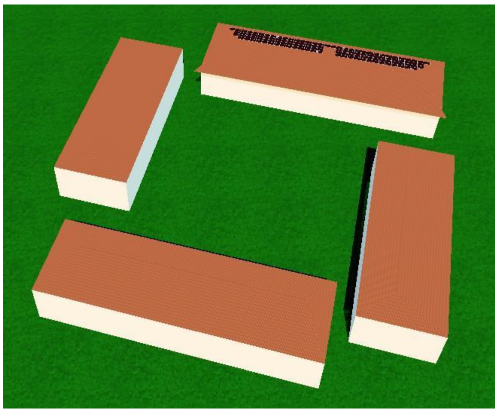


Fig. 5.25. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Northern Roof (S11)

Next picture shows the location and layout of solar cell panels on this surface from a Southern point of view. Next to this picture, a more detailed view of solar cell panels on this surface, which is not affected by any shadow, is shown.



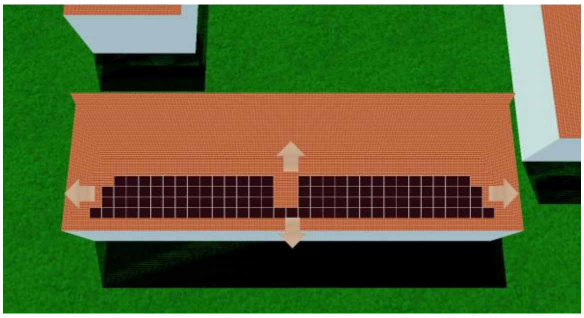


Fig. 5.26. Surface location (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The picture below shows the main values of energy flow for this surface: the produced energy, the consumption requirement and the energy delivered from and to grid. Due to the fact that almost all the produced energy is consumed by the load, practically no energy surplus is obtained.

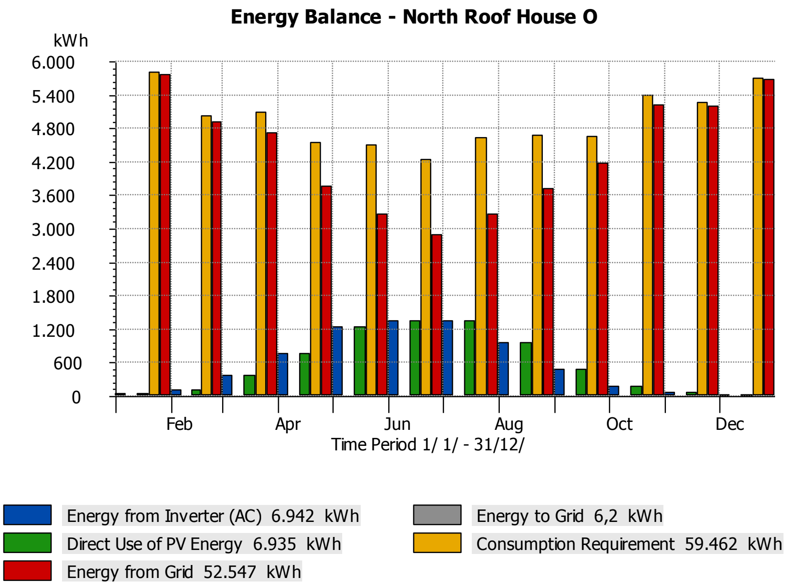


Fig. 5.27. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Western Facade (S12)

Next picture shows the location and layout of solar cell panels on this surface from a Southern-Western point of view. Next to this picture, the percentage of lost performance of each solar cell panel due to shading of other objects or buildings is shown.

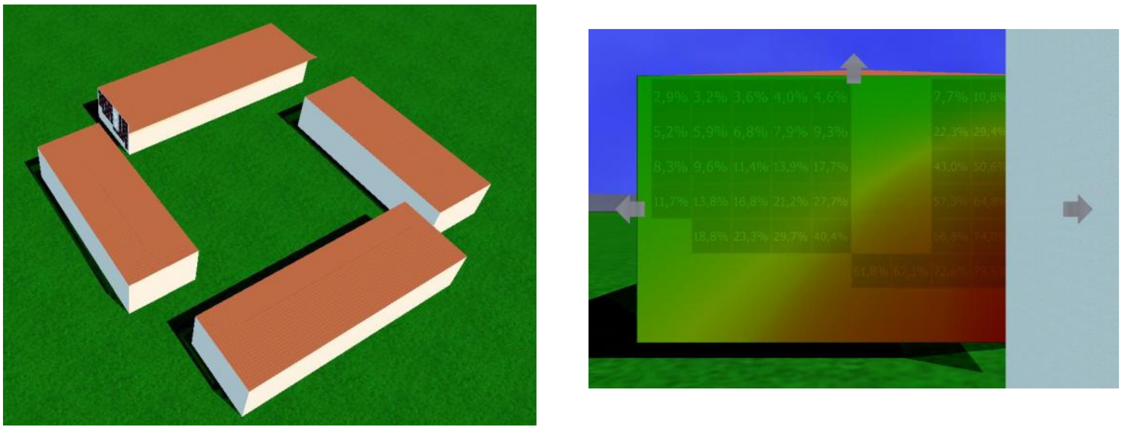


Fig. 5.28. Surface location and shading effect (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The picture below shows the main values of energy flow for this surface: the produced energy, the consumption requirement and the energy delivered from and to grid. This surface is strongly affected by shading from other buildings, specially on panels located at the lowest-right corner. As a consequence, there is no surplus energy.

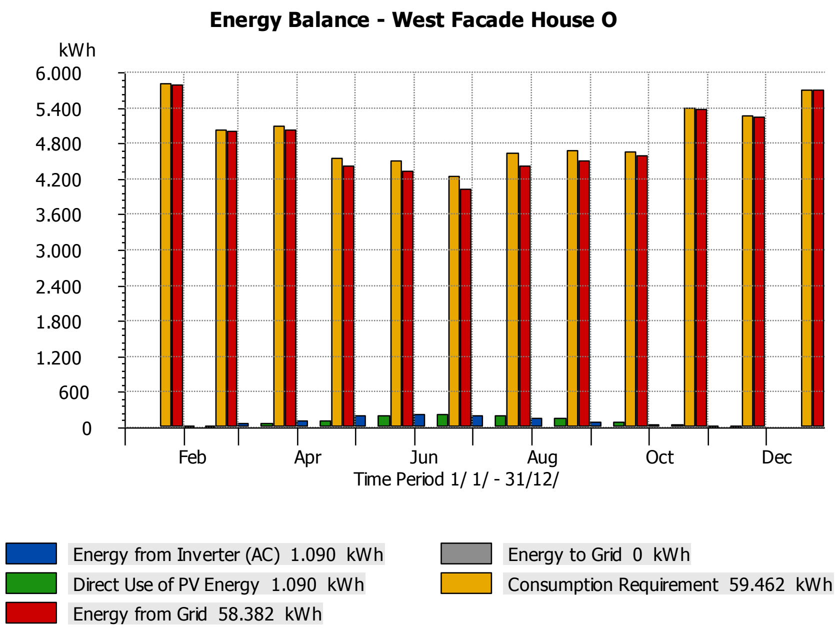


Fig. 5.29. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

5.2.2 Optimal energy production case

Next table compiles main parameters calculated for each surface.

HOUSE O	S10 (W Roof)	S11 (N Roof)	S12 (W Facade)	S5 (E Facade)	S7 (S Balcony)	S8 (S Roof)	S9 (E Roof)
PV Output [kW]	0.72	10.62	4.05	4.05	3.24	9.99	0.63
Gross PV Surface Area [m²]	11.44	168.74	64.35	64.35	51.48	158.73	10.01
Number of Modules	**8**	**118**	**45**	**45**	**36**	**111**	**7**
Orientation [°]	105.0	-165.0	105.0	-75.0	15.0	15.0	-75.0
Inclination [°]	20.0	13.1	90.0	90.0	90.0	14.0	21.4
*****SIMULATION RESULTS*****							
PV Array Irradiation [kWh]	9,782	135,779	25,525	40,581	34,313	163,040	9,432
Energy from Inverter (AC) [kWh]	**489**	**6,942**	**1,090**	**2,053**	**1,671**	**8,640**	**478**
Energy to Grid [kWh]	0	6	0	0	0	126	0
Energy from Grid [kWh]	58,979	52,547	58,382	57,420	57,807	50,969	58,991
Yield reduction due to shading [%]	1	1	35	4	19	1	1
Solar Fraction [%]	0.8	11.6	1.8	3.4	2.8	14.5	0.8
System Efficiency [%]	4.9	5.1	4.2	5.0	4.8	5.3	5.0
Performance Ratio [%]	80.3	82.9	68.9	81.9	78.5	86.0	81.2
Specific Annual Yield [kWh/kWp]	**670**	**652**	**267**	**504**	**511**	**863**	**747**
PV Array Efficiency [%]	5.6	5.5	4.7	5.6	5.4	5.7	5.6
Inverter Efficiency [%]	88.8	93.2	89.4	90.0	89.5	93.3	87.5
CO2 emissions avoided [kg/y]	296	4.252	663	1.254	1.016	5.327	289

Table 5.8. Main parameter results for all surfaces on House O

The result analysis for all surfaces has been made under the following conditions:

- PV Modules: **SCHÜCO International KG MPE 90 AL 01**
- Mount: with ventilation
- Consumption requirement = **59.5 MWh/y**

As it can be seen from the table data, there are two surfaces with good performance regarding solar power production: S8 and S9.

The first one, corresponding to Southern Roof, is the optimal as it can produce up to 8.6 MWh/y and almost all of this energy is directly consumed by the load. As a result, no storage system is required.

This means that regardless the grid topology (storage case or Net Metering case), this solution is very efficient and easy to install.

The production of these surfaces represents the 14.5% of the total demanded energy, resulting in the ideal solution for BEEM_UP project regarding this building.

The integration of solar cell panels in both Southern and Eastern roofs (S8 and S9) would be the best option for this building. This solution has been calculated and the results are displayed in the following analysis.

Next picture shows the location of solar cell panels on these surfaces from a Southern point of view.

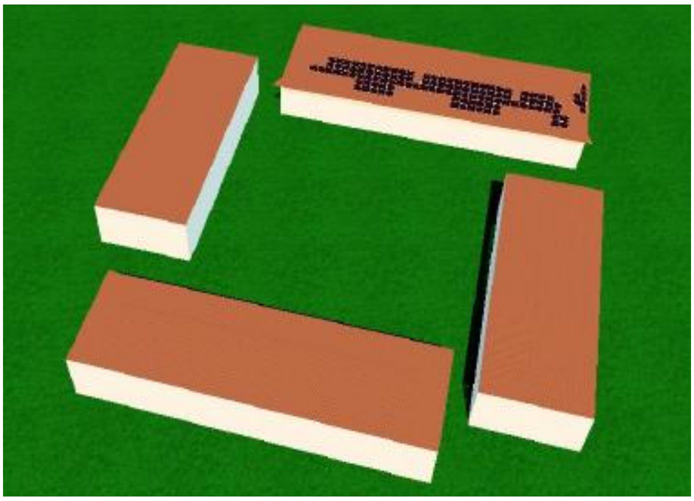


Fig. 5.30. Surface location (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next pictures show the detailed layout of solar cell panels on these surfaces.

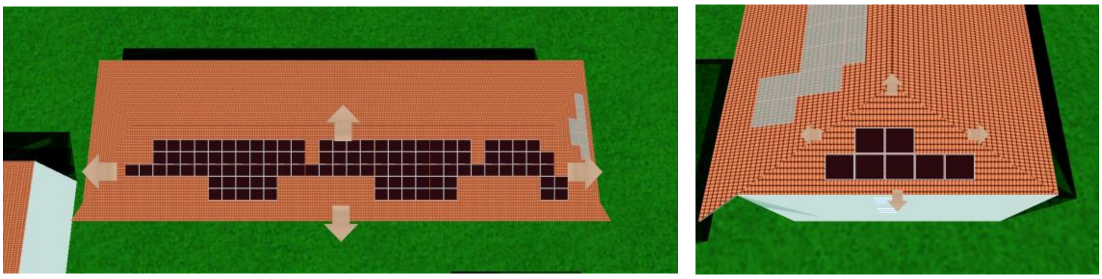


Fig. 5.31. Solar cell panels layout (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Below this picture, the percentage of lost performance for each solar cell panel due to shading of other objects or buildings in Southern roof is shown. Eastern roof is not affected by any shade.

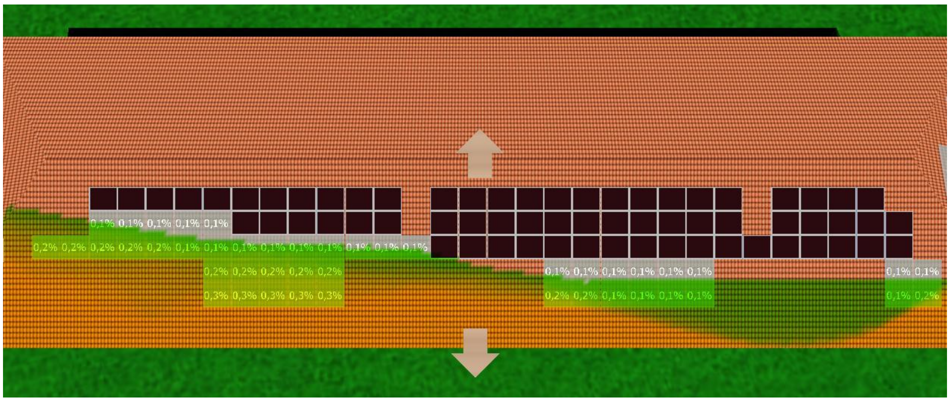


Fig. 5.32. Shading effect (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next diagram shows the scheme for the optimal system calculated for this building:

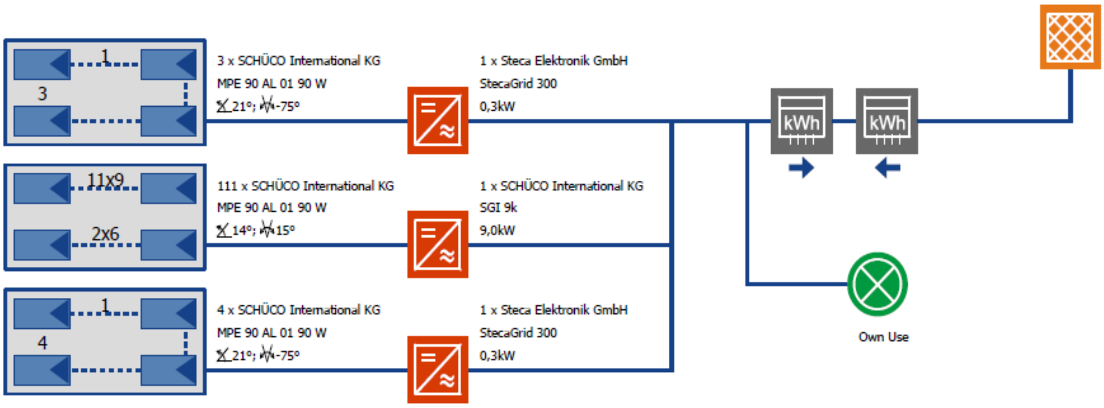


Fig. 5.33. Optimal topology scheme on House O (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The whole system consists of **118** solar cell panels connected to 3 inverters to integrate a system of **10.62 kWp** installed power.

The gross surface is around 169 m^2, generating more than 9.1 MWh/y and virtually without surplus energy.

This system generates **15.3%** of the total load, with an efficiency system of 5.3%, and with an specific annual yield of **856 kWh/kWp**.

The main parameters of this system are compiled on next table:

Location:	Alingsas_Brogarden - NOPQ	
Climate Data Record:	Alingsas_Brogarden - NOPQ (1981-2000)	
PV Output:	10,62	kWp
Gross/Active PV Surface Area:	168,74 / 172,79	m²
PV Array Irradiation:	172.487	kWh
Energy Produced by PV Array (AC):	9.118,2	kWh
Energy to Grid:	213,9	kWh
Consumption Requirement:	59.462	kWh
Direct Use of PV Energy:	8.904,3	kWh
Energy from Grid:	50.584,2	kWh
Yield Reduction Due to Shading:	1	%
Solar Fraction:	15,3	%
System Efficiency:	5,3	%
Performance Ratio:	85,8	%
Specific Annual Yield:	856,1	kWh/kWp
CO2 Emissions Avoided:	5.640	kg/a

Table 5.9. Main parameters calculated for optimal system on House O (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next table shows the system parameters in more detail, specifying the array modules and components included in this installation.

Array 1: System 2

Output:	0,27 kW	Ground Reflection:(Annual Average)	13,4 %
Gross/Active Solar Surface Area:	4,3 m² / 4,4 m²	Output Losses due to...	
PV Module	3 x	deviation from AM 1.5:	1,0 %
Manufacturer:	SCHÜCO International KG	deviation from Manufacturer's Specification:	2,0 %
Model:	MPE 90 AL 01	in Diodes:	0,5 %
Nominal Output:	90 W	due to Pollution:	0,0 %
Power Rating Deviation:	0 %	**Inverter**	1 x
Efficiency (STC):	6,3 %	Manufacturer:	Steca Elektronik GmbH
No. of Modules in Series:	1	Model:	StecaGrid 300
MPP Voltage (STC):	74 V	Output:	0,30 kW
Orientation:	-75,0 °	European Efficiency:	93,4 %
Inclination:	21,4 °	No. of MPP Trackers:	1
Mount:	with Ventilation	MPP Tracking:	45 V To 100 V
Shade:	Yes		

Array 2: System 1

Output:	9,99 kW	Ground Reflection:(Annual Average)	13,4 %
Gross/Active Solar Surface Area:	158,7 m² / 162,5 m²	Output Losses due to...	
PV Module	111 x	deviation from AM 1.5:	1,0 %
Manufacturer:	SCHÜCO International KG	deviation from Manufacturer's Specification:	2,0 %
Model:	MPE 90 AL 01	in Diodes:	0,5 %
Nominal Output:	90 W	due to Pollution:	0,0 %
Power Rating Deviation:	0 %	**Inverter**	1 x
Efficiency (STC):	6,3 %	Manufacturer:	SCHÜCO International KG
No. of Modules in Series:	9 | 6	Model:	SGI 9k
MPP Voltage (STC):	664 | 443 V	Output:	9,00 kW
Orientation:	15,0 °	European Efficiency:	97,4 %
Inclination:	14,0 °	No. of MPP Trackers:	2
Mount:	with Ventilation	MPP Tracking:	350 V To 800 V
Shade:	Yes		

Array 3: System 2

Output:	0,36 kW	Ground Reflection:	20,0 %
Gross/Active Solar Surface Area:	5,7 m² / 5,9 m²	Output Losses due to...	
PV Module	4 x	deviation from AM 1.5:	1,0 %
Manufacturer:	SCHÜCO International KG	deviation from Manufacturer's Specification:	2,0 %
Model:	MPE 90 AL 01	in Diodes:	0,5 %
Nominal Output:	90 W	due to Pollution:	0,0 %
Power Rating Deviation:	0 %	**Inverter**	1 x
Efficiency (STC):	6,3 %	Manufacturer:	Steca Elektronik GmbH
No. of Modules in Series:	1	Model:	StecaGrid 300
MPP Voltage (STC):	74 V	Output:	0,30 kW
Orientation:	-75,0 °	European Efficiency:	93,4 %
Inclination:	21,4 °	No. of MPP Trackers:	1

Table 5.10. Main parameters components for optimal system on House O (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next table shows the simulation results for total system related to the energy balance.

Simulation Results for Total System

Irradiation onto Horizontal:	161.958 kWh	Energy from Grid:	50.584 kWh
PV Array Irradiation:	172.487 kWh	Own Use:	26,5 kWh
Irradiation minus Reflection:	165.034 kWh	Energy Produced by PV Array:	9.768 kWh
Irradiation without Shade:	177.642 kWh	Solar Fraction:	15,3 %
Energy from Inverter (AC):	9.118 kWh	System Efficiency:	5,3 %
Energy to Grid:	214 kWh	Performance Ratio:	85,8 %
Consumption Requirement:	59.462 kWh	Final Yield:	2,3 h/d
Direct Use of PV Energy:	8.904 kWh	Specific Annual Yield:	856 kWh/kWp

Results for Array 1: System 2

Irradiation onto Horizontal:	4.115 kWh	Energy Produced (DC):	228 kWh
Array Irradiation:	4.042 kWh	System Efficiency:	4,9 %
Irradiation without Shade:	4.186 kWh	Performance Ratio:	80,4 %
Energy Produced (AC):	203 kWh	Specific Annual Yield:	740 kWh/kWp
Own Use:	3 kWh	Array Efficiency:	5,6 %
Inverter Efficiency:	87,5 %		

Results for Array 2: System 1

Irradiation onto Horizontal:	152.354 kWh	Energy Produced (DC):	9.234 kWh
Array Irradiation:	163.040 kWh	System Efficiency:	5,3 %
Irradiation without Shade:	167.859 kWh	Performance Ratio:	86,0 %
Energy Produced (AC):	8.640 kWh	Specific Annual Yield:	863 kWh/kWp
Own Use:	20 kWh	Array Efficiency:	5,7 %
Inverter Efficiency:	93,3 %		

Results for Array 3: System 2

Irradiation onto Horizontal:	5.493 kWh	Energy Produced (DC):	305 kWh
Array Irradiation:	5.404 kWh	System Efficiency:	5,0 %
Irradiation without Shade:	5.597 kWh	Performance Ratio:	81,9 %
Energy Produced (AC):	275 kWh	Specific Annual Yield:	755 kWh/kWp
Own Use:	3 kWh	Array Efficiency:	5,6 %
Inverter Efficiency:	89,1 %		

Table 5.11. Main simulation results for optimal system on House O (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next picture shows the energy balance throughout the year:

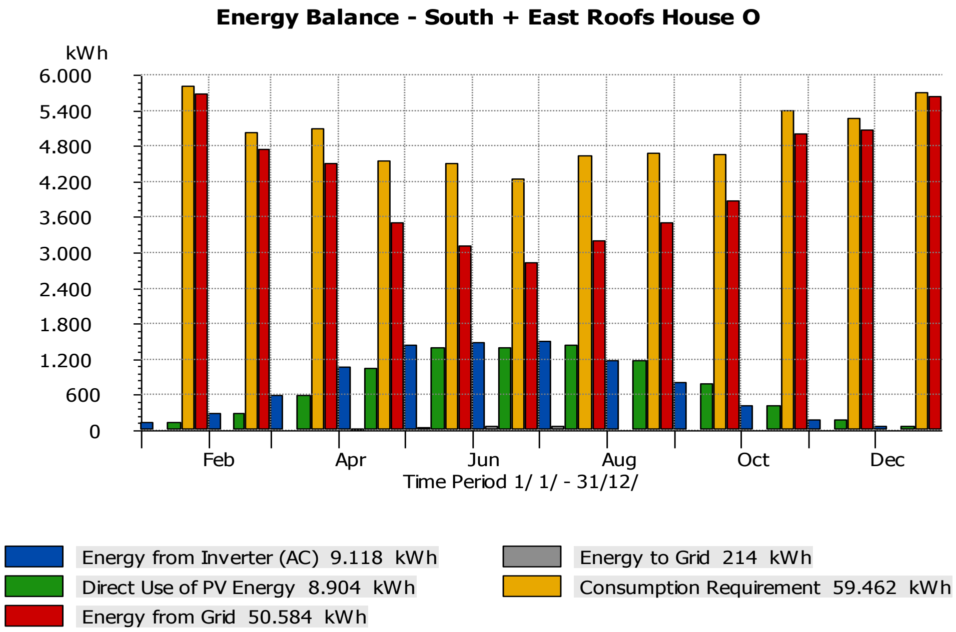


Fig. 5.34. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

5.3 House P

5.3.1 Maximum production without overproduction

The system is sized so that the surplus PV solar power at any time is virtually zero. Therefore no energy storage system is required.

For this idea the least consuming month and the highest PV energy production must be taken into account, resulting in June as the selected month.

Moreover, as the condition is to avoid overproduction at any time, a hourly-based time resolution for the calculation is required.

In this case, the GERES system design will bring about the simplest and cheapest installation. Next pictures show the buildings layout and the solar cell panels layout on the Eastern roof of building N:

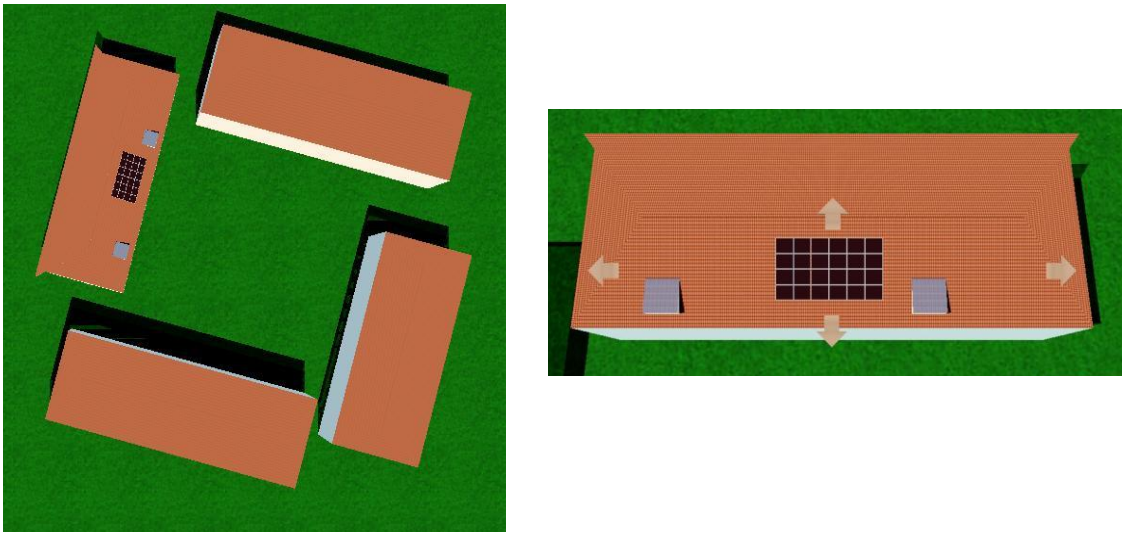


Fig. 5.35. Situation plane over the four buildings group and the solar cell panel layout on House P (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Below picture shows the shading effect over the solar cell panels on the Eastern roof of building P:

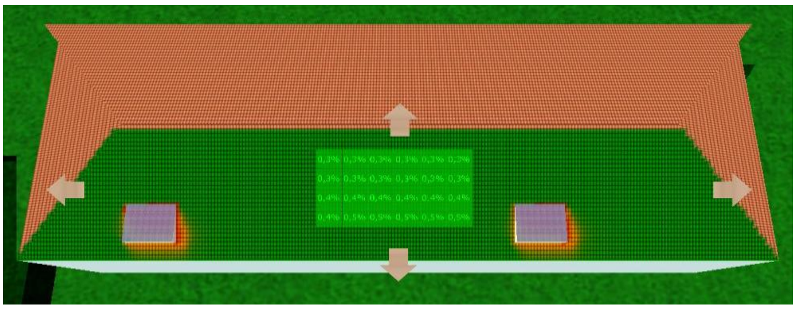
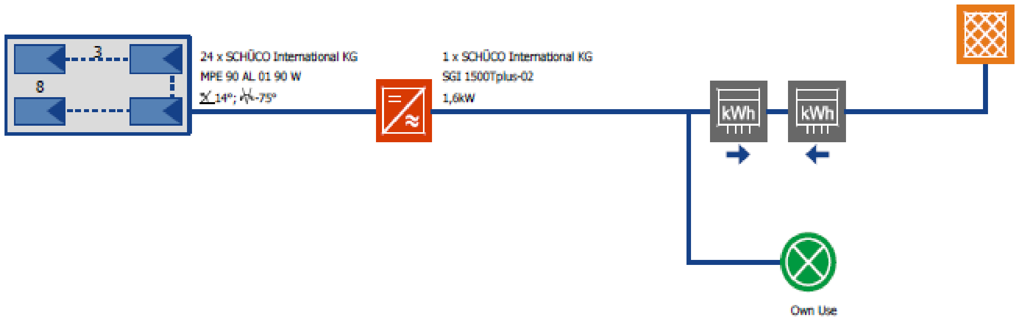


Fig. 5.36. Shading effect in performance reduction (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The basic topology for this installation is shown on next figure. Two counters can be found: one measures the input energy from the grid, as the other measures the output energy delivered into the grid (in this case is zero).

A possible configuration may consist of a 24 panel array, composed by 8 strings with 3 panels each one. This array is connected to a 1.6 kW inverter. The selected panel model is **Schüco MPE 90 AL 01**.



Location:	Alingsas_Brogarden - NOPQ	
Climate Data Record:	Alingsas_Brogarden - NOPQ (1981-2000)	
PV Output:	2,16	kWp
Gross/Active PV Surface Area:	34,32 / 35,14	m²
PV Array Irradiation:	32.369	kWh
Energy Produced by PV Array (AC):	1.648,3	kWh
Energy to Grid:	3,3	kWh
Consumption Requirement:	14.006	kWh
Direct Use of PV Energy:	1.645,0	kWh
Energy from Grid:	12.369,8	kWh
Yield Reduction Due to Shading:	1	%
Solar Fraction:	11,7	%
System Efficiency:	5,1	%
Performance Ratio:	82,4	%
Inverter Efficiency:	90,2	%
PV Array Efficiency:	5,6	%
Specific Annual Yield:	759,0	kWh/kWp
CO2 Emissions Avoided:	1.008	kg/a

Fig. 5.37. Topology scheme without using any storage system on House P (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The main parameters of this system are compiled on above table. The total installed power is 2.16 kWp, over an usable area around 34 m^2. All energy values on this table are on an annual basis.

This building demands 14 MWh/y, and the PV system generates 1.7 MWh/y, which is a small part of the demand. However the interesting parameter is the Energy to Grid, with a really small value of 3.3 kWh/y. This means that the PV system doesn´t produce surplus energy throughout the year.

The amount of energy supplied from the grid is 12.4 MWh/y.

Next table shows the system parameters in more detail, specifying the array modules and components and the simulation results for the whole system related to the energy balance.

These data reveal a solar fraction of 11.7% with respect to the demanded energy. The system efficiency is around 5.1%.

One of the most important parameters is the Specific Annual Yield, 759 kWh/kWp, which gives an idea of the energy and economic performance of the installation. This value represents the amount of energy the system can generate for each installed PV kWp.

Array 1: System 1

Output:	2,16 kW	Ground Reflection:(Annual Average)	13,4 %
Gross/Active Solar Surface Area:	34,3 m² / 35,1 m²	Output Losses due to...	
PV Module	24 x	deviation from AM 1.5:	1,0 %
Manufacturer:	SCHÜCO International KG	deviation from Manufacturer's Specification:	2,0 %
Model:	MPE 90 AL 01	in Diodes:	0,5 %
Nominal Output:	90 W	due to Pollution:	0,0 %
Power Rating Deviation:	0 %	**Inverter**	1 x
Efficiency (STC):	6,3 %	Manufacturer:	SCHÜCO International KG
No. of Modules in Series:	3	Model:	SGI 1500Tplus-02
MPP Voltage (STC):	221 V	Output:	1,65 kW
Orientation:	-75,0 °	European Efficiency:	93,3 %
Inclination:	14,0 °	No. of MPP Trackers:	1
Mount:	with Ventilation	MPP Tracking:	125 V To 510 V
Shade:	Yes		

Appliances 1 (Load Profile)

Annual Requirement:	14.006 kWh	
Max. Hourly Value:	2,56 kW	
Weekend Consumption:	Saturday: 100 %	Sunday: 100 %
Consumption Profile:	Alingsas - NOPQ - Average daily profile	
Holiday Periods:	None	

Individual Appliances Total Consumption: 0 kWh

Individual Appliance 1	Model: User-Independent Appl.	0 kWh

Simulation Results for Total System

Irradiation onto Horizontal:	32.941 kWh	Energy from Grid:	12.370 kWh
PV Array Irradiation:	32.369 kWh	Own Use:	8,8 kWh
Irradiation minus Reflection:	30.811 kWh	Energy Produced by PV Array:	1.817 kWh
Irradiation without Shade:	33.488 kWh	Solar Fraction:	11,7 %
Energy from Inverter (AC):	1.648 kWh	System Efficiency:	5,1 %
Energy to Grid:	3 kWh	Performance Ratio:	82,4 %
Consumption Requirement:	14.006 kWh	Final Yield:	2,1 h/d
Direct Use of PV Energy:	1.645 kWh	Specific Annual Yield:	759 kWh/kWp
Array Efficiency:	5,6 %		

Table 5.11. Main components and simulation results (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next picture shows the energy balance throughout the year:

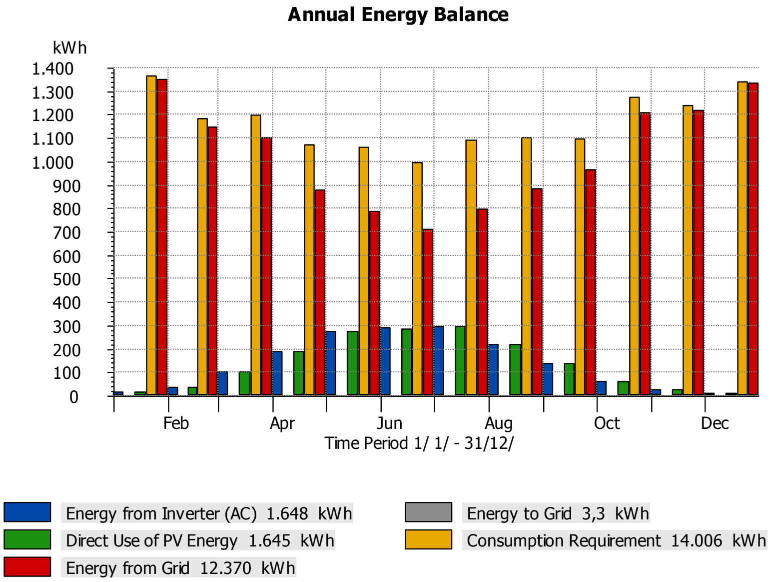


Fig. 5.38. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The figure below shows the energy values corresponding to June, since this is the selected month for the energy flow balance.

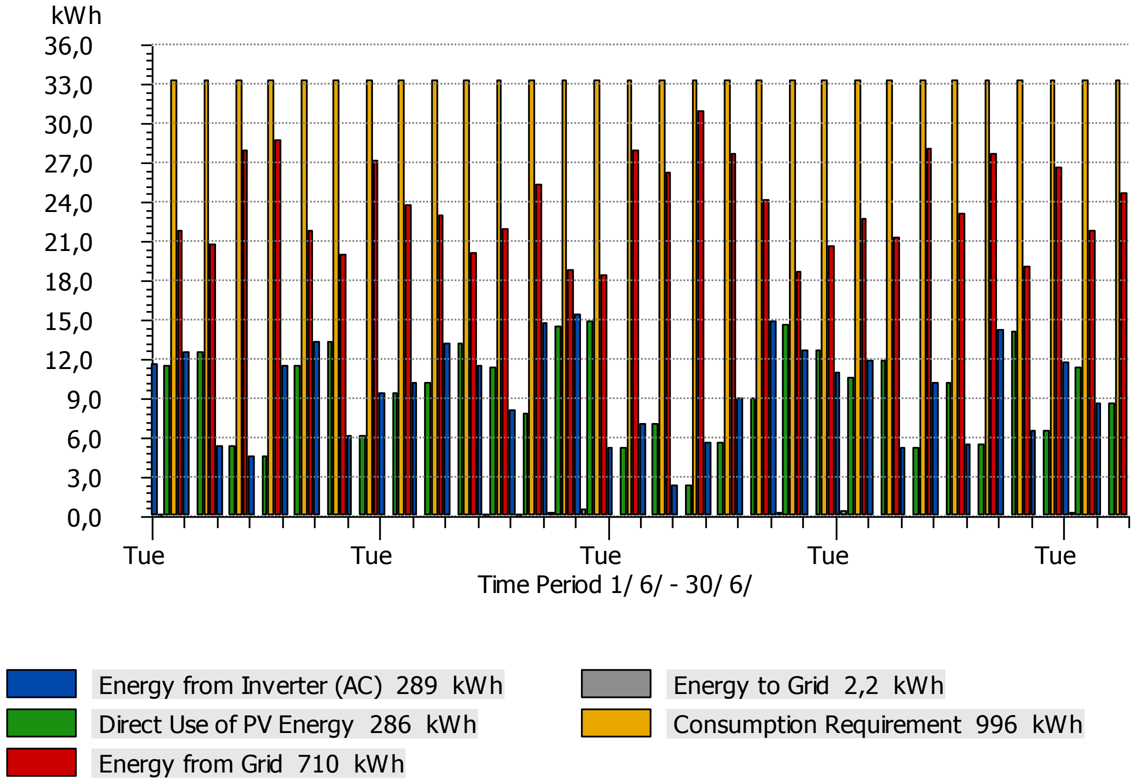


Fig. 5.39. Energy balance in June (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

It can be seen that the Energy to Grid value is almost zero, 2.2 kWh.

5.3.2 June consumption balanced with June production (storage case)

In this case, the electrical grid topology doesn´t buy the overproduced energy, so the system needs to store this surplus energy produced by the PV solar cell panels.

The system is sized so that the produced PV energy during June equals the demanded energy. This means an energy storage system is required since every day there will be surplus production and not satisfied demand in real time.

For this idea the least consuming month and the highest PV energy production must be considered, resulting in June as the selected month. Moreover, as the condition is to avoid overproduction in June, a monthly-based time resolution for the calculation is required.

In this case, the GERES system design could bring about a very complex installation. The daily overproduced energy must be stored on batteries during the day and it must be used later during the night. So, the batteries must be charged and discharged every day.

The solar cell panels layout is located on the Eastern roof of the building. Next picture shows the topology scheme of the installation.

A **76** panel array could be a possible configuration. This array is connected to one battery regulator, the battery bus and the 3 kW inverter. The panel model selected is **Schüco MPE 90 AL 01**.

The battery bus consists of 28 batteries of 230 Ah, 12 V each one. So, the battery bus can store up to **77 kWh**.

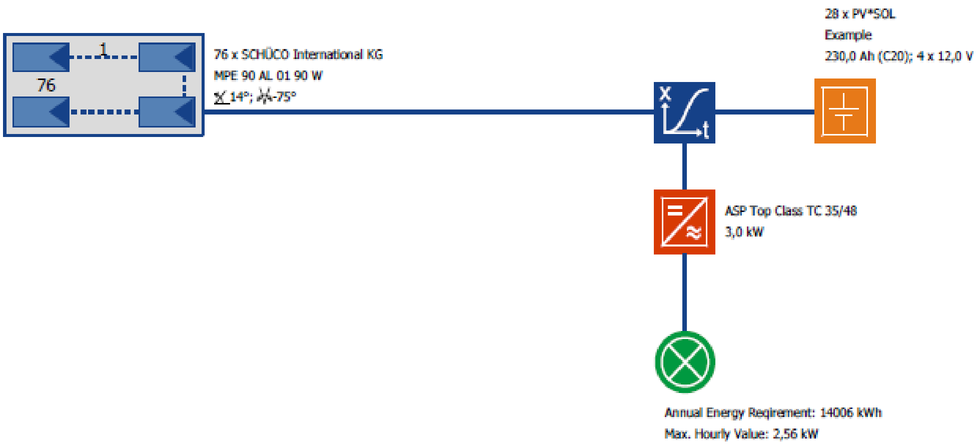
The total installed power is 6.84 kWp, over an usable area around 109 m^2. All energy values on this table are on an annual basis.

This building demands 14 MWh/y, and the PV system generates 4.3 MWh/y. Taking into account the losses and efficiencies of the storage system, the final energy provided by solar production is 3.9 MWh/y.

The amount of energy supplied from the grid is 10 MWh/y.

These data reveal a solar fraction of 28% with respect to the demanded energy. The system efficiency is around 3.7 %.

One of the most important parameters is the Specific Annual Yield, 568 kWh/kWp, which gives an idea of the energy and economic performance of the installation. This value represents the amount of energy the system can generate for each installed PV kWp.



Location:	Alingsas_Brogarden - NOPQ	
Climate Data Record:	Alingsas_Brogarden - NOPQ (1981-2000)	
PV Output:	6,84	kWp
Gross/Active PV Surface Area:	108,68 / 111,29	m²

PV Array Irradiation:	106.045	kWh
Energy Produced by PV Array:	4.344,9	kWh
Consumption Requirement:	14.006	kWh
Consumption Covered by Solar Energy:	3.882,1	kWh
Consumption Not Covered by System:	10.123,9	kWh

Solar Fraction:	27,7	%
Performance Ratio:	59,6	%
Specific Annual Yield:	567,6	kWh/kWp
CO2 Emissions Avoided:	2.385	kg/a
System Efficiency:	3,7	%
PV Array Efficiency:	4,1	%

Fig. 5.40. Topology scheme for June balanced on House P (storage case) (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next table shows the system parameters in more detail, specifying the array modules and components and the simulation results for the whole system related to the energy balance.

Array 1: Array Name

Output:	6,84 kW	Ground Reflection:(Annual Average)	13,4 %
Gross/Active Solar Surface Area:	108,7 m² / 111,3 m²	Output Losses due to...	
PV Module	76 x	deviation from AM 1.5:	1,0 %
Manufacturer:	SCHÜCO International KG	deviation from Manufacturer's Specification:	2,0 %
Model:	MPE 90 AL 01	in Diodes:	0,5 %
Nominal Output:	90 W	due to Pollution:	0,0 %
Power Rating Deviation:	0 %		
Efficiency (STC):	6,3 %		
No. of Modules in Series:	1		
MPP Voltage (STC):	74 V		
Orientation:	-75,0 °		
Inclination:	14,0 °		
Mount:	with Ventilation		
Shade:	No		

Battery

Manufacturer:	PV*SOL	Mean Charge Efficiency:	85,0 %
Model:	Example	Mean Discharge Efficiency:	99,0 %
Nominal Voltage:	12,0 V	Charge Controller	
C20 Capacity:	230,0 Ah	Lower Battery Discharge Threshold:	30,0 %
Self Discharge:	0,3 %/Tag		

Stand-Alone System Inverter

Manufacturer:	ASP	Nom. DC Voltage:	48,0 V
Model:	Top Class TC 35/48	Stand-by Consumption:	0,0 W
AC Power Rating:	3,0 kW	Efficiency at Nominal Output:	93,0 %
Nom. AC Voltage:	230,0 V		

Appliances 1 (Load Profile)

Annual Requirement:	14.006 kWh	
Max. Hourly Value:	2,56 kW	
Weekend Consumption:	Saturday: 100 %	Sunday: 100 %
Consumption Profile:	Alingsas - NOPQ - Average daily profile	
Holiday Periods:	None	

Simulation Results for Total System

Irradiation onto Horizontal:	104.311 kWh	Battery Losses:	170 kWh
PV Array Irradiation:	106.045 kWh	Charge Condition at Sim. Start:	23,5 %
Irradiation minus Reflection:	98.762 kWh	Charge Condition at Sim. End:	23,5 %
Energy Produced by PV Array:	4.345 kWh	Solar Fraction:	27,7 %
Consumption Requirement:	14.006 kWh	Performance Ratio:	59,6 %
Direct Use of PV Energy:	3.420 kWh	Final Yield:	1,6 h/d
Consumption Not Covered by System:	10.124 kWh	Specific Annual Yield:	568 kWh/kWp
PV Array Surplus:	0 kWh	System Efficiency:	3,7 %
Consumption Covered by Solar Energy:	3.882 kWh	Array Efficiency:	4,1 %
Battery Discharge:	755 kWh	Inverter Efficiency:	93,0 %

Table 5.12. Main components and simulation results (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The charging energy in batteries throughout the year is 955 kWh, and the battery losses are 170 kWh.

Next picture shows the energy balance throughout the year:

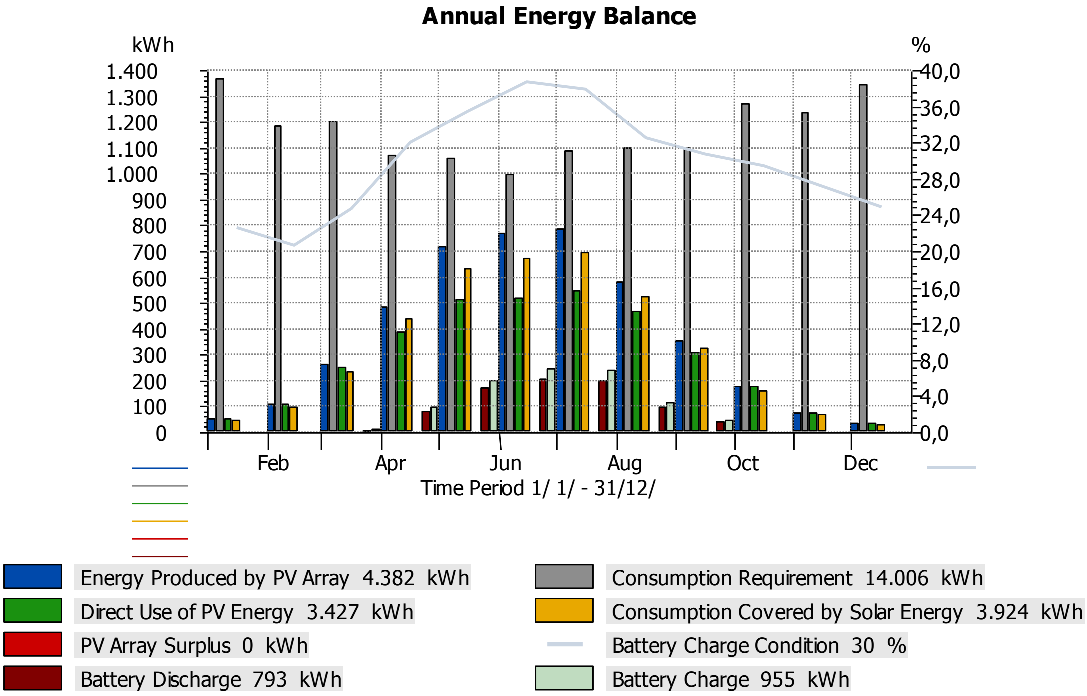


Fig. 5.41. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The figure below shows the values corresponding to June. It can be seen that the surplus energy from PV is 0 kWh/y.

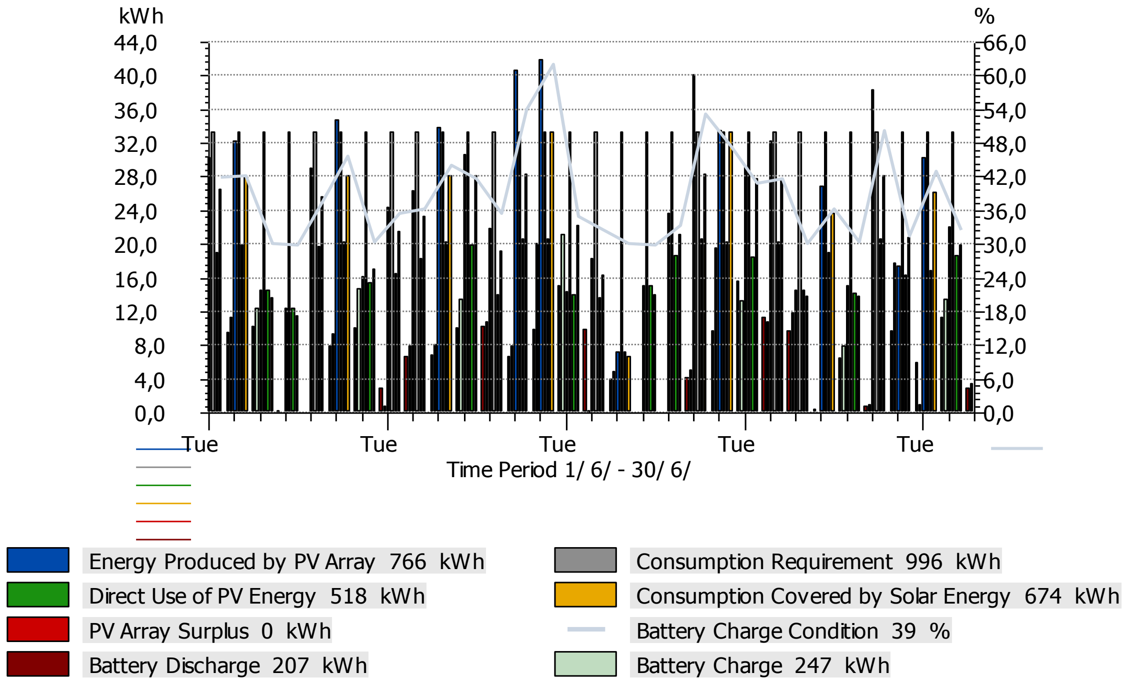


Fig. 5.42. Energy balance in June (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

5.3.3 June consumption balanced with June production (Net Metering case)

In the Net Metering case, the electrical grid topology buys the overproduced energy. The total bought and sold energy from and to the grid is compared and compensated afterwards. In this situation the system doesn´t need to store the surplus energy produced by the PV solar cell panels. This results in a very simple, cheap and efficient installation.

As the last case, the system is sized in such a way that the produced PV energy during June equals the demanded energy.

For this idea the least consuming month and the highest PV energy production must be taken into account, which results in June as the selected month. Moreover, as the condition is to avoid overproduction in June, a monthly-based time resolution for the calculation is required.

In this case, the GERES system design could be very simple. The daily overproduced energy must be delivered to the grid and at the same time the non-satisfied load at night must be taken from the grid.

The solar cell panels layout is located on the Eastern roof of the building.

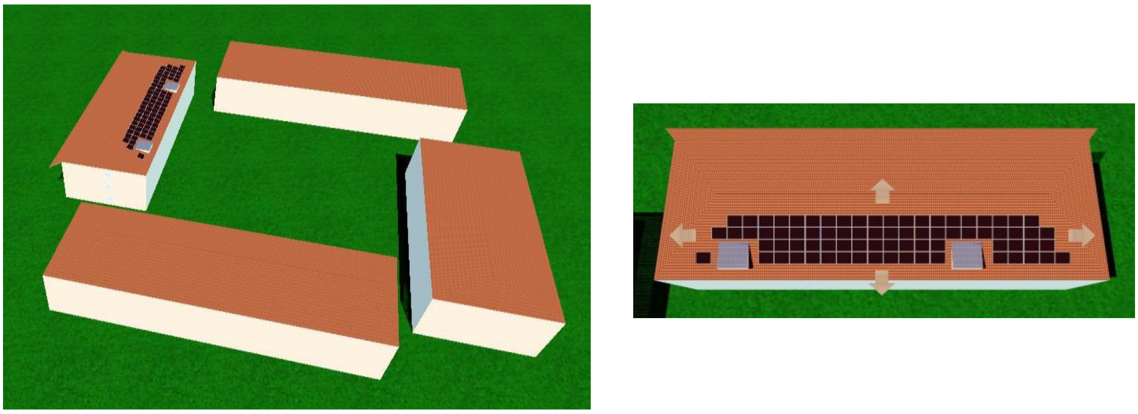


Fig. 5.43. Situation plane over the four buildings group and the solar cell panel layout on House P (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Figure 5.43 shows the corresponding layout to Net Metering case. The four buildings NOPQ, from the Southern view, can be seen. The buildings set is rotated 15º westwards.

The solar cell panels are located on the Eastern roof because this is the most efficient surface.

The figure below shows the shading effect on the performance reduction.

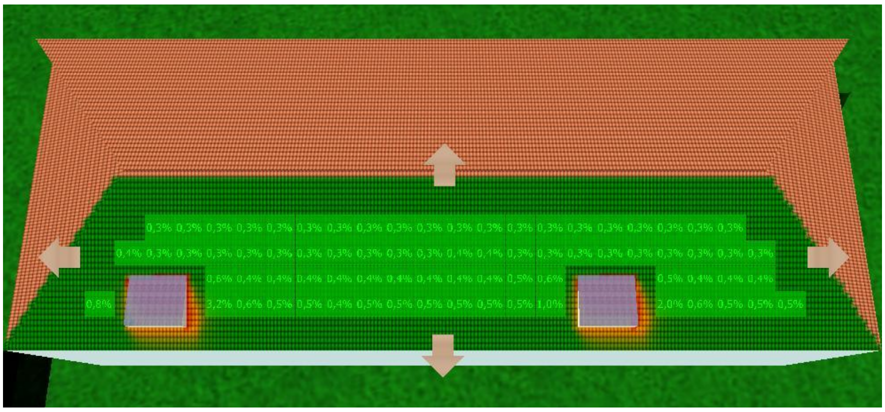


Fig. 5.44. Shading effect in performance reduction (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Figure 5.45 shows the topology scheme of the installation. Two counters can be found: one counter measures the input electrical energy to the system (energy bought from the grid), and the other one measures the energy sold to the grid by the system.

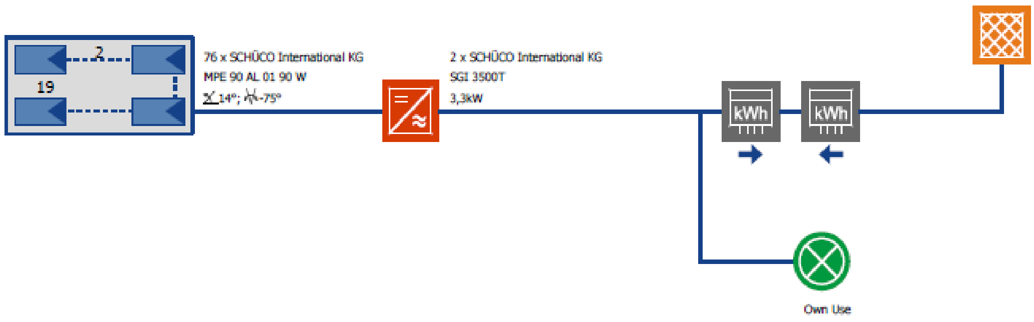
One possible configuration can be formed by 76 solar cell panels **Schüco MPE 90 AL 01** connected to two inverters of 3.3 kW each one.

The total installed power is 6.84 kWp, over an usable area around 109 m^2. All energy values on this table are on an annual basis.

This building demands 14 MWh/y, and the PV system generates 5.3 MWh/y. The amount of energy delivered to the grid is 1.8 MWh/y and the amount of energy supplied from the grid is 10.5 MWh/y.

The system efficiency is around 5.1%, significantly higher than the one with storage system. The solar fraction is very significant: 37%.

One of the most important parameters is the Specific Annual Yield, 765 kWh/kWp, which gives an idea of the higher energy and economic performance of this installation.



Location:	Alingsas_Brogarden - NOPQ	
Climate Data Record:	Alingsas_Brogarden - NOPQ (1981-2000)	
PV Output:	6,84	kWp
Gross/Active PV Surface Area:	108,68 / 111,29	m²

PV Array Irradiation:	102.410	kWh
Energy Produced by PV Array (AC):	5.248,2	kWh
Energy to Grid:	1.765,0	kWh
Consumption Requirement:	14.006	kWh
Direct Use of PV Energy:	3.483,3	kWh
Energy from Grid:	10.537,5	kWh
Yield Reduction Due to Shading:	1	%

Solar Fraction:	37,4	%
System Efficiency:	5,1	%
Performance Ratio:	83,1	%
Inverter Efficiency:	90,9	%
PV Array Efficiency:	5,6	%
Specific Annual Yield:	765,1	kWh/kWp
CO2 Emissions Avoided:	3.693	kg/a

Fig. 5.45. Topology scheme for June balanced Net Metering case on House P (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next table shows the system parameters in more detail, specifying the array modules and components included in this installation and the simulation results.

Array 1: System 1			
Output:	6,84 kW	Ground Reflection:(Annual Average)	13,4 %
Gross/Active Solar Surface Area:	108,7 m² / 111,3 m²	Output Losses due to...	
PV Module	76 x	deviation from AM 1.5:	1,0 %
Manufacturer:	SCHÜCO International KG	deviation from Manufacturer's Specification:	2,0 %
Model:	MPE 90 AL 01	in Diodes:	0,5 %
Nominal Output:	90 W	due to Pollution:	0,0 %
Power Rating Deviation:	0 %	**Inverter**	2 x
Efficiency (STC):	6,3 %	Manufacturer:	SCHÜCO International KG
No. of Modules in Series:	2	Model:	SGI 3500T
MPP Voltage (STC):	148 V	Output:	3,30 kW
Orientation:	-75,0 °	European Efficiency:	93,3 %
Inclination:	14,0 °	No. of MPP Trackers:	1
Mount:	with Ventilation	MPP Tracking:	125 V To 400 V
Shade:	Yes		

Appliances 1 (Load Profile)		
Annual Requirement:	14.006 kWh	
Max. Hourly Value:	2,56 kW	
Weekend Consumption:	Saturday: 100 %	Sunday: 100 %
Consumption Profile:	Alingsas - NOPQ - Average daily profile	
Holiday Periods:	None	

Individual Appliances Total Consumption: 0 kWh		
Individual Appliance 1	Model: User-Independent Appl.	0 kWh

Simulation Results for Total System			
Irradiation onto Horizontal:	104.312 kWh	Energy from Grid:	10.537 kWh
PV Array Irradiation:	102.410 kWh	Own Use:	14,7 kWh
Irradiation minus Reflection:	97.493 kWh	Energy Produced by PV Array:	5.759 kWh
Irradiation without Shade:	106.046 kWh	Solar Fraction:	37,4 %
Energy from Inverter (AC):	5.248 kWh	System Efficiency:	5,1 %
Energy to Grid:	1.765 kWh	Performance Ratio:	83,1 %
Consumption Requirement:	14.006 kWh	Final Yield:	2,1 h/d
Direct Use of PV Energy:	3.483 kWh	Specific Annual Yield:	765 kWh/kWp
Array Efficiency:	5,6 %		

Table 5.13. Main components and simulation results (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next picture shows the energy balance throughout the year:

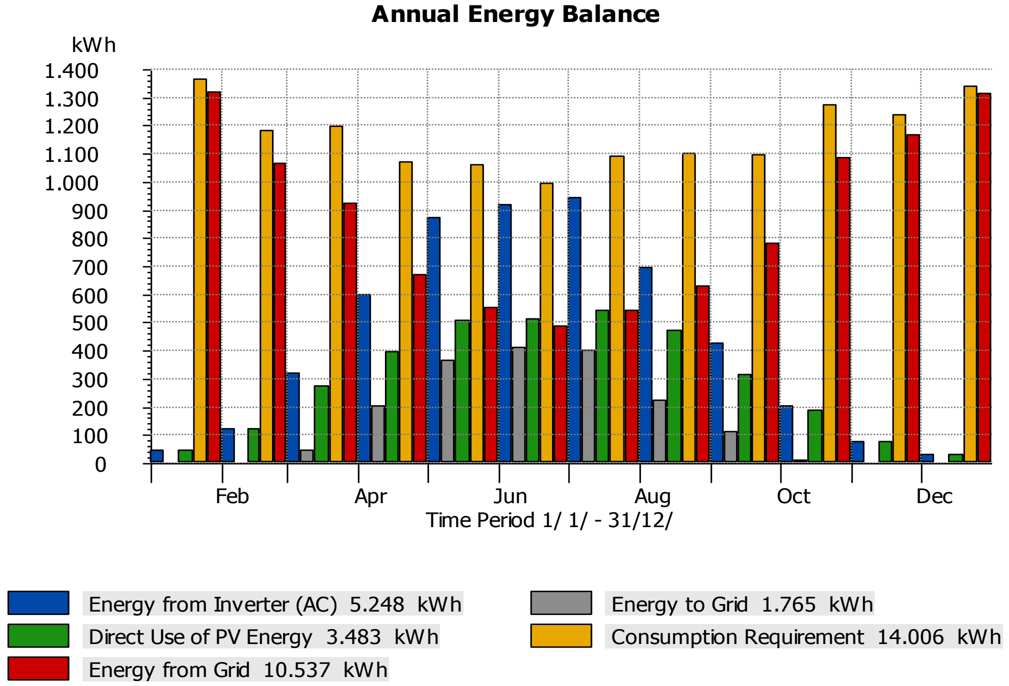


Fig. 5.46. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The consumption requirement in June is 996 kWh, and the produced energy is 920 kWh. On the other hand, the energy delivered to the grid is 410 and the energy taken from the grid is 486, resulting in a balanced flow.

Also, it can be seen that there are 14 days with overproduction and other 16 days with lack of energy, however at the end of the month the energy flow is balanced.

Below picture shows the energy balance in June:

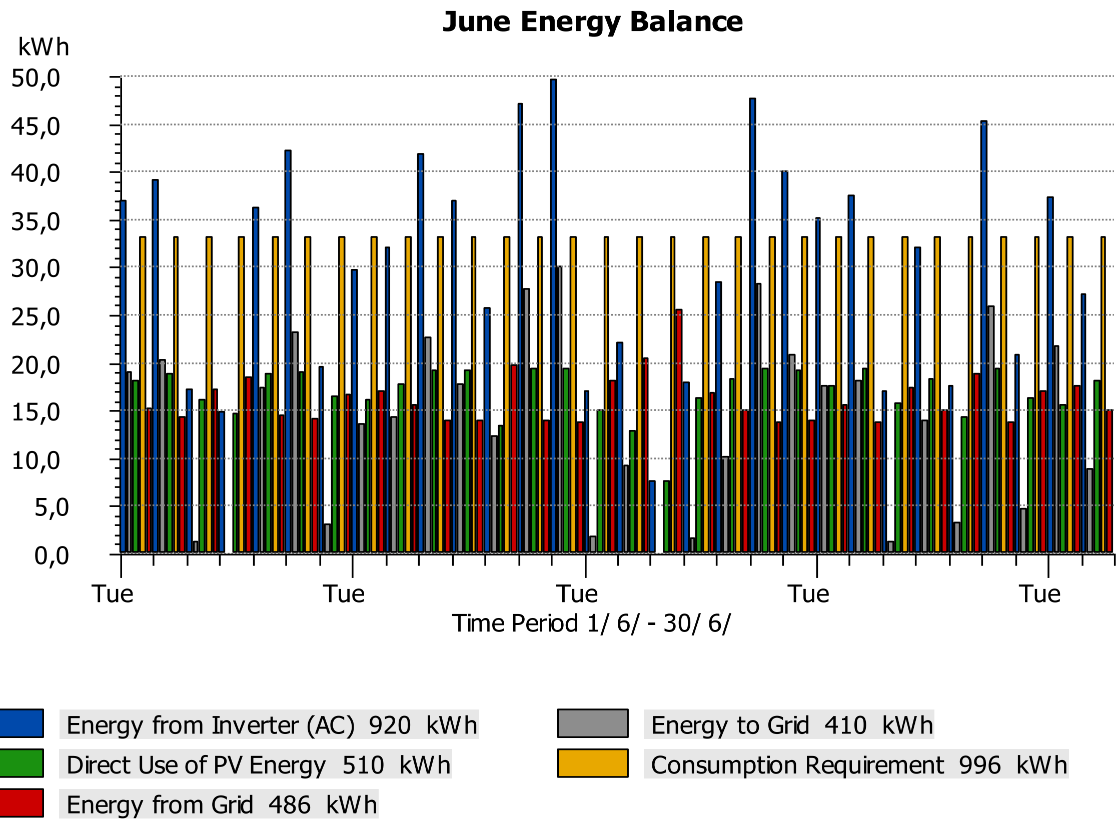


Fig. 5.47. Energy balance in June (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Remark!

With the same PV solar cell panels sizing, the system with batteries gets 10% less solar fraction than the Net Metering case.

5.4 House Q

5.4.1 All surfaces energy production comparative

Southern Roof (S8)

Next picture shows the location and layout of solar cell panels on this surface from a Southern point of view. Next to this picture, the same layout in more detail is shown.

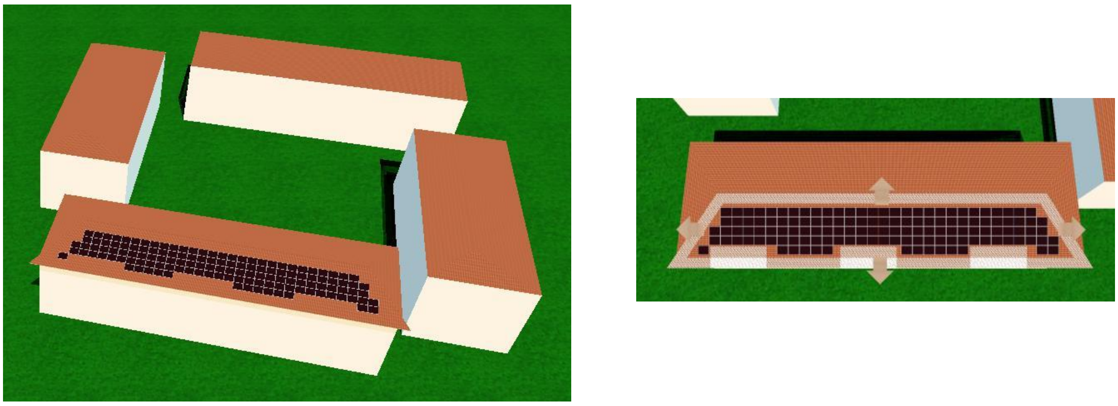


Fig. 5.48. Southern roof solar cell panel layout on House Q (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The picture below shows the main values of energy flow for this surface: the produced energy, the consumption requirement and the energy delivered from and to the grid.

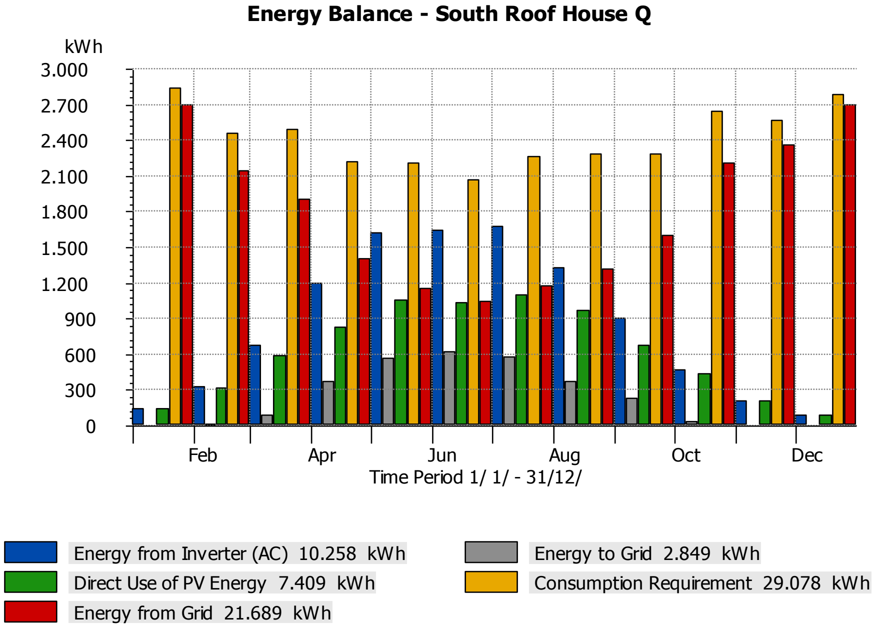


Fig. 5.49. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

It´s clear that in this case the solar production generates a very important surplus energy, around 2.8 MWh/y.

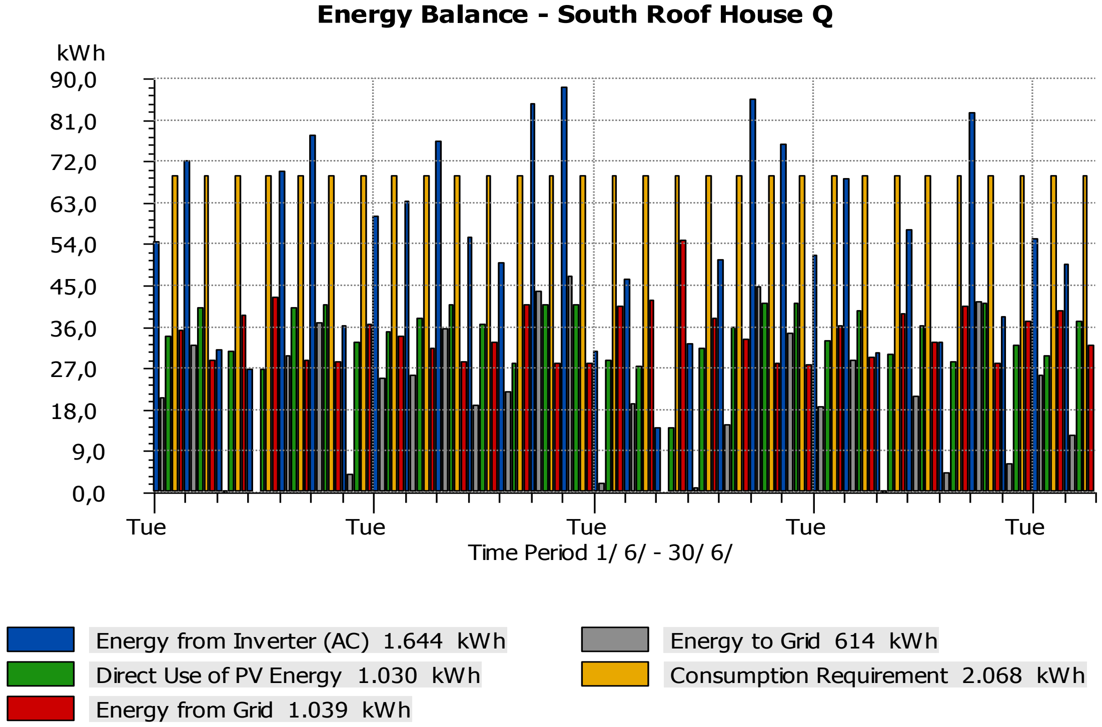


Fig. 5.50. Energy balance in June (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

If only June is taken into account, the surplus energy is reduced to 614 kWh/y. It is also important to remark that this surface completely covered by solar cell panels is nearly enough to satisfy the total load, being only necessary to add around 400 kWh/y by other surfaces.

Eastern Roof (S9)

Next picture shows the location and layout of solar cell panels on this surface from a Southern point of view. Next to this picture, a more detailed view of this roof is shown.

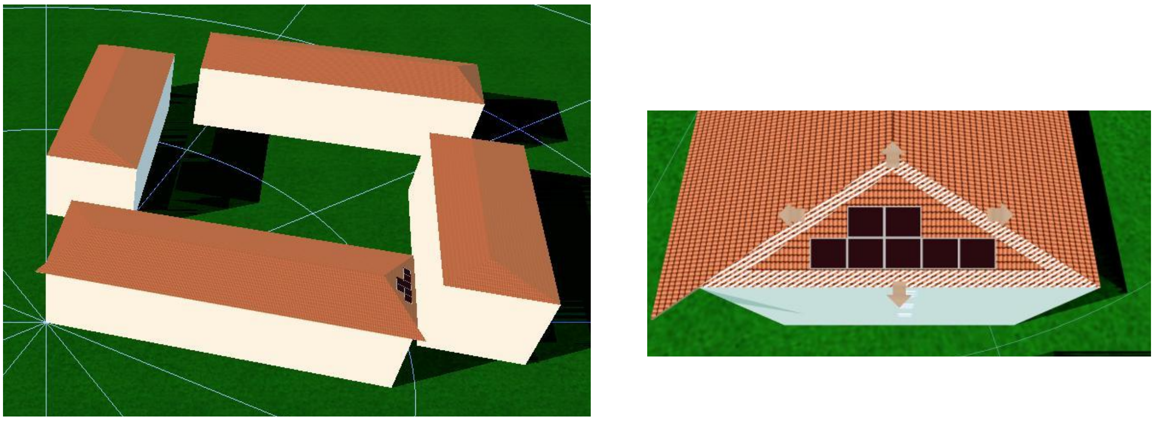


Fig. 5.51. Surface location (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The picture below shows the main values of energy flow for this surface: the produced energy, the consumption requirement and the energy delivered from and to the grid. Due to the fact that almost all the produced energy is consumed, practically no energy surplus is obtained.

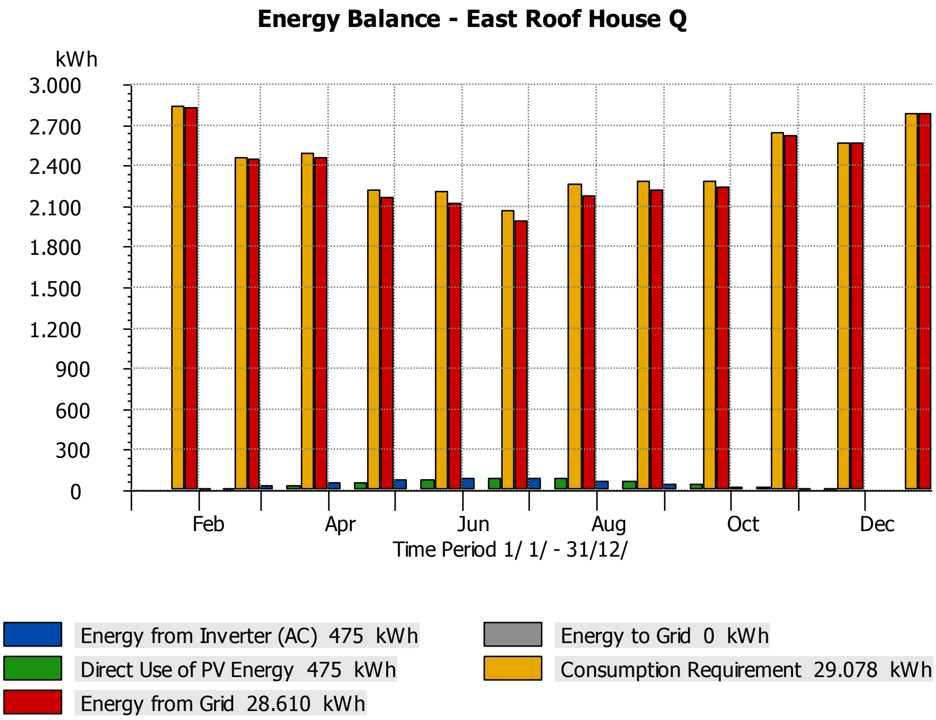


Fig. 5.52. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Western Roof (S10)

Next picture shows the location and layout of solar cell panels on this surface from a Southern point of view. Next to this picture, a more detailed view of solar cell panels on this surface, which is not affected by any shadow, is shown.

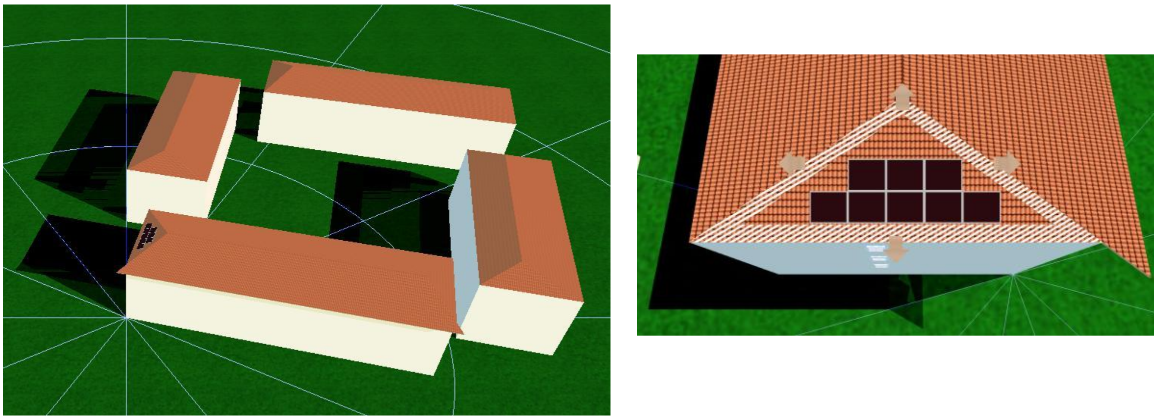


Fig. 5.53. Surface location (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The picture below shows the main values of energy flow for this surface: the produced energy, the consumption requirement and the energy delivered from and to the grid. Due to the very small energy production, no energy surplus is obtained.

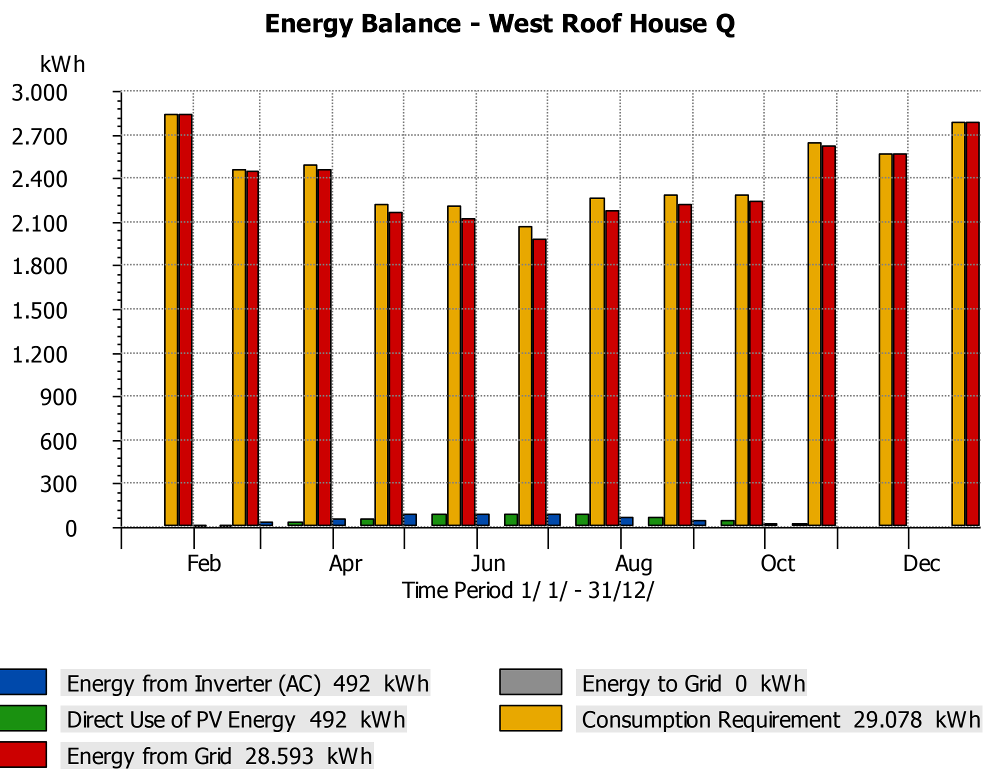


Fig. 5.54. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Western Facade (S12)

Next picture shows the location and layout of solar cell panels on this surface from a Southern-Western point of view. Next to this picture, the percentage of lost performance of each solar cell panel due to shading of other objects or buildings is shown.

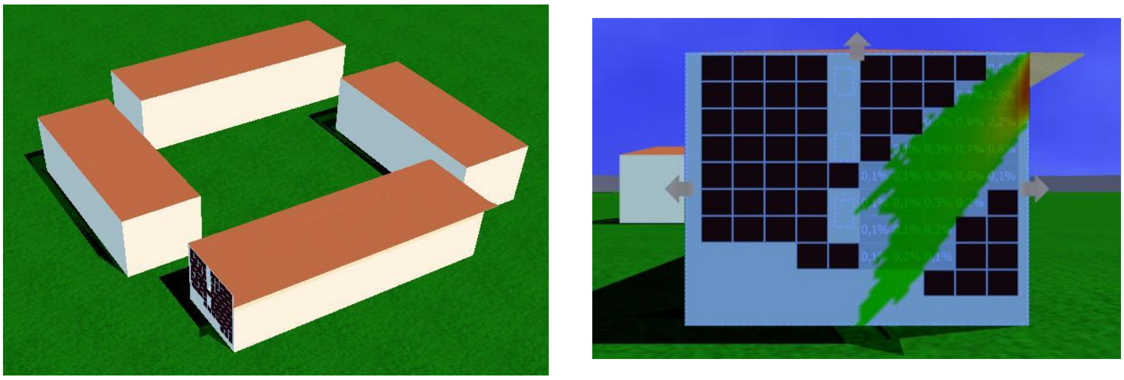


Fig. 5.55. Surface location and shading effect (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The picture below shows the main values of energy flow for this surface: the produced energy, the consumption requirement and the energy delivered from and to the grid. This surface is strongly affected by shading from other buildings, specially on panels located at the right side corner. As a consequence, there is no significant surplus energy.

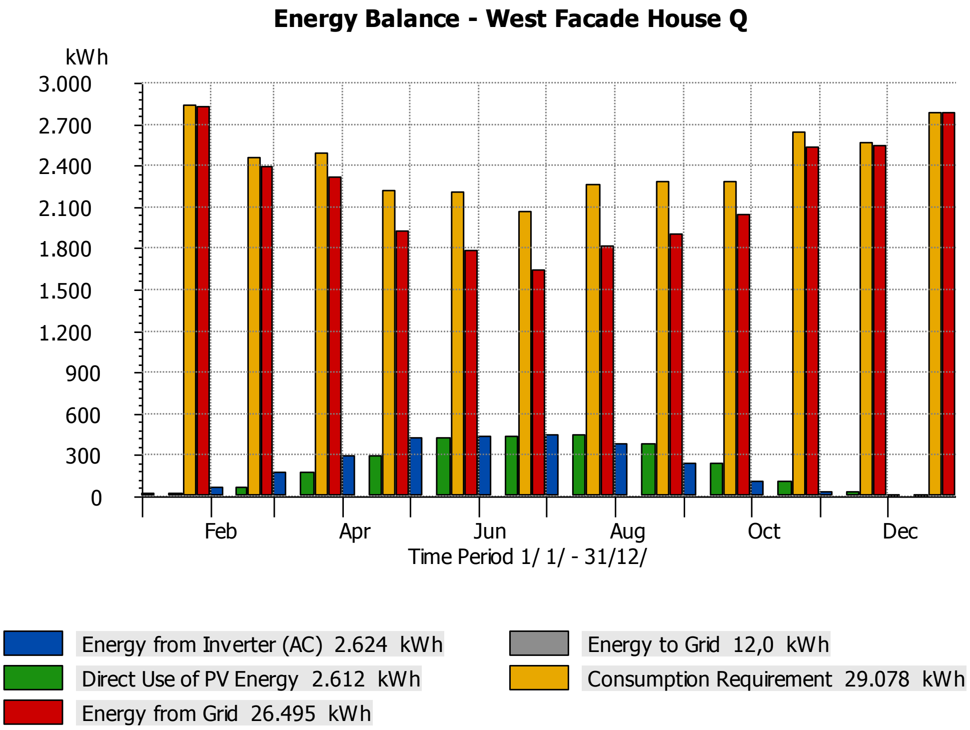


Fig. 5.56. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Eastern Facade (S5)

Next pictures show the location and layout of solar cell panels on this surface from a Southern-Eastern point of view. Next to this picture, the percentage of lost performance of each solar cell panel due to shading of other objects or buildings is shown.

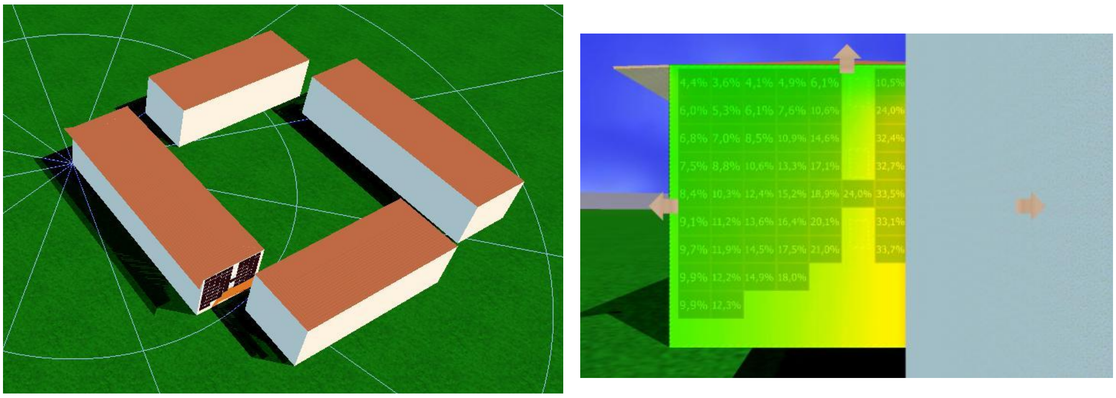


Fig. 5.57. Surface location and shading effect (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The picture below shows the main values of energy flow for this surface: the produced energy, the consumption requirement and the energy delivered from and to grid. Due to the very small energy production, no energy surplus is obtained.

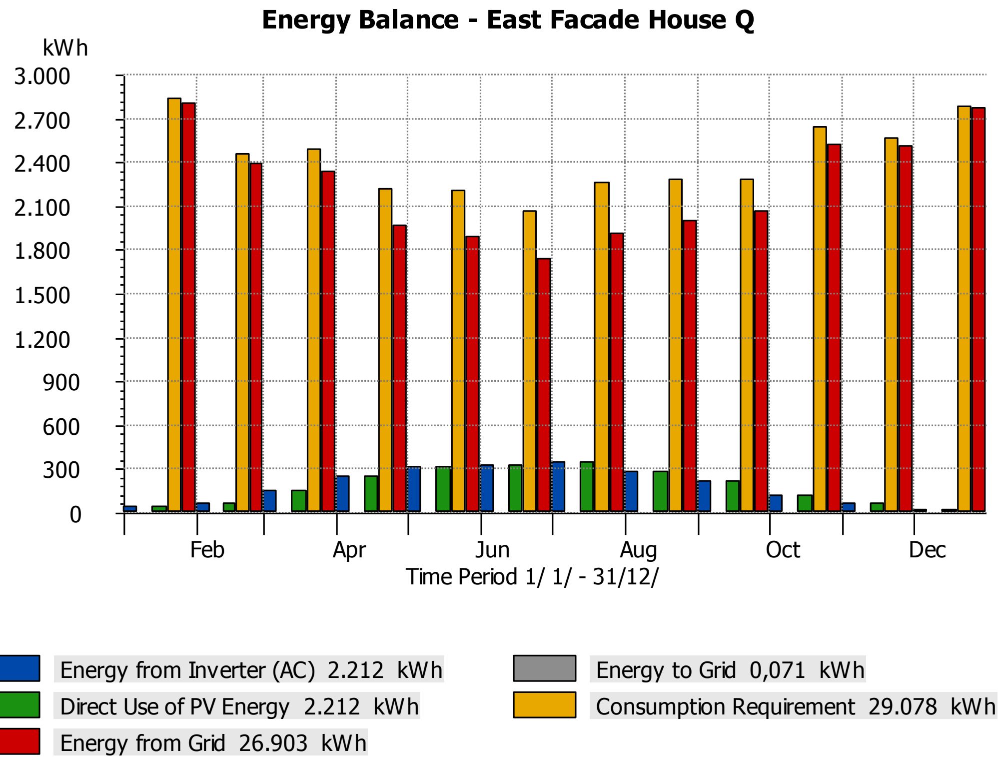


Fig. 5.58. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Southern Balconies (S7)

Next picture shows the location and layout of solar cell panels on this surface from a Southern point of view. On the figure below, the percentage of lost performance of each solar cell panel due to shading of other objects or buildings is shown.

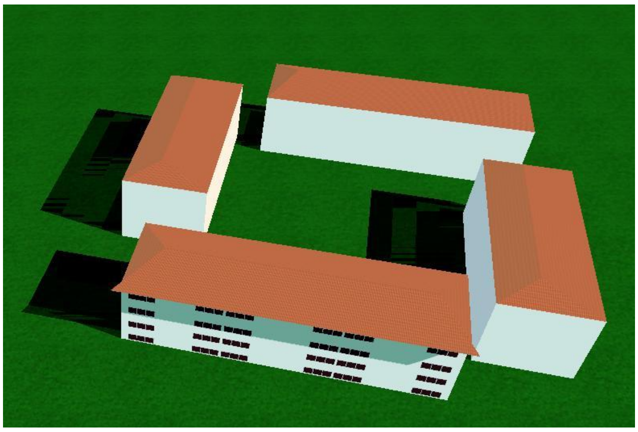


Fig. 5.59. Surface location (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

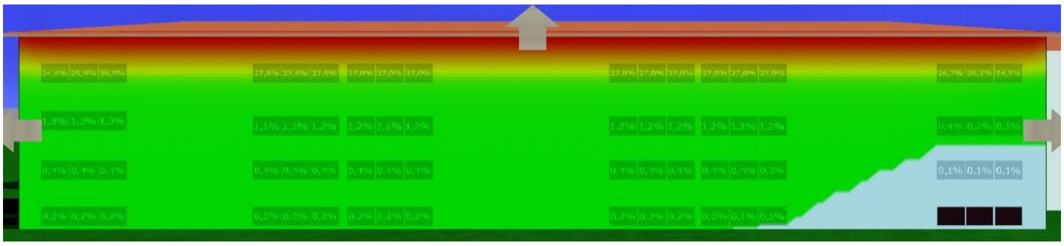


Fig. 5.60. Shading effect (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The picture below shows the main values of energy flow for this surface. The losses due to shading are significant on this surface. Due to the very small energy production, no energy surplus is obtained.

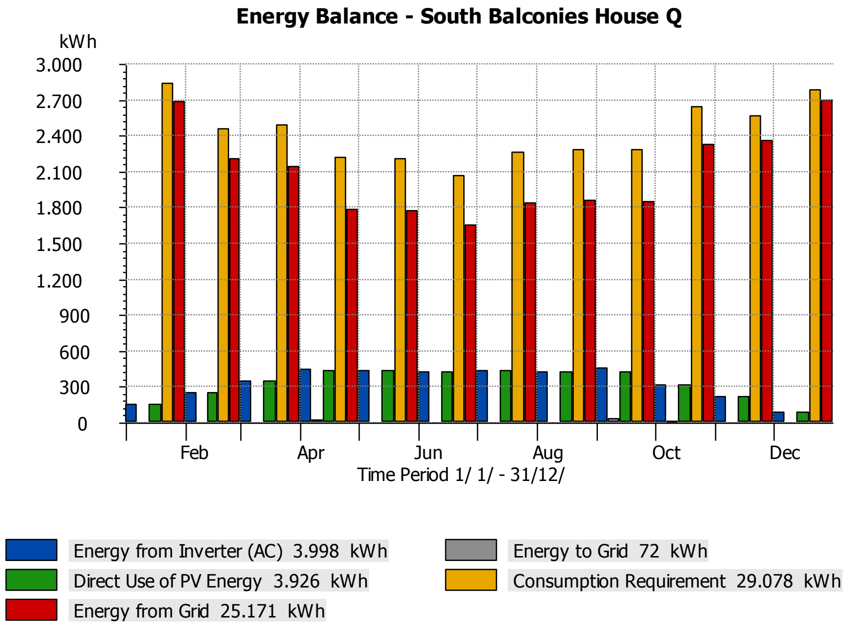


Fig. 5.61. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

5.4.2 Optimal energy production case

Next table compiles main parameters calculated for each surface.

HOUSE Q	S10 (W Roof)	S12 (W Facade)	S5 (E Facade)	S7 (S Balcony)	S8 (S Roof)	S9 (E Roof)
PV Output [kWp]	0.72	6.66	6.30	6.48	11.88	0.63
Gross PV Surface Area [m²]	11.44	105.82	100.10	102.96	188.76	10.01
Number of Modules	**8**	**74**	**70**	**72**	**132**	**7**
Orientation [°]	105.0	105.0	-75.0	15.0	15.0	-75.0
Inclination [°]	20.0	90.0	90.0	90.0	14.0	21.4
PV Array Irradiation [kWh/y]	9,809	54,014	50,134	78,954	193,944	9,397
Energy from Inverter (AC) [kWh/y]	**492**	**2,624**	**2,212**	**3,998**	**10,258**	**475**
Yield reduction due to shading [%]	1	2	32	4	1	2
Energy to Grid [kWh/y]	0	12	0	72	2,849	0
Energy from Grid [kWh/y]	28,593	26,495	26,903	25,171	21,689	28,610
Solar Fraction [%]	1.7	8.9	7.5	13.7	35.2	1.6
System Efficiency [%]	4.9	4.8	4.3	5.0	5.3	5.0
Performance Ratio [%]	80.5	78.2	70.6	82.0	85.9	81.1
Specific Annual Yield [kWh/kWp]	**674**	**390**	**345**	**614**	**862**	**744**
Array Efficiency [%]	5.6	5.5	5.0	5.5	5.7	5.6
Inverter Efficiency [%]	88.8	88.1	86.5	91.2	93.3	87.5
CO2 emissions avoided [kg/y]	298	1,597	1,335	2,463	7,061	288

Table 5.14. Main parameter results for all surfaces on House Q

The result analysis for all surfaces has been made under the following conditions:

- PV Modules: **SCHÜCO International KG MPE 90 AL 01**
- Mount: with ventilation
- Consumption requirement = **29 MWh/y**

As it can be seen from the table data, there are two surfaces with good performance regarding solar energy production: S8 and S9.

The first one, corresponding to Southern Roof, is the optimal as it can produce up to 10.3 MWh/y, however a storage system is required. The production of this surface represents the 35% of the total demanded energy.

S10 has a medium performance and its production level is low, however it may be considered as an option for implementation on the system.

All this means that depending on the grid topology (storage case or Net Metering case), the optimal solution can be different.

The best option for this building could be to integrate solar cell panels in Southern, Eastern and Western roofs (S8, S9 and S10). This system has been calculated with the same criteria as Houses N and P, and its results are shown in the following.

Maximum production without overproduction

The system is sized so that the surplus PV energy at any time is virtually zero, therefore no energy storage system is required.

For this idea the least consuming month and the highest PV energy production must be taken into account, resulting in June as the selected month. Moreover, as the condition is to avoid overproduction at any time, a hourly-based time resolution for the calculation is required.

In this case, the GERES system design will bring about the simplest and cheapest installation. Next pictures show the buildings layout and the solar cell panels layout on the Eastern roof of building Q:

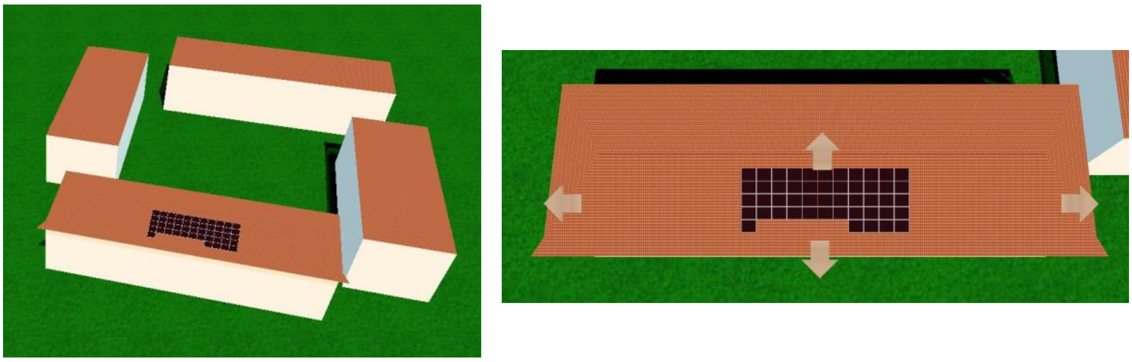


Fig. 5.62. Surface location (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The main parameters of this system are compiled on next table:

Location:	Alingsas_Brogarden - NOPQ	
Climate Data Record:	Alingsas_Brogarden - NOPQ (1981-2000)	
PV Output:	4,41	kWp
Gross/Active PV Surface Area:	70,07 / 71,75	m²
PV Array Irradiation:	71.994	kWh
Energy Produced by PV Array (AC):	3.773,3	kWh
Energy to Grid:	8,9	kWh
Consumption Requirement:	29.078	kWh
Direct Use of PV Energy:	3.764,4	kWh
Energy from Grid:	25.337,0	kWh
Yield Reduction Due to Shading:	1	%
Solar Fraction:	12,9	%
System Efficiency:	5,2	%
Performance Ratio:	84,7	%
Specific Annual Yield:	850,3	kWh/kWp
CO2 Emissions Avoided:	2.305	kg/a

Table 5.15. Main parameters system (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

A possible configuration may consist of a **49 Schüco MPE 90 AL 01 panels** array. This array is connected to two inverters of 2.2 kW each one.

The total installed power is 4.4 kWp, over an usable area around 70 m^2. All energy values on this table are on an annual basis.

This building demands 29 MWh/y, and the PV system generates 3.8 MWh/y, which is a small part of the demand. However the interesting parameter is the Energy to Grid, with a really small value of 8.9 kWh/y. This means that the PV system doesn´t produce surplus energy throughout the year.

The amount of energy supplied from the grid is 25 MWh/y.

These data show a solar fraction of 13% with respect to the demanded energy. The system efficiency is around 5.2%.

One of the most important parameters is the Specific Annual Yield, 850 kWh/kWp, which gives an idea of the energy and economical performance of the installation. This value represents the amount of energy the system can generate for each installed PV kWp.

Next pictures show the energy balance in different time periods. The first one shows the values throughout the year:

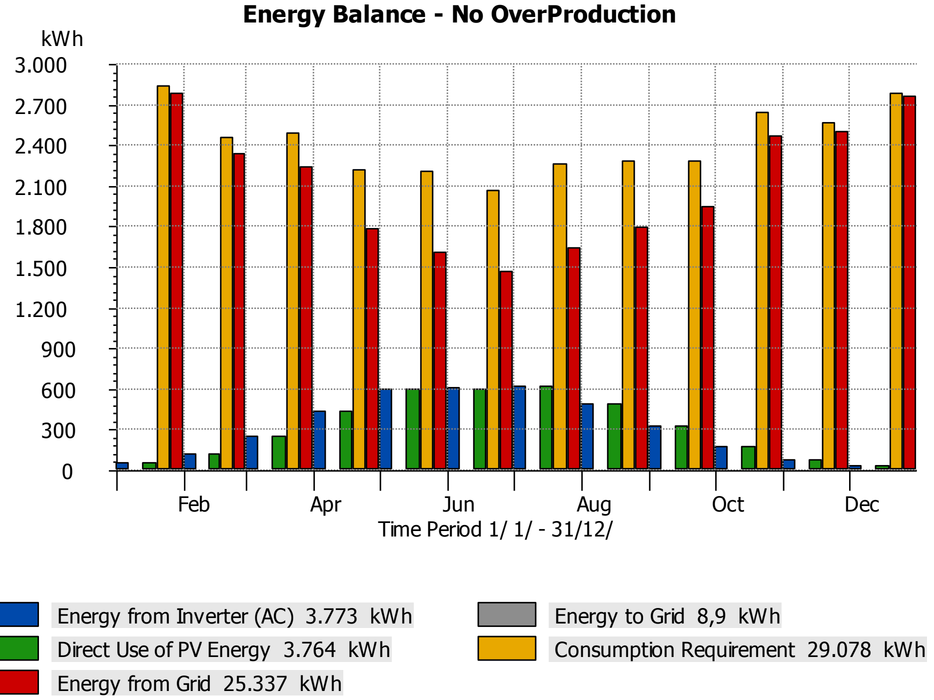


Fig. 5.63. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The second one shows the values corresponding to June, since this is the selected month for the energy flow balance.

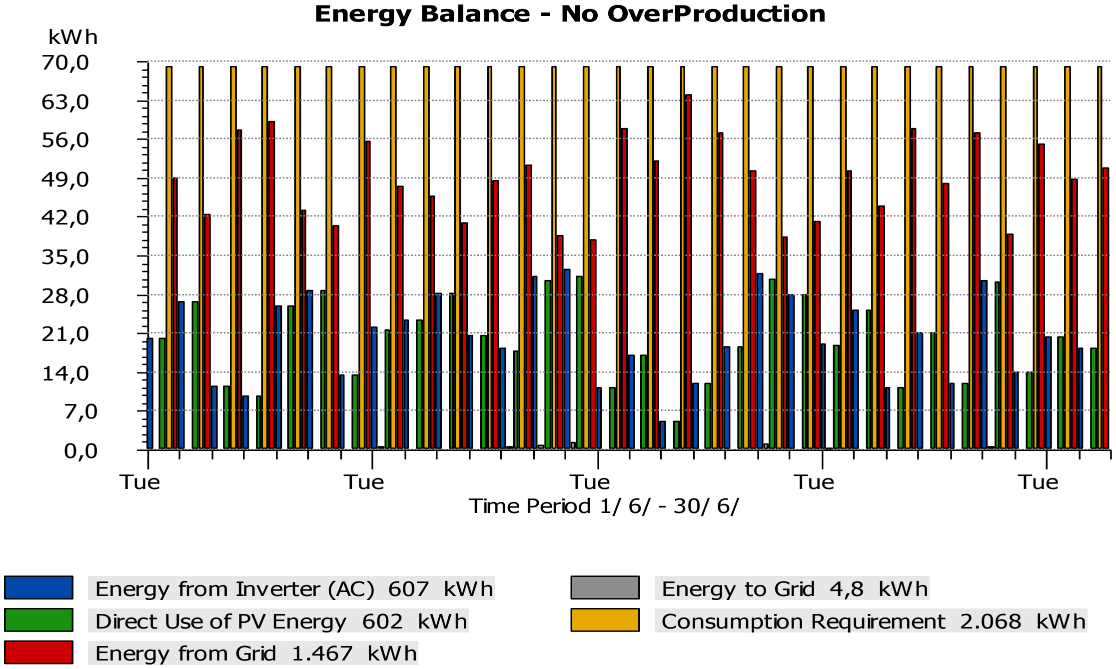


Fig. 5.64. Energy balance in June (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

It can be seen that the Energy to Grid value is almost zero, 4.8 kWh.

June consumption balanced with June production (storage case)

In this case, the electrical grid topology doesn´t buy the overproduced energy, so the system needs to store this surplus energy produced by the PV solar cell panels.

The system is sized in such a way that the produced PV energy in June equals the demanded energy. This means an energy storage system is required since every day there will be surplus production and not satisfied demand in real time.

For this idea the least consuming month and the highest PV energy production must be considered, resulting in June as the selected month. Moreover, as the condition is to avoid overproduction in June, a monthly-based time resolution for the calculation is required.

In this case, the GERES system design could bring about a very complex installation. The daily overproduced energy must be stored on batteries during the day and it must be used later during the night. So, the batteries must be charged and discharged every day.

The solar cell panels layouts are located on the Southern, Eastern and Western roofs of the building.

A **147** panel installation could be a possible configuration. These panels are connected to a battery regulator, the battery bus and the 7 kW inverter. The selected panel model is **Schüco MPE 90 AL 01**.

The battery bus consists of 20 batteries of 230 Ah, 12 V each one. So, the battery bus can store up to **55.2 kWh**.

The total installed power is 13.23 kWp, over an usable area around 210 m^2. All energy values on this table are on an annual basis.

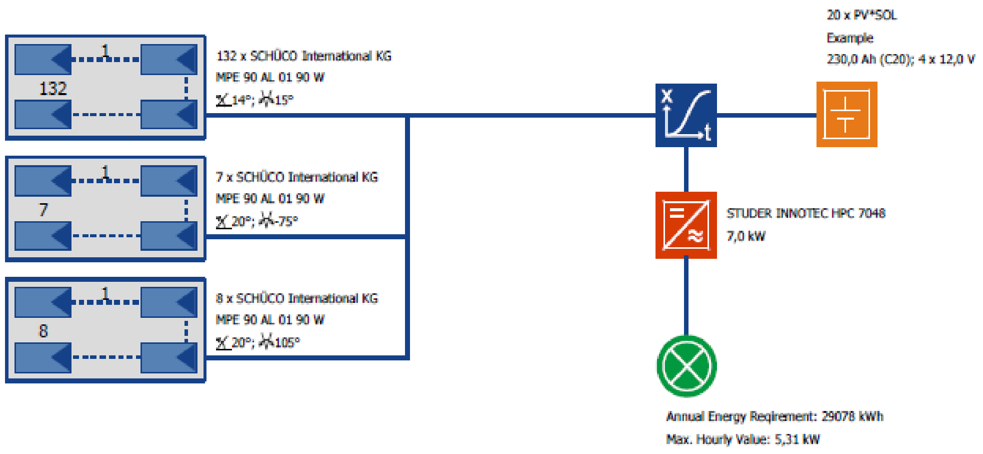
This building demands 29 MWh/y, and the PV system generates 9 MWh/y. Taking into account the losses and efficiencies of the storage system, the final energy provided by solar production is 8 MWh/y.

The amount of energy supplied from the grid is 21 MWh/y.

These data reveal a solar fraction of 29% with respect to the demanded energy. The system efficiency is around 3.8%.

One of the most important parameters is the Specific Annual Yield, 630 kWh/kWp, which gives an idea of the energy and economic performance of the installation. This value represents the amount of energy the system can generate for each installed PV kWp.

Next picture shows the topology scheme of the installation.



Location:	Alingsas_Brogarden - NOPQ	
Climate Data Record:	Alingsas_Brogarden - NOPQ (1981-2000)	
PV Output:	13,23	kWp
Gross/Active PV Surface Area:	210,21 / 215,25	m²
PV Array Irradiation:	219.579	kWh
Energy Produced by PV Array:	9.151,0	kWh
Consumption Requirement:	29.078	kWh
Consumption Covered by Solar Energy:	8.336,6	kWh
Consumption Not Covered by System:	20.741,4	kWh
Solar Fraction:	28,7	%
Performance Ratio:	61,8	%
Specific Annual Yield:	630,1	kWh/kWp
CO2 Emissions Avoided:	5.121	kg/a
System Efficiency:	3,8	%

Fig. 5.65. Topology scheme and main energy values (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next table shows the system parameters in more detail, specifying the array modules and components as well as the simulation results for the whole system related to the energy balance:

Array 1: South Roof

Output:	11,88 kW	Ground Reflection:(Annual Average)	13,4 %
Gross/Active Solar Surface Area:	188,8 m² / 193,3 m²	Output Losses due to...	
PV Module	132 x	deviation from AM 1.5:	1,0 %
Manufacturer:	SCHÜCO International KG	deviation from Manufacturer's Specification:	2,0 %
Model:	MPE 90 AL 01	in Diodes:	0,5 %
Nominal Output:	90 W	due to Pollution:	0,0 %
Power Rating Deviation:	0 %		
Efficiency (STC):	6,3 %		
No. of Modules in Series:	1		
MPP Voltage (STC):	74 V		
Orientation:	15,0 °		
Inclination:	14,0 °		
Mount:	with Ventilation		
Shade:	No		

Array 2: East Roof

Output:	0,63 kW	Ground Reflection:	20,0 %
Gross/Active Solar Surface Area:	10,0 m² / 10,3 m²	Output Losses due to...	
PV Module	7 x	deviation from AM 1.5:	1,0 %
Manufacturer:	SCHÜCO International KG	deviation from Manufacturer's Specification:	2,0 %
Model:	MPE 90 AL 01	in Diodes:	0,5 %
Nominal Output:	90 W	due to Pollution:	0,0 %
Power Rating Deviation:	0 %		
Efficiency (STC):	6,3 %		
No. of Modules in Series:	1		
MPP Voltage (STC):	74 V		
Orientation:	-75,0 °		
Inclination:	20,0 °		
Mount:	with Ventilation		
Shade:	No		

Array 3: West Roof

Output:	0,72 kW	Ground Reflection:	20,0 %
Gross/Active Solar Surface Area:	11,4 m² / 11,7 m²	Output Losses due to...	
PV Module	8 x	deviation from AM 1.5:	1,0 %
Manufacturer:	SCHÜCO International KG	deviation from Manufacturer's Specification:	2,0 %
Model:	MPE 90 AL 01	in Diodes:	0,5 %
Nominal Output:	90 W	due to Pollution:	0,0 %
Power Rating Deviation:	0 %		
Efficiency (STC):	6,3 %		
No. of Modules in Series:	1		
MPP Voltage (STC):	74 V		
Orientation:	105,0 °		
Inclination:	20,0 °		
Mount:	with Ventilation		
Shade:	No		

Battery

Manufacturer:	PV*SOL	Mean Charge Efficiency:	85,0 %
Model:	Example	Mean Discharge Efficiency:	99,0 %
Nominal Voltage:	12,0 V	Charge Controller	
C20 Capacity:	230,0 Ah	Lower Battery Discharge Threshold:	30,0 %
Self Discharge:	0,3 %/Tag		

Stand-Alone System Inverter

Manufacturer:	STUDER INNOTEC	Nom. DC Voltage:	48,0 V
Model:	HPC 7048	Stand-by Consumption:	0,0 W
AC Power Rating:	7,0 kW	Efficiency at Nominal Output:	96,0 %
Nom. AC Voltage:	230,0 V		

Appliances 1 (Load Profile)

Annual Requirement:	29.078 kWh	
Max. Hourly Value:	5,31 kW	
Weekend Consumption:	Saturday: 100 %	Sunday: 100 %
Consumption Profile:	Alingsas - NOPQ - Average daily profile	
Holiday Periods:	None	

Simulation Results for Total System

Irradiation onto Horizontal:	201.759 kWh	Battery Charge:	1.860 kWh
PV Array Irradiation:	219.579 kWh	Battery Losses:	313 kWh
Irradiation minus Reflection:	205.755 kWh	Charge Condition at Sim. Start:	23,7 %
Energy Produced by PV Array:	9.151 kWh	Charge Condition at Sim. End:	23,7 %
Consumption Requirement:	29.078 kWh	Solar Fraction:	28,7 %
Direct Use of PV Energy:	7.291 kWh	Performance Ratio:	61,8 %
Consumption Not Covered by System:	20.741 kWh	Final Yield:	1,7 h/d
PV Array Surplus:	0 kWh	Specific Annual Yield:	630 kWh/kWp
Consumption Covered by Solar Energy:	8.337 kWh	System Efficiency:	3,8 %
Battery Discharge:	1.547 kWh	Inverter Efficiency:	94,3 %
Battery Efficiency:	83,2 %		

Results for Array: South Roof

Array Irradiation:	199.617 kWh	Energy Produced (DC):	8.303 kWh
Array Efficiency:	4,2 %		

Results for Array: East Roof

Array Irradiation:	9.796 kWh	Energy Produced (DC):	417 kWh
Array Efficiency:	4,3 %		

Results for Array: West Roof

Array Irradiation:	10.165 kWh	Energy Produced (DC):	431 kWh
Array Efficiency:	4,2 %		

Table 5.16. Main array modules and components and the simulation results (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The charging energy in batteries throughout the year is 1.8 MWh, and the battery losses are 313 kWh, which means a battery efficiency around 83%.

Next pictures show the energy balance in different time periods. The first one shows the values throughout the year:

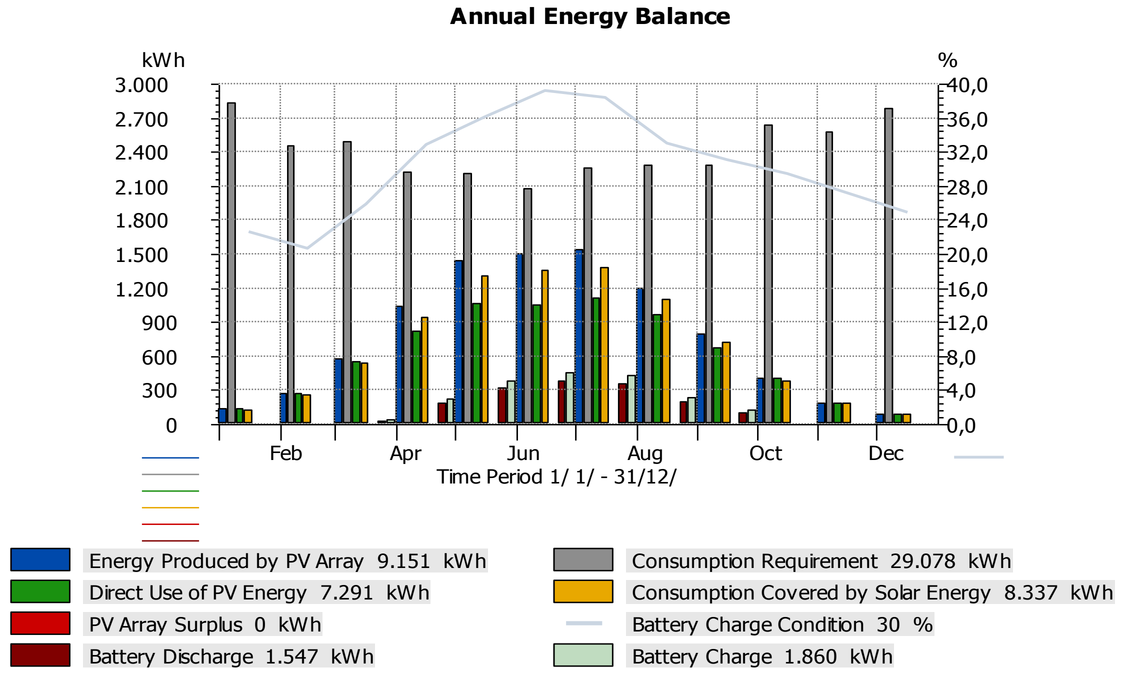


Fig. 5.66. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

It can be seen that the surplus energy from PV is 0 kWh/y, and the average battery charge condition is 30%.

The second picture shows the values corresponding to June, since this is the selected month for the energy flow balance.

The energy has not been completely balanced in June since a comparison of the values of the energy produced by PV array and the consumption requirement results in a difference around 700 kWh.

Finally the third one shows the day of June with the biggest charging condition in batteries.

It can be noticed that the energy stored during the day is consumed during the following night, so the battery bus is used under a daily charge-discharge cycle.

The battery bus is charging up to 90% at 17:00, and from this time on it is discharging down to 30% at 8:00 in the next morning.

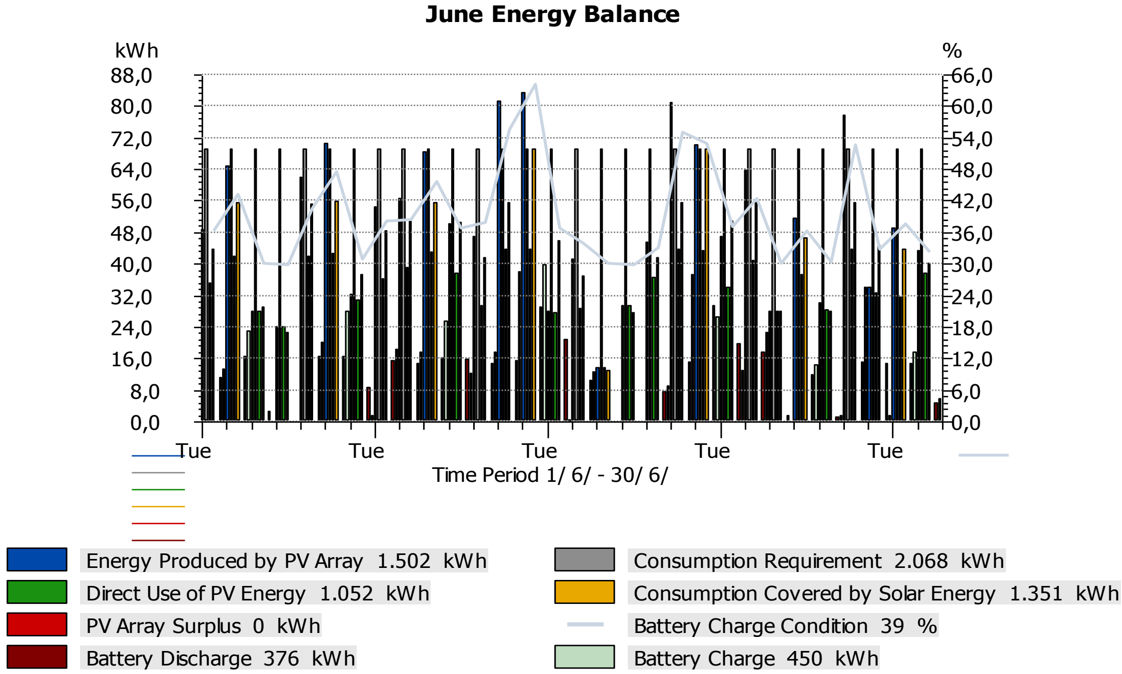
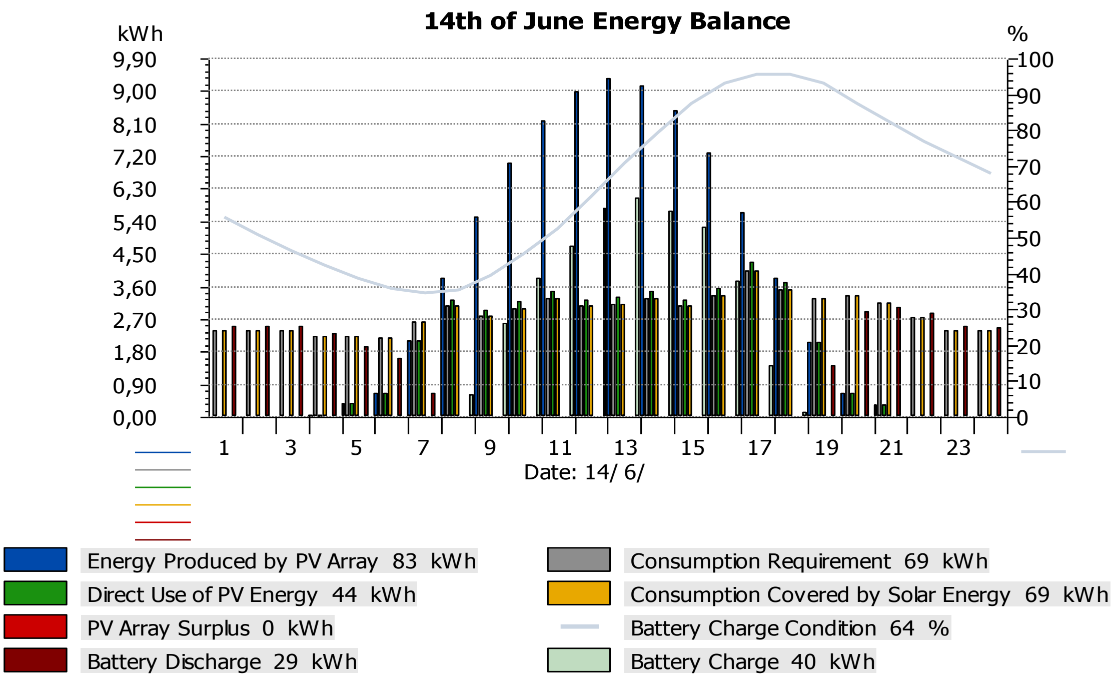


Fig. 5.67. Energy balance in June (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Fig. 5.68. Energy balance in biggest battery charge day of June (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])



June consumption balanced with June production (Net Metering case)

In the Net Metering case the electrical grid topology buys the overproduced energy. The total bought and sold energy from and to the grid is compared and compensated afterwards.

In this situation the system doesn´t need to store the surplus energy produced by the PV solar cell panels. This results in a very simple, cheap and efficient installation.

As the last storage case, the system is sized in such a way that the produced PV energy during June equals the demanded energy.

For this idea the least consuming month and the highest PV energy production must be taken into account, which results in June as the selected month. Moreover, as the condition is to avoid overproduction in June, a monthly-based time resolution for the calculation is required.

In this case, the GERES system design could be very simple. The daily overproduced energy must be delivered into the grid and at the same time the non-satisfied load at night must be taken from the grid.

The solar cell panels layout is located on the Southern, Eastern and Western roofs of the building.

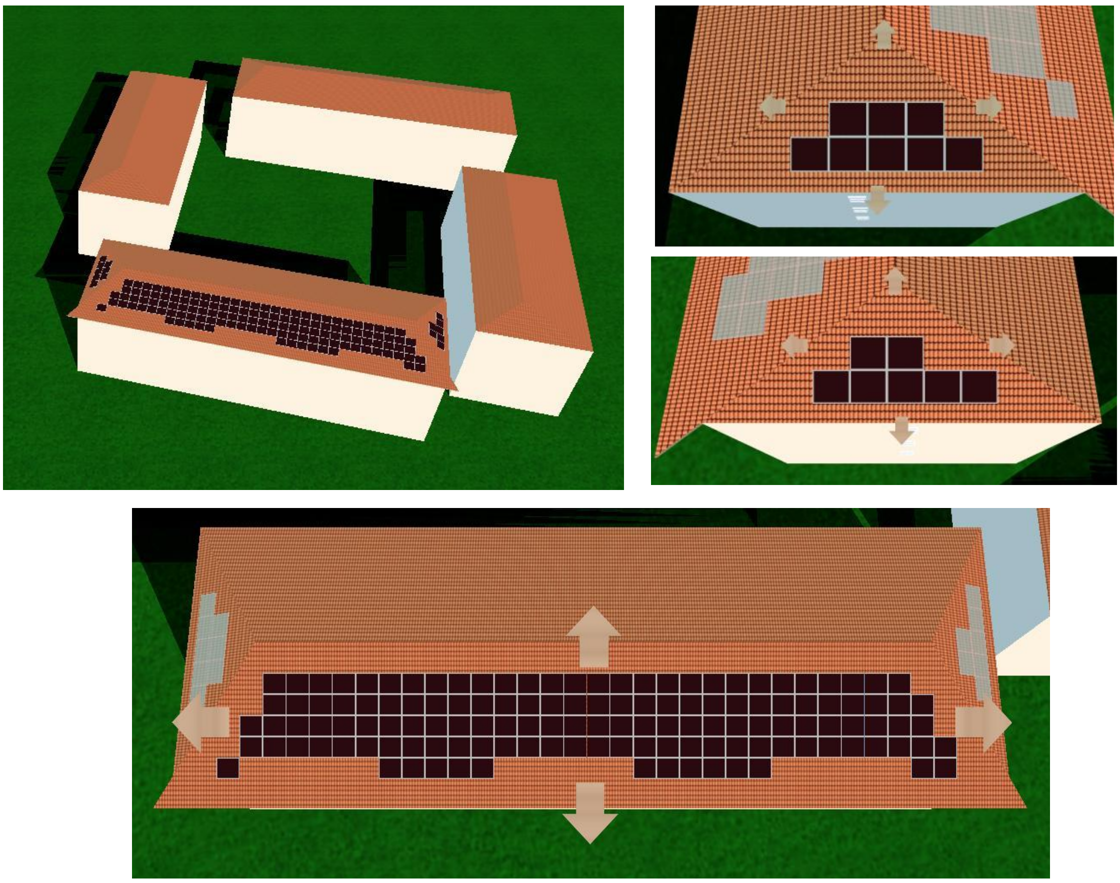
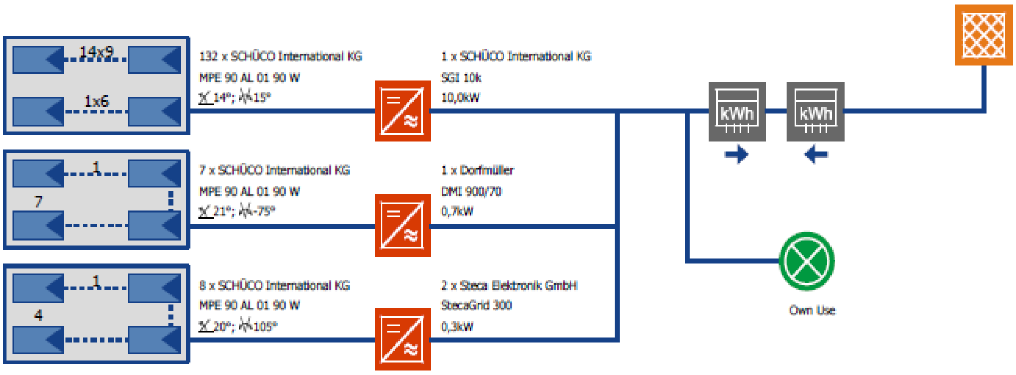


Fig. 5.69. Surface location (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Next picture shows the topology scheme of the installation and the main parameters calculated:



Location:	Alingsas_Brogarden - NOPQ	
Climate Data Record:	Alingsas_Brogarden - NOPQ (1981-2000)	
PV Output:	13,23	kWp
Gross/Active PV Surface Area:	210,21 / 215,25	m²

PV Array Irradiation:	213.176	kWh
Energy Produced by PV Array (AC):	11.210	kWh
Energy to Grid:	3.477,0	kWh
Consumption Requirement:	29.078	kWh
Direct Use of PV Energy:	7.733,4	kWh
Energy from Grid:	21.371,1	kWh
Yield Reduction Due to Shading:	1	%

Solar Fraction:	38,5	%
System Efficiency:	5,2	%
Performance Ratio:	85,4	%
Specific Annual Yield:	845,3	kWh/kWp
CO2 Emissions Avoided:	7.813	kg/a

Fig. 5.70. Topology scheme and main energy values (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Two counters can be found in the installation. One counter measures the input electrical energy to the system (energy bought from the grid), and the other one measures the energy sold to the grid by the system.

One valid configuration can consist of **147 solar cell panels Schüco MPE 90 AL 01** connected to four inverters of 11.3 kW on aggregate.

The total installed power is 13.23 kWp, over an usable area around 210 m^2. All energy values on this table are on an annual basis.

This building demands 29 MWh/y, and the PV system generates 11 MWh/y, which represents a 38.5% of the total load. The amount of energy delivered to the grid is 3.5 MWh/y and the amount of energy supplied from the grid is 21.3 MWh/y.

The system efficiency is around 5.2%, significantly higher than the one with storage system.

One of the most important parameters is the Specific Annual Yield, 845 kWh/kWp, which gives an idea of the higher energy and economic performance of this installation.

Next picture shows the energy balance throughout the year:

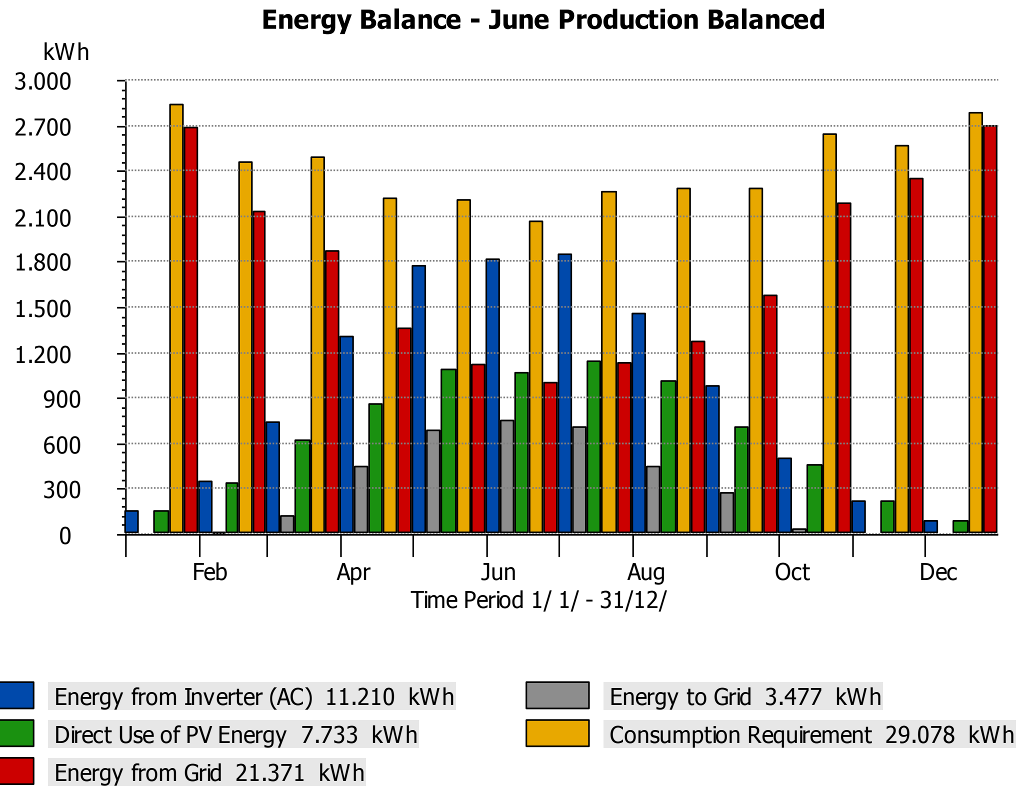


Fig. 5.71. Energy balance throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

On this figure, the whole last values of different energies can be seen.

The next one shows the values corresponding to June, since this is the selected month for the energy flow balance.

The consumption requirement in June is 2 MWh, and the produced energy is 1.8 MWh. On the other hand, the energy delivered to the grid is 746 and the energy taken from the grid is 1 MWh. As a result, June is not completely balanced though near this point.

Also, it can be noticed that there are 11 days with overproduction and other 19 days with lack of energy, however at the end of the month the energy flow is well balanced.

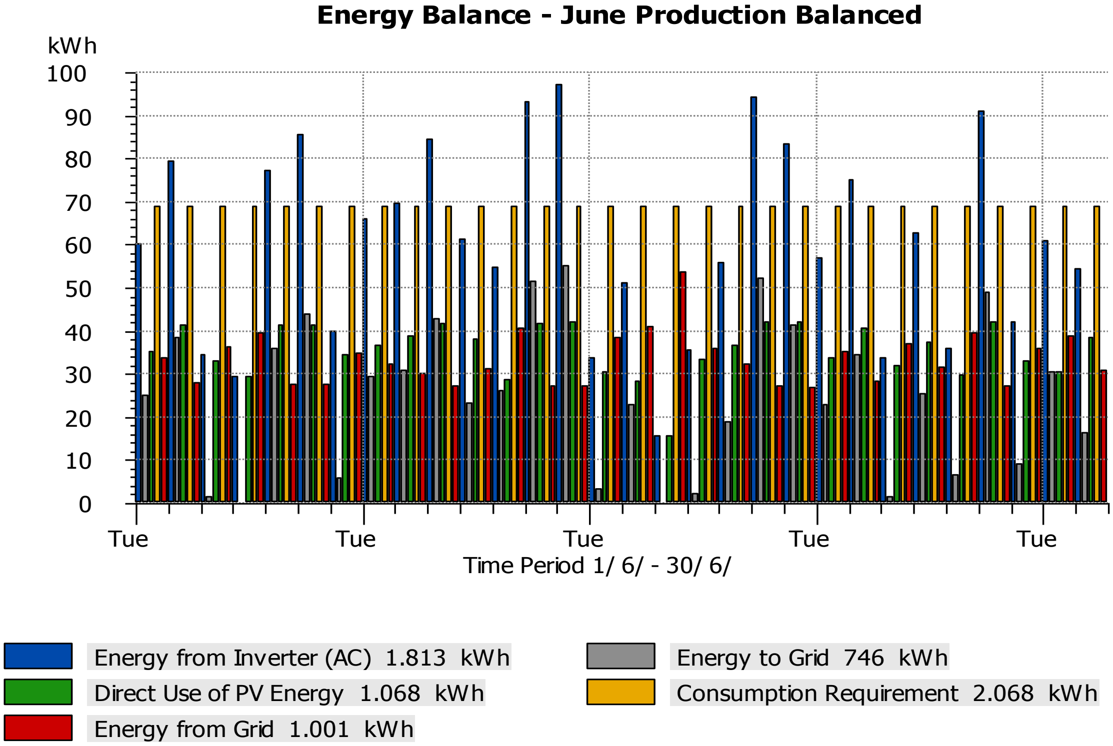


Fig. 5.72. Energy balance in June (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Remark!

With the same PV solar cell panels sizing, the system with batteries gets 10% less solar fraction than the Net Metering case.

5.5 Other considerations

5.5.1 Shadows

When the performance of a PV solar system is to be calculated, the produced shadows of other buildings or objects over the PV array must be taken into account.

In this analysis, other buildings on the group NOPQ and some very simple objects on roofs have been included in the simulation. There are however a lot of other objects on roofs and other nearby buildings or trees that should be taken into account for the complete simulation.

As an example of the shadow effect over the PV cell panel performance, below picture shows the reduction percentage of performance for each panel.

Graphically, a colour gradient is used. The green colour represents a very small reduction, whereas on the other side the red colour represents a significant reducing performance.

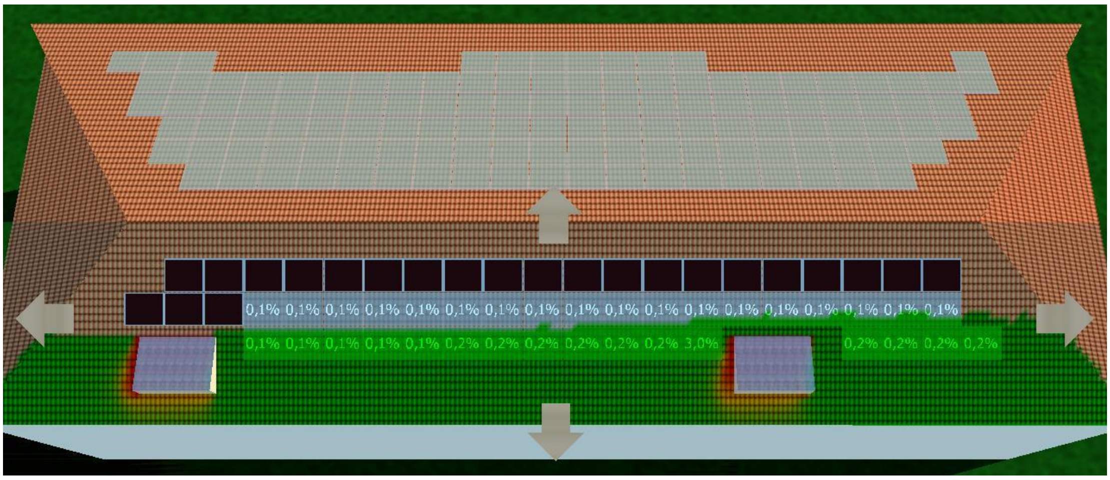


Fig. 5.73. Example of shadows projection over the PV cell panels layout (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

5.5.2 Cabling connections

A significant percentage of performance losses in a PV system are produced by the topology of connection layout among all the components (PV cell panel strings, inverters, regulators, batteries, ..).

Each system may have many possible ways of connecting the elements, so selecting the optimal one is not an easy task. In this report, different valid configurations for each system have been analyzed, though the optimal layout would require further analysis.

As an example of a possible layout to connect the strings in a PV cell panel array, next picture shows a PV cell panels layout on the roof divided into strings. Each string consists of a number of panels (three, in this case) with the same colour.

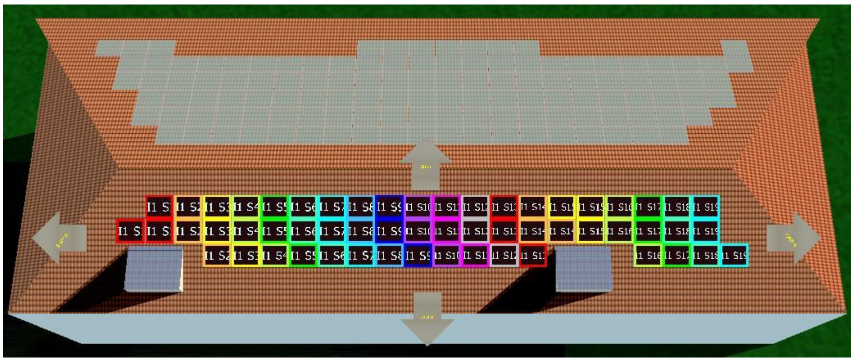


Fig. 5.74. Example of PV cell panels strings connection (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

The panels in each string are connected together in a serial way and the string output is connected to the input of an inverter (or battery regulator .., depending on the topology).

This roof could also be connected by strings bigger or smaller than the showed one, and the connection among PV cell panels could be both horizontal, vertical or any other way the installer decides. So, the number of combinations is virtually infinite.

5.5.3 Solar horizon

Another important issue to consider for real performance calculation in a PV installation is the solar horizon. This is the effect of the landscape contour over the sun path.

Depending on each location, the solar horizon could be a really important parameter in performance reduction, especially in mountain areas.

This aspect is usually considered in the calculations by taking some pictures over 360º from the surface itself, mainly roof surfaces (facades and balconies are more difficult to take). An especial camera may be used to take these pictures.

Nevertheless, for Brogården site the solar horizon is not very important, as this city is located on a more or less flat valley surrounded mainly by forests with lakes and low far away mountains. This can be verified on the photos below taken from Google Earth in a road place near Brogården. It must be taken into account that the real point of view over the roofs has to be risen around 10 meters with respect to the picture point of view.[11]

Towards the North, the slope is arising:

Fig. 5.75. Northern view from place close to Brogården (© 2012 Google)

The photo below shows the western side of House P visible behind the Lidl building, as well as the House Q roof. Therefore towards the East the landscape is basically flat:

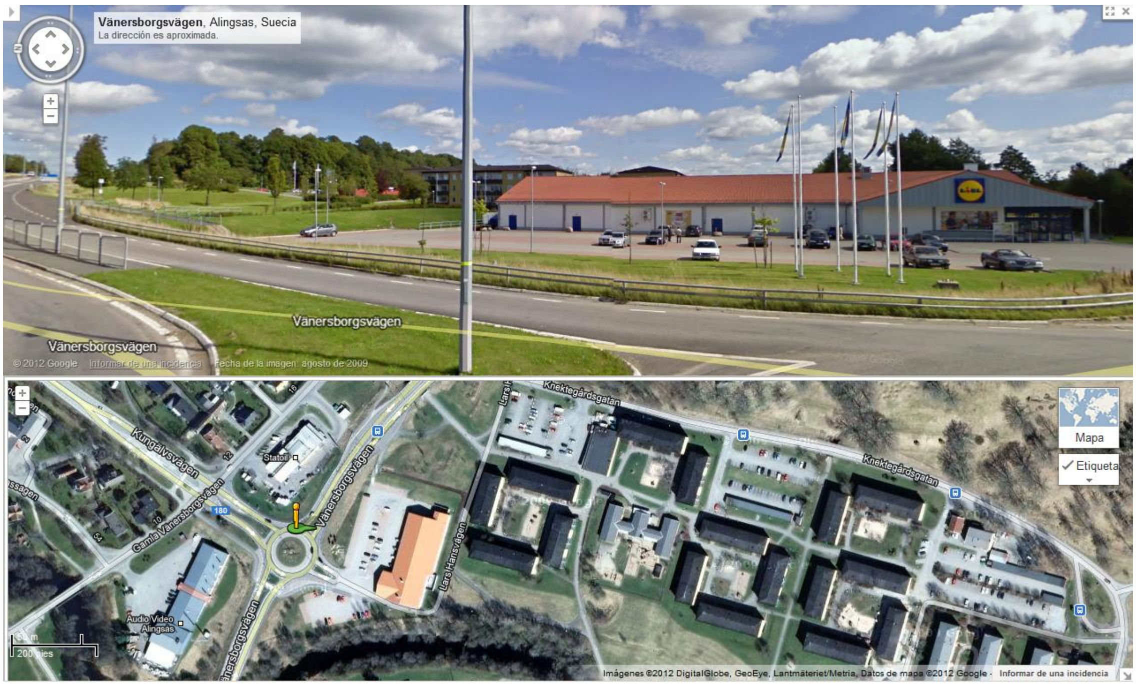


Fig. 5.76. Eastern view from place close to Brogården (© 2012 Google)

The Southern view shows a very flat landscape:

Fig. 5.77. Southern view from place close to Brogården (© 2012 Google)

Similar remarks can be made with the Western view:

Fig. 5.78. Western view from place close to Brogården (© 2012 Google)

5.5.4 Constructive elements

The available area for each surface has been estimated from the constructive plans for the roofs taking into account a number of objects placed on it, though many objects such as roof ladders, roof ducts, fire-gas fans, snow guards and roof caps might be an obstacle when mounting the solar cells. In fact they could even reduce the available area in a real calculation. By eventual implementation more thorough calculations would be necessary.

5.5.5 Common PV cell panel parameters

There are a number of parameters regarding the PV cell panels configuration to be adjusted for real situation (deviation from manufacturer´s yield, pollution, ..).

Albedo values (representing the sun light reflected on the ground) have been taken from NASA-SEE data.

There are other parameters such like the height of systems installed on the roofs, the length of the cabling between PV cell panels and the inverter, its cross section, and the type of installation. Free-Standing involves the PV cell panel to be mounted on a metallic structure with rear ventilation and optimal inclination (this is the best performance). On the other hand, without ventilation involves PV cell panels integrated with the roof construction material (this is the worst performance). Finally, with ventilation involves an intermediate case, where the PV cell panel is mounted on the roof construction material.

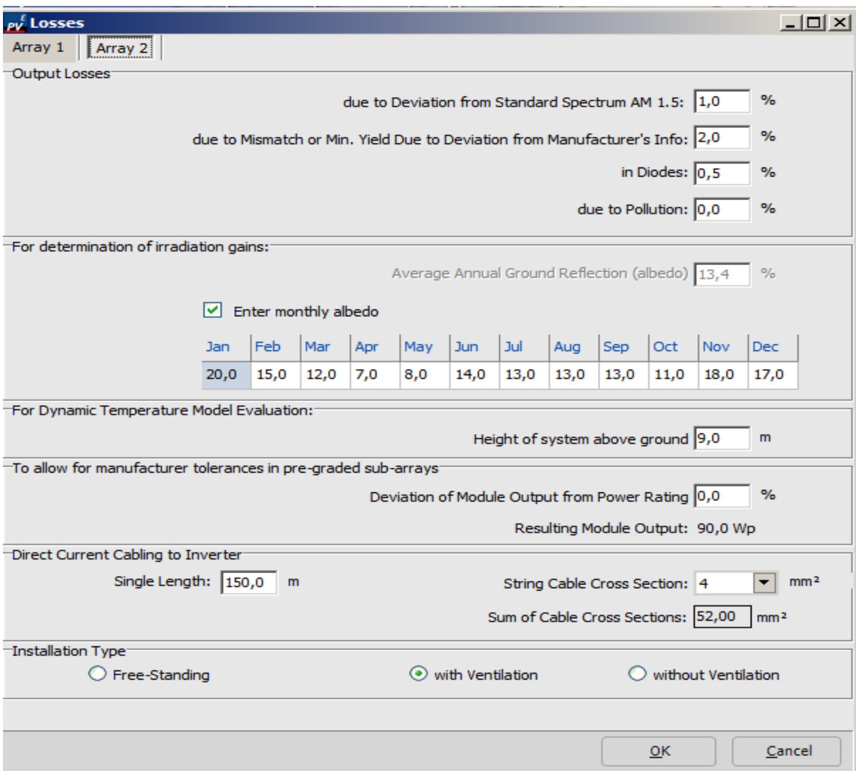


Fig. 5.79. Common PV cell panel parameters (Screenshot done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

5.5.6 Optimal inclination angle

Changing the inclination angle both in facades and balconies is not a logical solution for mounting reasons, except for its implementation on roofs.

All calculations and simulations have been made with fixed roof inclination angles (14º or 20º depending on the slope), since the PV cell panel installation is mounted over the roof construction material.

However, it is also possible to install the panels on a metallic structure and leaving the inclination angle as an adjustable parameter. This allows the selection of the best angle which improves the solar irradiation. Next picture shows the optimal angle depending on the month:

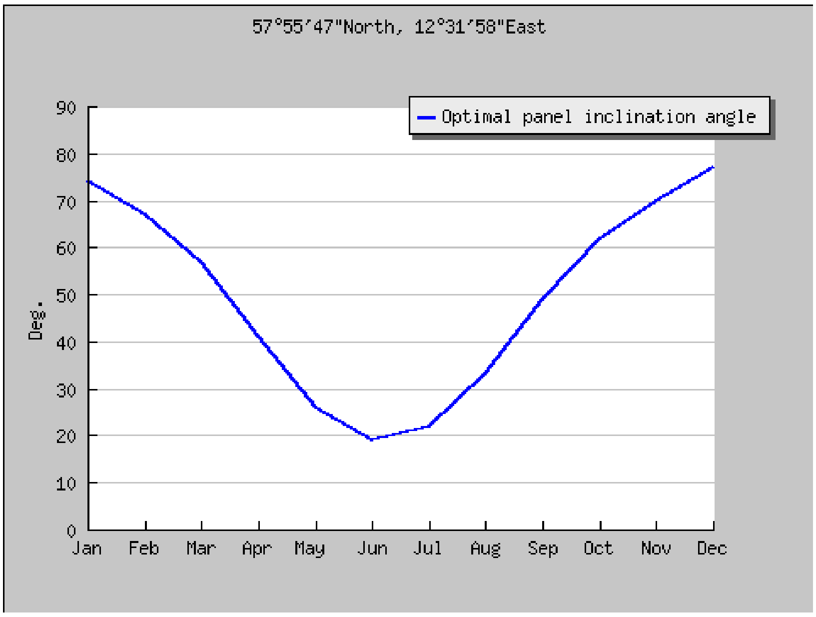


Fig. 5.80. Optimal inclination angle throughout the year (© PVGIS - European Union, 1995-2012)

The optimal angle for the whole year is **41º**. However, considering that in winter the solar irradiation is virtually negligible, a summer oriented system would be a better option, with an optimal inclination angle of **32º**.

Next table shows the solar irradiation during summer time (kWh/m^2/day):

	April	May	June	July	August	September	AVG
H(14º)	4,38	5,26	5,50	4,93	4,09	3,04	**4,53**
H(41º)	4,87	5,14	5,26	4,85	4,28	3,50	**4,65**
H(32º)	4,82	5,24	5,43	4,98	4,30	3,41	**4,69**

Table 5.17. Solar irradiation in different inclination angles during summer time

Since the improvement is not very important (2,5% - 3,6%), it would be interesting to evaluate the economical impact of the investment.

5.5.7 System efficiency

As it has been mentioned previously on chapter 4, the PV technology is still growing and improving its performance, lowering prices and rising applications.

The PV cell panel model selected for calculations on this analysis belongs to an intermediate group (Efficiency = 6,5%), so there are other PV cell panel models with better efficiencies in the same conditions (up to 15% or even more).

Of course, PV cell panels are not the only element to be improved in the installation. There are other models of battery regulators, batteries, inverters and so on, which have offered higher efficiencies in the same conditions.

This involves that the total system efficiency can be improved by changing the corresponding elements, though it would probably increase the total installation cost.

5.6 Economic analysis

In this section, a simple economic review is exposed, including different systems shown before for each building. Net Metering cases are not to be analyzed since the real conditions and prices contracted with the electrical supply company are not available and this would bring about a significant uncertainty to the results of the analysis.

Nevertheless, in all the cases the possibility to apply for **funds is available for solar installations**. In Sweden, in the case of big companies, the maximum funding can reach up to **55% of the investment cost**, or a maximum of **226,000 € (2,000,000 SEK)** per solar cell system. The connection of the system to an internal grid at the real state or an external grid sets the limit, as well as the maximum cost per installed kWp, around **8,500 € (75,000 SEK)**. The application for funding is issued at the county administrative board. These conditions were used for the calculations included on this report, but lately they have been revised and new calculations will be included in the next report D4.5.

An important parameter for economical analysis is the **current Swedish tariff for buying electricity**. As different sources (November 2011) on the Internet state, this value can reach, for the electricity cost in households, up to around **0.2066 €/kWh (1.82 SEK/kWh)**, all taxes included.[12] This price applies for individual households, and it may be reduced in a bigger contract for all buildings in Brogården. This value will be revised in the next report D4.5., and added to economic analysis recalculation.

The investment cost of the equipment and installation have been estimated around 3,900 €/kWp (without storage system) or around 4,150 €/kWp + 300 €/battery (with storage system). These values have been taken from web shops on the internet (February 2012), and they apply for shopping by units, though shopping by high quantities is expected to be lowered in a 10% or even more. As a result, the final price considered in the analysis reaches **3,500 €/kWp** (without storage system) or **3,700 €/kWp + 270 €/battery** (with storage system).

In the end, the analysis has been done without taking into account any kind of **loans**, though they should be included in a real economic analysis.

With all these data in mind the economic analysis for each building is shown below.

5.6.1 House N

Maximum production without using any storage system

The main parameters calculated for this installation are:

Installed Power	= 2.25 kWp
Energy Produced by PV Array (AC)	= 1,773 kWh/y
Consumption Requirement	= 14,006 kWh/y
Direct Use of PV Energy	= 1,755 kWh/y
Energy from Grid	= 12,268 kWh/y
Solar Fraction	= 12.5%
Specific Annual Yield	= 781 kWh/kWp

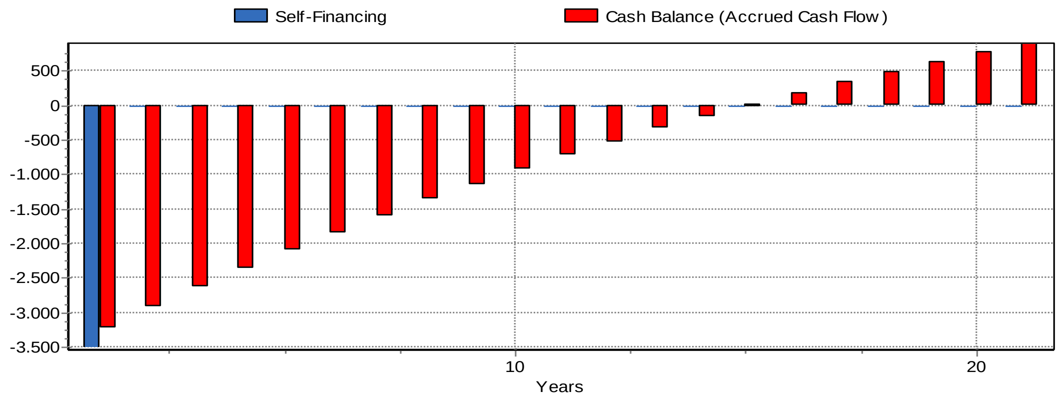


Fig. 5.81. Self-Financing and Cash Flow Balance (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Position	Total [€]	Year 1	Year 5	Year 10	Year 15	Year 20
Self-Financing	-3,543.75	-3543.75	0.00	0.00	0.00	0.00
Electricity Savings	5,292.53	366.14	312.30	255.36	208.17	167.04
Total Investments	-7,875.00	-7875.00	0.00	0.00	0.00	0.00
Total Operating Costs	-849.75	-53.52	-47.55	-41.02	-35.38	-30.52
Total Subsidies	4,331.25	4331.25	0.00	0.00	0.00	0.00
Cash Balance (Accrued Cash Flow)	899.03	-3231.13	-2102.62	-933.98	9.85	766.48

Table 5.18. Economic Efficiency Evolution throughout operating period (Values calculated with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Results according to Net Present Value method:

Net Present Value:	**899.03 €**
Payback Period:	**14.9 Years**
Yield:	**5.5 %**
Electricity Production Costs:	**0.16 €/kWh**

June consumption balanced with June production (storage case)

The main parameters calculated for this installation are:

Installed Power	= 9.72 kWp
Number of Batteries	= 28 (230 Ah 12V)
Energy Produced by PV Array (AC)	= 6,300 kWh/y
Consumption Requirement	= 14,006 kWh/y
Consumption Covered by PV Energy	= 5,277 kWh/y
Consumption Covered by Grid	= 8,729 kWh/y
Solar Fraction	= 37.7%
Specific Annual Yield	= 543 kWh/kWp

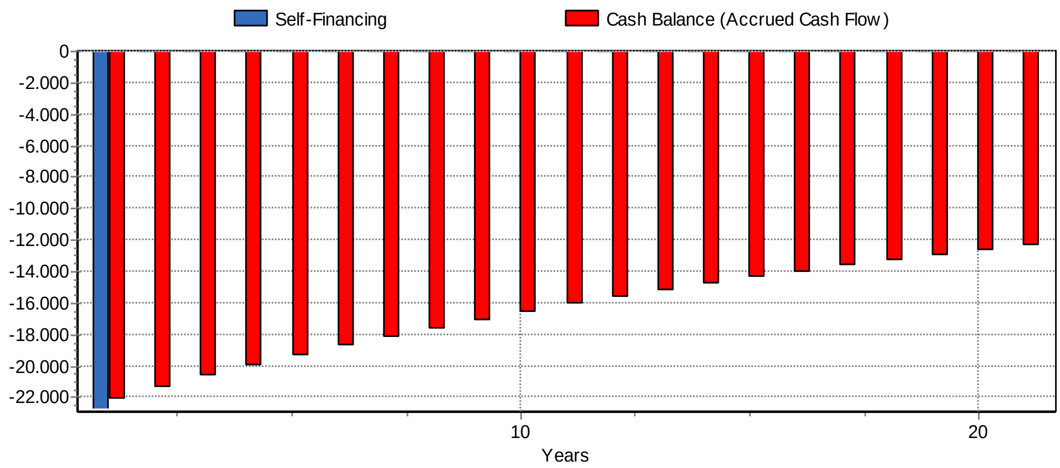


Fig. 5.82. Self-Financing and Cash Flow Balance (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Position	Total [€]	Year 1	Year 5	Year 10	Year 15	Year 20
Self-Financing	-22,915.80	-22915.80	0.00	0.00	0.00	0.00
Stored Energy Savings	5,367.39	371.17	316.59	258.87	211.03	171.46
Direct Energy Savings	10,622.71	734.88	626.81	512.53	417.82	335.27
Total Investments	-50,924.00	-50924.00	0.00	0.00	0.00	0.00
Total Operating Costs	-5,494.96	-346.09	-307.49	-265.25	-228.80	-197.37
Total Subsidies	28,008.20	28008.20	0.00	0.00	0.00	0.00
Cash Balance (Accrued Cash Flow)	-12,420.67	-22155.83	-19432.23	-16652.30	-14448.42	-12718.96

Table 5.19. Economic Efficiency Evolution throughout operating period (Values calculated with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Results according to Net Present Value method:

Net Present Value:	**-12,420.67 €**
Payback Period:	**more than 20 years**
Electricity Production Costs:	**0.35 €/kWh**

5.6.2 House O

Maximum production without using any storage system

In this house there is only a single solution. The main parameters calculated for this installation are:

Installed Power	= 10.62 kWp
Energy Produced by PV Array (AC)	= 9,118 kWh/y
Consumption Requirement	= 59,462 kWh/y
Direct Use of PV Energy	= 8,904 kWh/y
Energy from Grid	= 50,584 kWh/y
Solar Fraction	= 15.3%
Specific Annual Yield	= 856 kWh/kWp

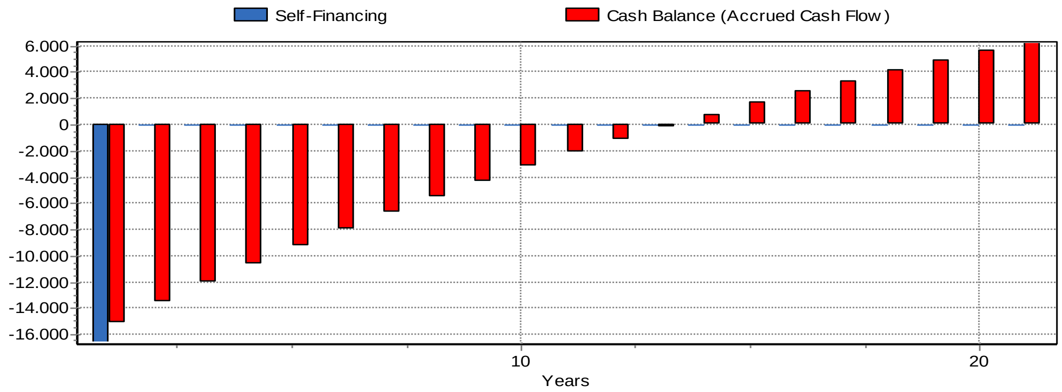


Fig. 5.83. Self-Financing and Cash Flow Balance (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Position	Total [€]	Year 1	Year 5	Year 10	Year 15	Year 20
Self-Financing	-16,726.50	-16726.50	0.00	0.00	0.00	0.00
Electricity Savings	27,027.53	1869.77	1594.81	1304.05	1063.08	853.04
Total Investments	-37,170.00	-37170.00	0.00	0.00	0.00	0.00
Total Operating Costs	-4,010.84	-252.61	-224.44	-193.61	-167.01	-144.06
Total Subsidies	20,443.50	20443.50	0.00	0.00	0.00	0.00
Cash Balance (Accrued Cash Flow)	6,290.20	-15109.34	-9269.39	-3217.24	1675.27	5601.87

Table 5.20. Economic Efficiency Evolution throughout operating period (Values calculated with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Results according to Net Present Value method:

Net Present Value:	**6,290.20 €**
Payback Period:	**13.2 Years**
Yield:	**6.7 %**
Electricity Production Costs:	**0.15 €/kWh**

5.6.3 House P

Maximum production without using any storage system

The main parameters calculated for this installation are:

Installed Power	= 2.16 kWp
Energy Produced by PV Array (AC)	= 1,648 kWh/y
Consumption Requirement	= 14,006 kWh/y
Direct Use of PV Energy	= 1,645 kWh/y
Energy from Grid	= 12,370 kWh/y
Solar Fraction	= 11.7%
Specific Annual Yield	= 759 kWh/kWp

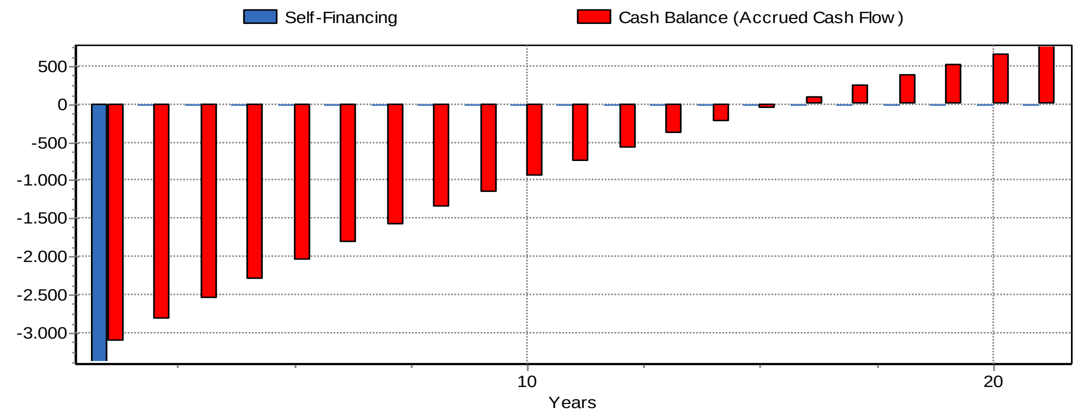


Fig. 5.84. Self-Financing and Cash Flow Balance (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Position	Total [€]	Year 1	Year 5	Year 10	Year 15	Year 20
Self-Financing	-3,402.00	-3402.00	0.00	0.00	0.00	0.00
Electricity Savings	4,981.35	344.61	293.94	240.35	195.93	157.22
Total Investments	-7,560.00	-7560.00	0.00	0.00	0.00	0.00
Total Operating Costs	-815.76	-51.38	-45.65	-39.38	-33.97	-29.30
Total Subsidies	4,158.00	4158.00	0.00	0.00	0.00	0.00
Cash Balance (Accrued Cash Flow)	763.59	-3108.77	-2050.35	-954.51	-69.71	639.40

Table 5.21. Economic Efficiency Evolution throughout operating period (Values calculated with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Results according to Net Present Value method:

Net Present Value:	**763.59 €**
Payback Period:	**15.4 Years**
Yield:	**5.2 %**
Electricity Production Costs:	**0.17 €/kWh**

June consumption balanced with June production (storage case)

The main parameters calculated for this installation are:

Installed Power	= 6.84 kWp
Number of Batteries	= 28 (230 Ah 12V)
Energy Produced by PV Array (AC)	= 4,345 kWh/y
Consumption Requirement	= 14,006 kWh/y
Consumption Covered by PV Energy	= 3,882 kWh/y
Consumption Covered by Grid	= 10,124 kWh/y
Solar Fraction	= 27.7%
Specific Annual Yield	= 568 kWh/kWp

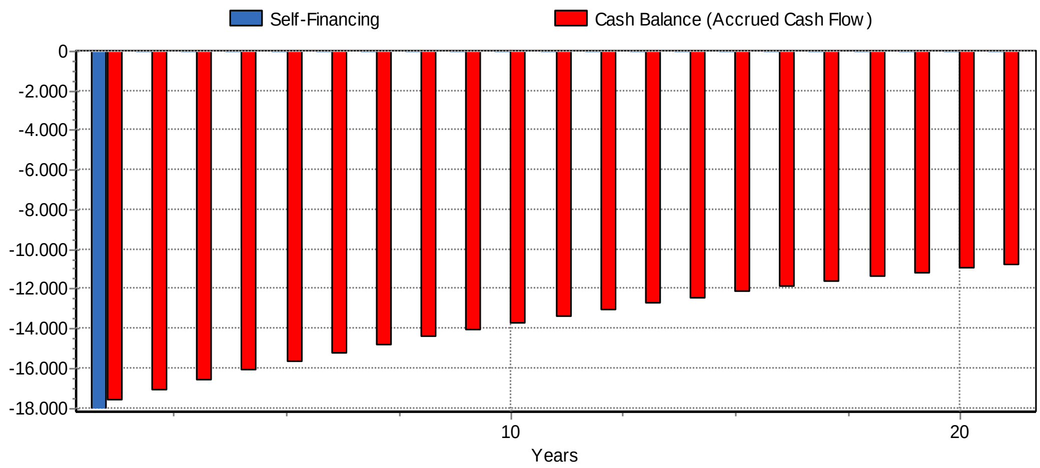


Fig. 5.85. Self-Financing and Cash Flow Balance (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Position	Total [€]	Year 1	Year 5	Year 10	Year 15	Year 20
Self-Financing	-18,192.60	-18192.60	0.00	0.00	0.00	0.00
Stored Energy Savings	1,366.10	94.47	80.58	65.89	53.71	43.64
Direct Energy Savings	10,361.96	716.84	611.43	499.95	407.57	327.04
Total Investments	-40,428.00	-40428.00	0.00	0.00	0.00	0.00
Total Operating Costs	-4,362.39	-274.75	-244.11	-210.58	-181.64	-156.69
Total Subsidies	22,235.40	22235.40	0.00	0.00	0.00	0.00
Cash Balance (Accrued Cash Flow)	-10,826.94	-17656.04	-15735.88	-13781.76	-12238.50	-11034.17

Table 5.22. Economic Efficiency Evolution throughout operating period (Values calculated with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Results according to Net Present Value method:

Net Present Value:	**-10,826.94 €**
Payback Period:	**more than 20 years**
Electricity Production Costs:	**0.30 €/kWh**

5.6.4 House Q

Maximum production without using any storage system

The main parameters calculated for this installation are:

Installed Power	= 4.41 kWp
Energy Produced by PV Array (AC)	= 3,773 kWh/y
Consumption Requirement	= 29,078 kWh/y
Direct Use of PV Energy	= 3,765 kWh/y
Energy from Grid	= 25,337 kWh/y
Solar Fraction	= 12.9 %
Specific Annual Yield	= 850 kWh/kWp

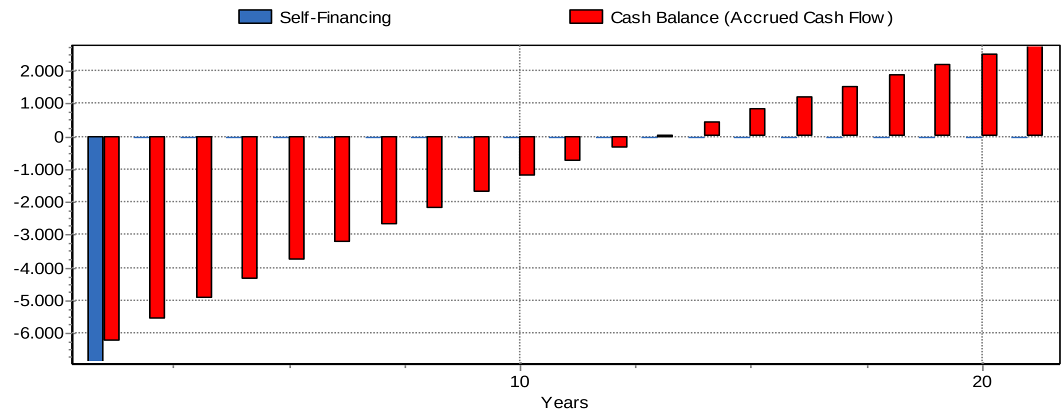


Fig. 5.86. Self-Financing and Cash Flow Balance (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Position	Total [€]	Year 1	Year 5	Year 10	Year 15	Year 20
Self-Financing	-6,945.75	-6945.75	0.00	0.00	0.00	0.00
Electricity Savings	11,389.14	787.90	672.04	549.51	447.97	359.46
Total Investments	-15,435.00	-15435.00	0.00	0.00	0.00	0.00
Total Operating Costs	-1,665.52	-104.90	-93.20	-80.40	-69.35	-59.82
Total Subsidies	8,489.25	8489.25	0.00	0.00	0.00	0.00
Cash Balance (Accrued Cash Flow)	2,777.87	-6262.75	-3796.09	-1239.46	827.63	2486.96

Table 5.23. Economic Efficiency Evolution throughout operating period (Values calculated with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Results according to Net Present Value method:

Net Present Value:	**2,777.87 €**
Payback Period:	**12.9 Years**
Yield:	**6.9 %**
Electricity Production Costs:	**0.15 €/kWh**

June consumption balanced with June production (storage case)

The main parameters calculated for this installation are:

Installed Power	= 13.23 kWp
Number of Batteries	= 20 (230 Ah 12V)
Energy Produced by PV Array (AC)	= 9,151 kWh/y
Consumption Requirement	= 29,078 kWh/y
Consumption Covered by PV Energy	= 8,337 kWh/y
Consumption Covered by Grid	= 20,741 kWh/y
Solar Fraction	= 28.7%
Specific Annual Yield	= 630 kWh/kWp

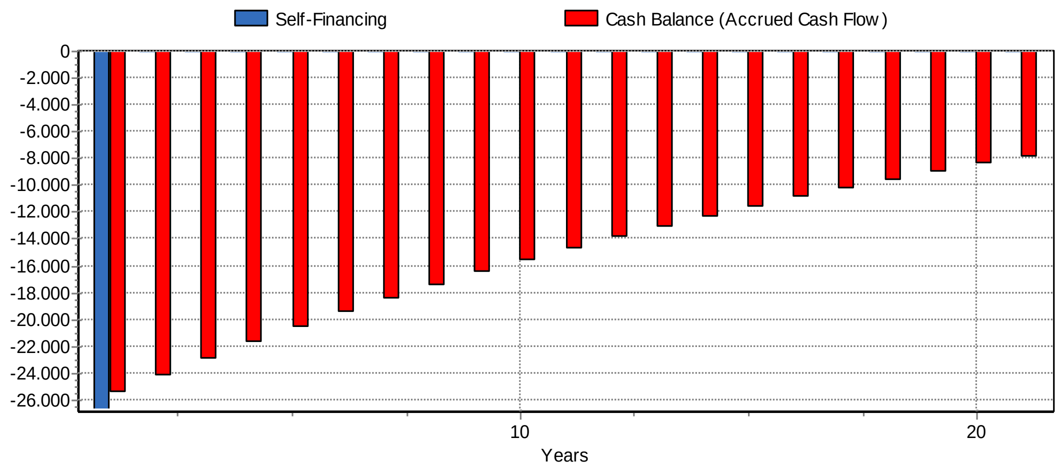


Fig. 5.87. Self-Financing and Cash Flow Balance (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Position	Total [€]	Year 1	Year 5	Year 10	Year 15	Year 20
Self-Financing	-26,887.95	-26887.95	0.00	0.00	0.00	0.00
Stored Energy Savings	3,098.83	214.29	182.78	149.46	121.84	98.99
Direct Energy Savings	22,315.83	1543.81	1316.79	1076.72	877.75	704.33
Total Investments	-59,751.00	-59751.00	0.00	0.00	0.00	0.00
Total Operating Costs	-6,447.44	-406.07	-360.79	-311.22	-268.46	-231.58
Total Subsidies	32,863.05	32863.05	0.00	0.00	0.00	0.00
Cash Balance (Accrued Cash Flow)	-7,920.73	-25535.92	-20671.25	-15666.35	-11657.63	-8474.63

Table 5.24. Economic Efficiency Evolution throughout operating period (Values calculated with PV*SOL Expert Pro 5.5, © Valentin Software[1])

Results according to Net Present Value method:

Net Present Value:	**-7,920.73 €**
Payback Period:	**more than 20 years**
Electricity Production Costs:	**0.21 €/kWh**

Chapter 6 Conclusions

Renewable energy sources for Alingsas-Brogården

- ✓ Both photovoltaic solar and wind energy have been analyzed.
- ✓ Next conclusion has been extracted from the Bachelor Thesis in Physics, Sustainable Energy: "*Locally Produced Renewable Electricity for Heating at Brogården*", this work was made by Lin Liljefors (Skanska Sverige AB) in 2010: "*For small scale electricity production locally at Brogården, this leaves only solar and wind as interesting options.".*[3]
- ✓ Wind power systems do not fit properly the average speed requirements and operational conditions at Brogården site.

Load identification

- ✓ This report has analyzed the energy consumption for buildings group NOPQ during 2011. This analysis has been based on real data for buildings group CDEF taken during April to September period.
- ✓ The load types present in this report are residential loads, laundry rooms located in House O, lightning from garbage house, outdoor yard and parking lot, and elevator located in House Q.
- ✓ Different time basis profiles have been identified to characterize the any load (annual profile, monthly profile, daily profile).
- ✓ Annual and daily profiles have been used to perform the calculations on the simulation software.
- ✓ Individual profiles for each building have been calculated.

PV solar system pre-sizing

- ✓ A detailed review of current official weather data sources has been studied.
- ✓ Weather data from Meteonorm and NASA-SEE database have been selected to perform the software simulation. They can be considered ones of the most confident databases present in the market.
- ✓ Three different areas have been considered for installing PV cell panels for each building:
    - o Roofs, Facades and Balconies.
- ✓ The different roof, facade and balcony areas have been estimated from drawings found in the construction documents.

- ✓ The roof areas have been calculated over drawing plans taking into account some obstacles such as roof ladders, roof ducts, fire-gas fans, snow guards and roof caps. But a real implementation could add more limitations in available surface for integrating PV cell panels.

- ✓ Moreover, a more detailed analysis about mechanical restrictions such as wind or snow loads over the PV cell panels should be done.

- ✓ Solar energy production has been evaluated for all surfaces.

- ✓ Further research will be required to define the possibilities to use different façade elements at Brogården for solar cells. However, it is suggested to focus most of the effort of the present project at the roof areas to design a “highly” industrialization process system for retrofitting buildings.

- ✓ Different PV cell panel technologies have been showed. There is an important difference in efficiencies and costs among them.

- ✓ Current renewable energy simulation software review has been showed. The PV*SOL Expert Pro v5.5 simulation software has been selected to perform the present study.

Energy balance

- ✓ Implementation of a solar cell system at Brogården may be suitable.

- ✓ Energy balance results have been individually calculated for each building.

- ✓ Only for the energy storage case with batteries: Sizing the system to balance the consumption and the production throughout the year (this means to overproduce in Summer to compensate the demand in Winter) might not be the best optimization. The reason is due to the solar production in Winter and Autum is very low and the consumption in this period is very high, so storeging this amount of energy from Summer to Winter means having too much losses by autodischarging on batteries.

- ✓ Different topologies of Swedish grid connection (without selling case and possible future Net Metering case) and different calculations criteria (level production without storage system and level production balanced with June consumption) have been analyzed and their results have been showed.

- ✓ From the energy efficiency point of view, the most appropriate surfaces for installing photovoltaic solar cell panels are Southern, Eastern and Western roofs.

- ✓ But it is important to take into account that other surfaces, like facades and balconies, can give added value such as architectural, aesthetic, communicative and/or pedagogical functions.

- ✓ The **solar fraction calculation without any storage system** for the buildings would be around:
  - 12% of the House N demand
  - 15% of the House O demand
  - 12% of the House P demand
  - 13% of the House Q demand
- ✓ The **solar fraction calculation with storage system (June balanced)** for the buildings would be:
  - 38% of the House N demand
  - 28% of the House P demand
  - 29% of the House Q demand
- ✓ The **solar fraction calculation for Net Metering topology (June balanced)** for the buildings would be:
  - 41% of the House N demand
  - 37% of the House P demand
  - 38% of the House Q demand
- ✓ The **minimum PV energy production (without energy storage) is around 16 MWh/year for the buildings group (Houses NOPQ)**. It represents the **14%** of the total demanded energy (**116 MWh/y**). This installation requires **219 PV cell panels**, which represents **19.43 kWp** installed power, with PV surface area of **309 m^2**. The quantity of CO2 emissions avoided with this topology is around **10 Ton/y**.
- ✓ As average value, the **solar fraction** obtained on a system with batteries is **10%** lower than the system without batteries (Net Metering case).
- ✓ As average value, the **system efficiency** obtained without using any storage system is around **5.2%**, but with storage system falls down to **3.5%**.
- ✓ Several aspects for evaluating losses have not been considered in the simulations:
  - Energy losses due to solar horizon
  - Performance reduction due to shading of all real objects over the surfaces

    - Real energy losses presented in the real installation of PV cell panels (clearance between panels, aisles between arrays, clearance with surface borders, ..)

- ✓ On the other hand, several aspects for improving the system performance are out of the scope of this project, for example:
    - A 1-axis or 2-axis tracking solar system could be installed
    - An extra energy storage system to profit from Swedish energy prices during the night and day could be taken into account
    - The installation could be optimized mounting panels with the best orientation (azimuth) and inclination (tilt) angles
    - The panel efficiency could be improved simply using other solar cell panels with better efficiency. It must be noticed that this technology is continuosly improving
    - An optimal selection of components could be done
    - An optimal connection topology among components could be further investigated

Economic analysis

- ✓ Financial analysis has been included in the present study.
- ✓ Only in cases without overproduction, the payback period is less than 20 years (between **13 – 15 years**) and the electricity production costs may vary between **0.15 – 0.17 €/kWh**.
- ✓ For June balanced production cases, in Houses NPQ, the payback period is **more than 20 years**. The electricity production costs vary between **0.21 – 0.35 €/kWh** produced.

Remark!

All supplied data and results included on this report are only estimations, so they will never be considered as definitive or compromising ones. For example, if strategic decisions must be taken from economic results is strongly recommended to develop a deeper analysis.

Annexes

A.1 Consumption data tables and profiles in Alingsas-Brogården

In this Annex the consumption data from building group NOPQ in Alingsas-Brogården is showed.

Unfortunately, the consumption data have only been taken for 6 months, from April to September. Thanks to the experience of Skanska, it can be supposed that the consumption in winter period, October to March, is going to be around **20%** higher than the summer period.

As a consequence of this, next table shows the correction factor applied on the estimated months and the corresponding energy value for each month.

The correction between estimated and reference months has been done on the basis of the average outdoor temperature (from the table 4.3), the number of the days for each month (28/30/31) and the energy values of the reference months. The basic idea has been to match the coldest months with the highest consumptions. Next table shows these values:

ESTIMATED MONTHS	REFERENCE MONTH	CORRECTION FACTOR	ENERGY (kWh/Month)
January	September	1.2 x (31/30)	11,156
February	May	1.2 x (28/31)	9,791
March	July	1.2	10,693
October	June	1.2 x (31/30)	10,449
November	April	1.2	10,398
December	August	1.2	10,970

Table A.1. Consumption of estimated months

The selected connection between months could have been chosen in a different way, on the basis of other criteria, but the definitive numbers would have been very similar.

On next tables A.2 to A.13 all consumption data are shown. Each monthly table consists of values for each hour and day. All shown values are kWh.

January

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
1	13	12	12	13	13	11	12	12	11	14	20	20	19	11	10	14	19	16	19	24	13	12	12	12	346
2	12	12	12	12	12	12	13	17	16	13	17	14	14	16	18	16	16	12	16	20	22	17	14	13	355
3	14	13	13	14	13	13	16	18	17	17	16	13	17	19	17	20	24	25	20	26	20	14	13	13	408
4	13	14	13	14	13	13	12	12	12	14	17	18	13	12	24	29	22	23	19	22	20	17	13	13	394
5	13	13	13	14	13	14	19	22	13	13	19	14	11	12	11	16	24	16	12	17	20	14	13	14	362
6	13	13	14	13	14	13	12	13	11	13	11	11	14	20	17	14	16	17	18	18	14	14	14	13	343
7	13	14	13	14	14	14	16	22	17	16	12	11	11	14	16	13	11	11	14	20	19	17	13	14	350
8	13	14	13	14	13	14	13	14	11	16	19	17	17	16	11	17	26	22	23	28	22	18	14	14	400
9	13	14	14	14	16	13	13	13	11	18	26	23	18	16	17	13	17	13	16	22	17	14	14	13	379
10	14	13	14	13	14	13	16	24	22	20	17	18	19	17	13	14	18	17	12	14	14	14	13	13	379
11	14	13	13	13	13	14	13	13	11	12	18	13	13	19	19	18	18	14	17	25	23	19	13	13	374
12	13	13	13	14	13	14	12	23	16	16	12	11	11	12	13	20	20	14	11	12	13	12	12	12	334
13	12	12	12	12	12	13	16	24	17	14	18	12	12	10	10	8	10	11	11	12	13	12	13	12	307
14	12	12	12	13	12	13	13	19	14	10	10	10	13	16	12	10	10	13	22	24	24	17	12	12	334
15	12	13	12	13	12	13	13	20	13	12	14	14	18	23	19	22	23	18	19	25	20	14	13	12	390
16	12	13	12	13	13	12	14	18	14	18	23	18	11	10	10	12	20	13	18	18	17	13	12	13	348
17	13	13	13	12	13	12	14	20	14	12	11	13	10	10	10	16	23	19	19	24	25	16	13	12	358
18	12	12	12	13	12	12	12	16	12	20	19	18	16	12	18	24	20	24	19	19	19	16	12	12	382
19	12	12	12	13	12	12	16	13	10	14	24	18	20	22	23	19	20	13	11	13	13	13	12	12	360
20	12	12	12	12	12	12	12	14	20	18	18	16	17	23	20	12	14	14	16	26	19	16	12	12	372
21	12	12	12	12	13	12	17	25	19	19	22	19	18	17	14	14	10	10	14	20	18	16	12	12	370
22	12	12	12	13	12	12	14	17	16	20	19	19	17	19	24	24	22	17	19	17	14	13	13	12	390
23	12	12	13	12	13	13	14	18	16	13	13	10	13	13	20	20	24	20	19	19	14	12	12	13	361
24	12	12	12	13	12	12	14	17	14	10	13	13	11	10	8	14	23	23	17	13	12	13	12	12	323
25	12	12	12	12	12	13	16	17	14	16	18	18	17	11	11	16	20	25	22	20	17	13	12	12	367
26	13	12	12	12	12	12	14	18	12	13	20	13	12	14	13	18	20	17	12	12	13	12	12	12	332
27	12	12	12	13	12	13	11	11	10	8	10	8	10	10	8	12	17	17	17	20	20	16	13	12	304
28	12	12	12	12	12	12	14	19	16	14	14	16	14	22	18	17	17	24	17	25	25	18	11	12	385
29	12	12	11	12	12	12	14	16	12	17	22	22	16	10	10	17	19	19	16	13	12	12	12	11	338
30	12	12	12	12	11	12	12	10	10	17	20	19	14	19	18	16	26	22	18	12	12	12	12	12	352
31	12	12	12	12	11	12	12	10	10	18	21	20	15	20	19	17	27	23	18	12	12	12	12	12	360
																								Total	11.156

Table A.2. Hourly consumption in January (in kWh) (© SKANSKA Sverige AB)

February

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
1	12	12	12	12	12	11	12	11	11	19	22	18	19	17	14	14	18	18	17	18	13	12	12	12	348
2	12	12	12	13	12	12	14	13	13	12	11	12	13	23	22	20	20	18	14	18	17	13	13	12	353
3	12	13	13	13	12	11	14	13	12	16	20	16	12	12	12	17	25	16	13	19	18	16	13	12	350
4	13	12	13	13	12	11	17	20	16	18	24	24	22	22	14	17	22	18	16	22	18	16	12	13	403
5	12	13	12	13	11	12	12	12	14	17	18	18	20	17	12	12	11	11	11	10	13	12	12	12	317
6	12	11	13	12	11	11	13	17	11	20	25	20	14	18	14	13	22	24	19	16	13	13	12	12	367
7	12	12	12	12	12	12	11	11	12	11	11	11	14	16	14	20	22	19	14	11	12	12	12	12	317
8	11	12	12	11	12	11	11	11	11	18	22	17	22	24	22	18	25	23	11	11	14	12	11	12	361
9	11	11	12	12	11	11	12	11	11	13	16	18	17	12	12	22	22	23	17	24	22	14	12	12	355
10	12	12	12	12	11	11	11	11	12	17	18	16	17	16	14	17	18	19	14	19	16	12	12	12	340
11	11	12	12	12	10	10	14	18	16	14	12	13	12	12	10	14	19	14	17	11	12	12	12	12	311
12	11	12	12	12	10	11	11	11	11	12	14	16	13	12	12	17	18	19	14	16	18	16	12	12	320
13	13	12	12	13	11	10	13	17	17	12	11	11	14	17	17	12	11	11	13	13	14	12	13	11	310
14	12	13	12	12	11	11	11	11	11	12	11	11	11	11	11	16	26	20	23	19	24	14	13	12	337
15	13	11	12	13	11	11	11	14	16	13	18	17	19	16	19	23	26	22	19	22	17	13	13	12	380
16	12	12	12	12	12	10	16	13	11	14	14	12	12	11	11	13	22	13	20	25	20	17	13	12	340
17	13	12	12	12	12	11	11	11	12	13	20	17	20	17	18	19	25	23	23	20	19	14	13	12	380
18	12	12	12	13	11	11	14	19	13	13	11	12	17	23	19	14	19	18	18	19	18	12	12	12	355
19	13	12	12	12	12	11	16	25	20	14	19	17	20	23	13	13	19	17	18	13	11	13	13	12	370
20	12	13	13	12	11	11	11	12	11	18	25	17	18	19	16	20	17	17	18	13	16	14	12	13	359
21	12	12	13	12	11	11	11	13	17	20	19	18	25	25	23	18	24	20	22	19	14	12	12	12	396
22	12	12	12	12	11	11	11	10	11	13	18	12	14	17	19	19	23	20	19	14	16	13	12	12	343
23	12	12	13	12	10	11	14	12	11	13	17	14	17	20	17	14	23	17	13	14	12	12	12	12	335
24	12	12	12	12	12	11	13	17	14	23	18	18	18	20	16	12	19	16	11	11	12	13	12	12	346
25	13	12	12	12	11	11	12	11	11	16	16	17	18	18	17	16	25	22	18	26	24	17	13	13	379
26	12	12	13	12	11	11	13	17	20	16	18	18	17	12	11	14	19	16	13	12	12	12	12	13	336
27	12	12	12	11	11	11	17	20	25	19	19	23	19	18	22	14	20	14	13	14	17	14	12	13	384
28	12	12	12	12	11	11	11	11	12	12	12	11	11	11	11	14	19	14	14	16	13	13	12	12	299
																								Total	9.791

Table A.3. Hourly consumption in February (in kWh) (© SKANSKA Sverige AB)

March

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
1	12	11	12	12	11	10	13	17	13	20	24	24	25	23	20	24	17	13	16	17	19	12	12	12	389
2	11	12	12	12	11	10	12	17	12	11	11	11	11	11	11	13	19	16	12	11	11	12	11	12	289
3	11	12	11	11	11	10	10	11	11	19	26	22	12	11	11	17	24	19	19	14	12	12	12	12	338
4	11	12	12	11	11	10	16	19	16	12	12	11	17	26	17	14	14	14	17	16	13	12	11	12	335
5	12	12	12	11	11	10	14	24	19	13	11	11	11	11	11	17	22	13	12	17	19	16	12	12	331
6	12	11	12	11	10	11	11	10	11	13	10	12	11	14	18	19	25	24	19	17	19	14	12	11	336
7	12	11	12	11	10	10	11	11	11	10	13	16	16	18	16	19	20	23	22	22	17	13	11	12	343
8	12	11	12	11	10	10	11	14	11	23	24	16	17	16	12	11	10	11	16	18	18	14	12	11	328
9	12	12	12	11	10	11	13	19	16	16	18	16	14	17	16	12	14	19	25	26	23	16	11	12	370
10	11	12	11	12	11	10	11	11	10	16	24	22	19	11	16	12	19	17	18	17	13	12	12	11	335
11	12	12	12	11	10	11	12	17	16	19	19	19	20	29	19	16	22	12	13	13	11	12	12	11	359
12	12	11	12	12	10	10	13	17	16	16	18	18	14	19	18	17	25	25	17	16	14	12	12	11	364
13	12	12	12	12	11	10	14	17	14	18	22	24	26	20	17	19	25	23	24	19	19	14	12	12	409
14	11	12	12	12	11	10	12	12	13	13	16	11	12	10	11	16	18	16	16	16	18	14	12	11	312
15	12	12	12	12	12	11	16	20	16	14	24	18	13	16	14	13	16	16	17	14	13	13	12	11	347
16	12	11	12	12	11	10	11	11	11	13	16	12	11	11	11	17	29	22	28	25	20	13	12	11	349
17	12	12	11	12	11	10	11	10	11	14	25	23	19	20	19	17	20	17	20	22	13	12	12	12	365
18	12	12	12	11	12	10	17	22	14	14	11	11	16	24	18	18	22	17	12	11	11	12	12	12	341
19	11	12	12	12	11	10	10	11	11	13	12	11	17	14	19	14	16	20	22	17	22	16	12	11	334
20	12	11	12	12	11	10	13	16	13	11	10	12	12	14	14	16	26	20	14	18	16	13	12	12	330
21	11	12	11	12	11	10	17	13	12	13	17	17	16	13	11	12	14	17	16	19	19	17	11	12	331
22	11	12	12	12	11	11	16	14	16	14	11	11	13	14	14	19	23	18	17	19	19	16	11	12	346
23	11	11	12	12	11	11	13	19	18	14	19	16	16	23	19	17	18	17	22	18	13	12	12	12	365
24	11	11	12	12	12	10	11	10	11	12	17	17	18	12	10	12	11	12	11	11	13	12	12	12	289
25	11	12	12	12	12	10	16	16	13	12	11	11	14	18	13	17	19	12	14	24	22	16	11	12	338
26	12	12	12	11	12	10	14	17	16	13	18	16	14	20	17	16	18	17	17	13	13	12	12	12	343
27	11	12	11	12	11	10	16	25	20	12	16	12	11	11	11	14	18	17	16	23	19	13	11	12	342
28	11	12	12	11	11	10	11	11	10	17	18	16	18	17	12	16	28	22	19	19	14	12	11	11	346
29	12	12	11	12	10	11	10	11	11	13	23	19	16	14	16	16	16	13	20	17	16	12	12	11	331
30	12	11	12	12	10	11	17	22	17	17	19	20	13	11	12	17	23	20	20	25	25	16	12	11	384
31	12	12	11	12	11	10	11	10	11	13	17	19	20	18	24	22	18	19	24	22	22	16	12	12	376
																						Total			10.693

Table A.4. Hourly consumption in March (in kWh) (© SKANSKA Sverige AB)

April

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
1	11	10	11	10	10	11	11	10	11	11	11	11	14	17	18	18	20	18	15	12	11	11	11	10	303
2	10	11	10	10	10	11	12	16	17	18	15	14	12	11	10	11	13	15	11	11	10	11	11	10	290
3	10	10	11	10	10	11	10	10	12	17	11	10	13	13	16	17	16	11	11	12	10	10	11	10	282
4	10	10	11	10	10	11	13	15	11	11	11	11	13	16	15	13	10	10	11	11	11	10	10	10	274
5	11	10	10	10	11	10	12	11	11	15	19	15	18	22	18	15	14	10	12	11	11	10	11	10	307
6	10	10	10	10	11	10	11	11	10	16	14	14	14	20	19	16	23	23	19	11	11	10	10	11	324
7	10	10	10	10	11	10	9	10	11	16	25	17	15	10	11	12	14	14	11	10	9	10	10	10	285
8	9	10	10	9	10	9	10	11	10	10	10	11	14	17	15	15	14	10	12	11	11	11	11	10	270
9	10	11	10	11	10	10	12	15	14	15	22	17	13	13	16	11	12	10	10	10	11	11	10	11	295
10	10	10	11	11	11	11	10	10	11	10	10	10	13	16	21	18	19	19	14	11	10	11	10	10	297
11	10	10	10	10	11	10	10	11	10	12	16	15	13	17	12	10	10	9	10	10	11	10	11	10	268
12	11	11	11	11	11	10	13	17	15	13	18	15	13	12	11	13	25	19	11	12	11	11	10	11	315
13	10	10	11	10	11	10	10	11	10	10	11	11	13	19	18	19	21	17	11	11	10	11	11	10	296
14	11	10	11	11	10	10	11	10	11	12	16	14	11	10	10	14	22	12	12	16	11	12	11	10	288
15	11	11	11	11	11	10	11	11	10	11	10	10	16	25	20	10	12	14	15	12	11	10	11	10	294
16	10	10	11	10	10	11	10	9	11	13	16	11	13	16	15	14	20	21	13	12	11	11	10	10	298
17	11	10	11	10	11	10	10	10	11	11	10	10	12	15	15	13	24	19	10	10	11	10	11	10	285
18	11	10	10	11	10	11	10	10	10	10	9	10	19	21	16	15	11	10	10	10	10	9	10	10	273
19	10	10	11	10	10	10	10	10	10	11	15	15	11	11	9	17	24	20	12	10	11	9	10	9	285
20	10	9	10	10	9	10	16	21	13	10	9	10	9	10	9	15	26	20	15	9	10	10	10	9	289
21	10	10	9	11	10	10	11	16	13	13	16	15	14	12	9	12	15	17	21	25	10	10	10	10	309
22	9	10	10	10	10	10	13	12	11	12	11	9	14	23	20	16	20	14	11	9	10	10	9	9	292
23	9	10	10	9	10	9	8	9	9	9	9	9	10	9	8	11	15	15	12	9	10	9	9	9	236
24	10	10	9	10	10	9	9	9	9	9	9	9	11	12	11	13	20	15	13	13	11	11	10	10	262
25	9	10	10	9	10	9	13	17	15	14	17	15	18	20	18	15	16	14	14	17	11	10	9	9	319
26	10	9	10	9	9	10	12	23	14	12	15	15	19	19	10	13	19	16	18	15	17	14	10	9	327
27	10	10	10	9	10	9	9	14	16	12	10	9	11	11	9	15	14	9	10	15	12	11	10	9	264
28	10	10	9	10	10	9	15	15	13	12	14	9	13	15	15	12	21	16	15	13	16	11	10	9	302
29	10	10	10	11	10	9	11	15	12	13	15	11	10	9	9	9	9	9	10	17	16	13	10	10	268
30	10	10	10	10	10	9	9	9	10	13	22	19	17	9	10	11	12	11	9	9	9	10	10	10	268
																						Total			8.665

Table A.5. Hourly consumption in April (in kWh) (© SKANSKA Sverige AB)

May

Day	Time 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
1	10	10	10	10	10	9	10	9	9	16	18	15	16	14	12	12	15	15	14	15	11	10	10	10	290
2	10	10	10	11	10	10	12	11	11	10	9	10	11	19	18	17	17	15	12	15	14	11	11	10	294
3	10	11	11	11	10	9	12	11	10	13	17	13	10	10	10	14	21	13	11	16	15	13	11	10	292
4	11	10	11	11	10	9	14	17	13	15	20	20	18	18	12	14	18	15	13	18	15	13	10	11	336
5	10	11	10	11	9	10	10	10	12	14	15	15	17	14	10	10	9	9	9	8	11	10	10	10	264
6	10	9	11	10	9	9	11	14	9	17	21	17	12	15	12	11	18	20	16	13	11	11	10	10	306
7	10	10	10	10	10	10	9	9	10	9	9	9	12	13	12	17	18	16	12	9	10	10	10	10	264
8	9	10	10	9	10	9	9	9	9	15	18	14	18	20	18	15	21	19	9	9	12	10	9	10	301
9	9	9	10	10	9	9	10	9	9	11	13	15	14	10	10	18	18	19	14	20	18	12	10	10	296
10	10	10	10	10	9	9	9	9	10	14	15	13	14	13	12	14	15	16	12	16	13	10	10	10	283
11	9	10	10	10	8	8	12	15	13	12	10	11	10	10	8	12	16	12	14	9	10	10	10	10	259
12	9	10	10	10	8	9	9	9	9	10	12	13	11	10	10	14	15	16	12	13	15	13	10	10	267
13	11	10	10	11	9	8	11	14	14	10	9	9	12	14	14	10	9	9	11	11	12	10	11	9	258
14	10	11	10	10	9	9	9	9	9	10	9	9	9	9	9	13	22	17	19	16	20	12	11	10	281
15	11	9	10	11	9	9	9	12	13	11	15	14	16	13	16	19	22	18	16	18	14	11	11	10	317
16	10	10	10	10	10	8	13	11	9	12	12	10	10	9	9	11	18	11	17	21	17	14	11	10	283
17	11	10	10	10	10	9	9	9	10	11	17	14	17	14	15	16	21	19	19	17	16	12	11	10	317
18	10	10	10	11	9	9	12	16	11	11	9	10	14	19	16	12	16	15	15	16	15	10	10	10	296
19	11	10	10	10	10	9	13	21	17	12	16	14	17	19	11	11	16	14	15	11	9	11	11	10	308
20	10	11	11	10	9	9	9	10	9	15	21	14	15	16	13	17	14	14	15	11	13	12	10	11	299
21	10	10	11	10	9	9	9	11	14	17	16	15	21	21	19	15	20	17	18	16	12	10	10	10	330
22	10	10	10	10	9	9	9	8	9	11	15	10	12	14	16	16	19	17	16	12	13	11	10	10	286
23	10	10	11	10	8	9	12	10	9	11	14	12	14	17	14	12	19	14	11	12	10	10	10	10	279
24	10	10	10	10	10	9	11	14	12	19	15	15	15	17	13	10	16	13	9	9	10	11	10	10	288
25	11	10	10	10	9	9	10	9	9	13	13	14	15	15	14	13	21	18	15	22	20	14	11	11	316
26	10	10	11	10	9	9	11	14	17	13	15	15	14	10	9	12	16	13	11	10	10	10	10	11	280
27	10	10	10	9	9	9	14	17	21	16	16	19	16	15	18	12	17	12	11	12	14	12	10	11	320
28	10	10	10	10	9	9	9	9	10	10	10	9	9	9	9	12	16	12	12	13	11	11	10	10	249
29	10	10	11	10	9	9	9	9	9	14	19	18	10	10	9	14	22	16	12	16	14	12	10	10	292
30	11	10	10	10	8	9	12	14	12	13	12	11	14	20	15	15	17	14	18	16	22	15	10	10	318
31	10	9	10	10	8	8	7	7	7	9	7	8	9	11	13	18	14	13	14	19	17	11	8	8	255
																							Total		9.024

Table A.6. Hourly consumption in May (in kWh) (© SKANSKA Sverige AB)

June

Day	Time 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
1	8	8	8	8	6	7	7	7	7	10	14	15	16	16	16	15	17	16	17	9	9	9	9	9	263
2	9	9	9	10	7	8	8	8	8	8	8	8	9	8	8	17	20	17	12	13	9	10	9	9	241
3	9	8	9	9	8	8	10	13	12	10	16	13	12	15	14	12	13	12	13	8	15	13	9	9	270
4	9	8	10	8	7	8	11	18	15	12	13	11	11	18	15	15	15	12	13	17	13	12	9	9	289
5	9	8	9	9	7	8	8	7	8	8	8	9	11	16	12	16	19	19	16	13	16	13	9	9	267
6	9	8	9	8	7	8	9	10	8	11	16	9	10	12	12	12	14	9	8	8	8	9	9	9	232
7	9	8	10	8	8	7	9	15	12	12	16	16	13	16	14	13	13	9	13	14	15	11	9	9	279
8	9	9	9	9	8	7	11	16	14	11	15	14	17	12	11	14	20	16	16	17	13	11	9	9	297
9	9	9	9	9	9	8	9	8	7	12	19	17	15	11	9	15	19	18	17	12	10	10	9	9	279
10	9	9	9	9	9	8	10	17	18	17	15	18	19	18	15	14	13	12	17	14	14	13	11	10	318
11	9	10	10	10	9	8	9	8	9	9	11	16	17	17	13	13	21	19	10	14	14	12	10	10	288
12	10	9	10	9	8	8	11	17	13	14	14	15	11	9	9	9	8	9	14	19	19	16	10	10	281
13	10	10	10	9	9	8	11	10	11	14	14	14	13	14	12	11	9	9	15	21	21	14	10	10	289
14	9	10	10	9	9	8	11	13	12	12	14	15	14	17	14	12	18	14	13	14	14	11	10	10	293
15	10	10	9	10	8	9	15	19	13	10	9	10	13	15	16	20	22	15	14	16	22	14	10	10	319
16	10	10	10	10	8	9	9	9	9	12	15	14	13	15	13	10	9	8	12	13	9	10	10	9	256
17	10	9	10	10	10	9	9	10	9	11	20	16	14	16	13	11	9	9	11	13	11	11	10	10	271
18	10	10	10	9	9	8	11	14	13	10	10	9	9	9	9	14	21	21	18	14	10	10	10	10	278
19	10	10	9	10	9	8	9	9	8	9	9	9	16	21	18	16	17	14	13	19	13	13	10	10	289
20	10	10	10	10	9	9	9	10	15	16	14	15	12	15	14	17	18	13	13	16	16	11	10	10	302
21	9	10	10	10	9	9	9	8	9	10	14	11	12	14	14	15	22	16	18	14	9	11	10	10	283
22	10	10	10	10	9	9	11	17	18	20	16	10	13	15	17	18	21	19	15	15	13	10	10	10	326
23	10	9	10	10	9	8	11	16	13	14	16	12	13	15	12	12	21	17	9	9	9	9	10	10	284
24	10	10	10	9	9	8	11	11	13	11	14	15	16	16	13	20	20	17	18	15	11	10	11	10	308
25	10	10	9	9	9	8	11	16	12	10	9	9	11	10	12	11	9	9	9	9	8	10	9	10	239
26	10	10	10	9	9	8	9	8	9	11	14	14	13	9	9	17	22	18	20	16	19	13	11	9	297
27	10	10	10	9	9	8	13	15	13	12	21	12	14	19	16	12	10	9	17	13	12	10	10	9	293
28	9	10	10	8	8	9	9	8	9	8	9	10	9	9	9	11	16	13	13	14	14	11	10	10	246
29	9	10	9	9	8	8	14	16	14	10	8	10	11	14	10	10	13	15	15	9	9	10	9	10	260
30	9	10	9	9	8	9	8	9	9	13	16	19	16	15	12	16	17	14	13	15	14	11	9	10	290
																							Total		8.427

Table A.7. Hourly consumption in June (in kWh) (© SKANSKA Sverige AB)

July

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
1	10	9	10	10	9	8	11	14	11	17	20	20	21	19	17	20	14	11	13	14	16	10	10	10	324
2	9	10	10	10	9	8	10	14	10	9	9	9	9	9	9	11	16	13	10	9	9	10	9	10	241
3	9	10	9	9	9	8	8	9	9	16	22	18	10	9	9	14	20	16	16	12	10	10	10	10	282
4	9	10	10	9	9	8	13	16	13	10	10	9	14	22	14	12	12	12	14	13	11	10	9	10	279
5	10	10	10	9	9	8	12	20	16	11	9	9	9	9	9	14	18	11	10	14	16	13	10	10	276
6	10	9	10	9	8	9	9	8	9	11	8	10	9	12	15	16	21	20	16	14	16	12	10	9	280
7	10	9	10	9	8	8	9	9	9	8	11	13	13	15	13	16	17	19	18	18	14	11	9	10	286
8	10	9	10	9	8	8	9	12	9	19	20	13	14	13	10	9	8	9	13	15	15	12	10	9	273
9	10	10	10	9	8	9	11	16	13	13	15	13	12	14	13	10	12	16	21	22	19	13	9	10	308
10	9	10	9	10	9	8	9	9	8	13	20	18	16	9	13	10	16	14	15	14	11	10	10	9	279
11	10	10	10	9	8	9	10	14	13	16	16	16	17	24	16	13	18	10	11	11	9	10	10	9	299
12	10	9	10	10	8	8	11	14	13	13	15	15	12	16	15	14	21	21	14	13	12	10	10	9	303
13	10	10	10	10	9	8	12	14	12	15	18	20	22	17	14	16	21	19	20	16	16	12	10	10	341
14	9	10	10	10	9	8	10	10	11	11	13	9	10	8	9	13	15	13	13	13	15	12	10	9	260
15	10	10	10	10	10	9	13	17	13	12	20	15	11	13	12	11	13	13	14	12	11	11	10	9	289
16	10	9	10	10	9	8	9	9	9	11	13	10	9	9	9	14	24	18	23	21	17	11	10	9	291
17	10	10	9	10	9	8	9	8	9	12	21	19	16	17	16	14	17	14	17	18	11	10	10	10	304
18	10	10	10	9	10	8	14	18	12	12	9	9	13	20	15	15	18	14	10	9	9	10	10	10	284
19	9	10	10	10	9	8	8	9	9	11	10	9	14	12	16	12	13	17	18	14	18	13	10	9	278
20	10	9	10	10	9	8	11	13	11	9	8	10	10	12	12	13	22	17	12	15	13	11	10	10	275
21	9	10	9	10	9	8	14	11	10	11	14	14	13	11	9	10	12	14	13	16	16	14	9	10	276
22	9	10	10	10	9	9	13	12	13	12	9	9	11	12	12	16	19	15	14	16	16	13	9	10	288
23	9	9	10	10	9	9	11	16	15	12	16	13	13	19	16	14	15	14	18	15	11	10	10	10	304
24	9	9	10	10	10	8	9	8	9	10	14	14	15	10	8	10	9	10	9	9	11	10	10	10	241
25	9	10	10	10	10	8	13	13	11	10	9	9	12	15	11	14	16	10	12	20	18	13	9	10	282
26	10	10	10	9	10	8	12	14	13	11	15	13	12	17	14	13	15	14	14	11	11	10	10	10	286
27	9	10	9	10	9	8	13	21	17	10	13	10	9	9	9	12	15	14	13	19	16	11	9	10	285
28	9	10	10	9	9	8	9	9	8	14	15	13	15	14	10	13	23	18	16	16	12	10	9	9	288
29	10	10	9	10	8	9	8	9	9	11	19	16	13	12	13	13	13	11	17	14	13	10	10	9	276
30	10	9	10	10	8	9	14	18	14	14	16	17	11	9	10	14	19	17	17	21	21	13	10	9	320
31	10	10	9	10	9	8	9	8	9	11	14	16	17	15	20	18	15	16	20	18	18	13	10	10	313
																					Total				8.911

Table A.8. Hourly consumption in July (in kWh) (© SKANSKA Sverige AB)

August

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
1	9	9	10	10	8	9	13	17	13	16	13	11	17	17	15	13	20	15	12	17	20	14	10	9	317
2	10	10	9	10	8	8	9	9	9	11	13	12	14	18	15	14	16	14	16	19	19	15	9	10	297
3	10	9	10	10	9	8	13	19	16	18	9	12	15	15	14	15	18	15	14	16	17	13	10	10	315
4	9	10	10	9	9	8	12	16	15	11	13	16	9	9	9	10	14	11	12	16	15	11	10	10	274
5	9	10	9	10	10	9	11	14	11	10	16	14	11	10	9	11	17	14	16	16	16	13	9	10	285
6	10	10	9	10	10	8	11	15	13	13	14	13	11	16	14	17	19	14	13	15	14	10	10	10	299
7	10	9	10	10	10	8	9	9	9	9	9	9	12	13	14	11	14	13	14	18	20	13	10	9	272
8	10	10	10	10	9	9	14	18	15	10	10	9	9	9	9	13	20	12	10	9	10	11	10	10	266
9	10	10	10	10	10	8	9	9	9	9	9	9	12	17	14	11	12	14	10	8	11	10	10	10	251
10	10	10	9	10	10	8	12	16	13	13	15	13	16	19	20	19	18	21	14	13	11	10	10	9	319
11	10	10	9	10	10	9	9	9	9	13	13	13	12	16	14	16	17	18	16	13	13	11	9	10	289
12	10	11	10	10	10	9	12	16	14	15	17	15	10	9	9	13	17	16	18	16	13	10	10	10	300
13	10	10	11	10	10	9	12	15	12	11	15	15	16	21	15	13	17	14	9	9	10	10	10	10	294
14	10	9	10	10	9	9	9	12	17	17	16	14	13	22	13	19	18	16	13	12	16	12	10	10	316
15	10	10	10	10	10	10	13	10	9	11	15	13	13	10	9	13	17	13	10	12	13	10	10	10	271
16	10	10	10	10	9	9	14	22	16	17	14	14	17	12	15	14	23	17	14	16	15	10	10	10	328
17	11	10	10	11	10	9	12	17	14	12	13	13	14	17	13	15	12	9	9	10	10	10	10	10	281
18	10	10	11	10	10	9	13	22	17	13	16	12	16	17	21	21	20	16	17	19	17	12	10	10	349
19	10	10	10	11	10	9	14	13	15	13	9	9	10	9	10	9	13	13	10	10	11	10	10	10	258
20	10	10	11	10	10	9	11	16	13	11	9	9	12	15	12	11	15	16	13	10	15	16	10	9	283
21	10	11	10	10	10	9	9	9	12	11	14	13	14	20	20	22	16	17	19	17	18	12	10	10	323
22	9	10	9	10	10	9	13	12	9	11	13	15	11	13	13	11	11	10	11	14	14	10	10	10	268
23	10	9	10	10	10	9	9	9	9	11	9	9	9	9	9	13	22	13	11	10	10	10	10	10	250
24	10	10	10	10	10	10	12	16	12	9	10	9	14	15	15	15	13	11	13	15	14	12	10	10	285
25	10	9	10	10	10	9	11	14	9	15	19	18	16	17	14	9	9	9	13	19	14	12	10	10	296
26	9	10	10	10	10	9	13	26	18	11	14	12	12	15	16	15	17	14	16	17	15	11	9	10	319
27	10	10	9	10	10	9	11	15	14	15	19	20	13	13	10	15	23	18	19	23	23	12	10	10	341
28	9	10	10	10	10	9	11	13	11	11	15	10	10	14	16	19	18	19	20	14	15	12	10	10	306
29	10	10	10	11	10	9	9	10	9	8	10	9	14	19	15	15	17	15	18	16	13	11	10	9	287
30	10	10	10	10	10	10	9	9	9	14	10	17	15	17	15	11	16	13	14	11	10	10	10	11	281
31	10	10	10	10	11	10	14	20	13	14	18	18	18	17	11	13	17	19	12	13	13	11	10	10	322
																					Total				9.142

Table A.9. Hourly consumption in August (in kWh) (© SKANSKA Sverige AB)

September

Day	Time 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
1	11	10	10	11	11	9	10	10	9	12	17	17	16	9	8	12	16	13	16	20	11	10	10	10	288
2	10	10	10	10	10	10	11	14	13	11	14	12	12	13	15	13	13	10	13	17	18	14	12	11	296
3	12	11	11	12	11	11	13	15	14	14	13	11	14	16	14	17	20	21	17	22	17	12	11	11	340
4	11	12	11	12	11	11	10	10	10	12	14	15	11	10	20	24	18	19	16	18	17	14	11	11	328
5	11	11	11	12	11	12	16	18	11	11	16	12	9	10	9	13	20	13	10	14	17	12	11	12	302
6	11	11	12	11	12	11	10	11	9	11	9	9	12	17	14	12	13	14	15	15	12	12	12	11	286
7	11	12	11	12	12	12	13	18	14	13	10	9	9	12	13	11	9	9	12	17	16	14	11	12	292
8	11	12	11	12	11	12	11	12	9	13	16	14	14	13	9	14	22	18	19	23	18	15	12	12	333
9	11	12	12	12	13	11	11	11	9	15	22	19	15	13	14	11	14	11	13	18	14	12	12	11	316
10	12	11	12	11	12	11	13	20	18	17	14	15	16	14	11	12	15	14	10	12	12	12	11	11	316
11	12	11	11	11	11	12	11	11	9	10	15	11	11	16	16	15	15	12	14	21	19	16	11	11	312
12	11	11	11	12	11	12	10	19	13	13	10	9	9	10	11	17	17	12	9	10	11	10	10	10	278
13	10	10	10	10	10	11	13	20	14	12	15	10	10	8	8	7	8	9	9	10	11	10	11	10	256
14	10	10	10	11	10	11	11	16	12	8	8	8	11	13	10	8	8	11	18	20	20	14	10	10	278
15	10	11	10	11	10	11	11	17	11	10	12	12	15	19	16	18	19	15	16	21	17	12	11	10	325
16	10	11	10	11	11	10	12	15	12	15	19	15	9	8	8	10	17	11	15	15	14	11	10	11	290
17	11	11	11	10	11	10	12	17	12	10	9	11	8	8	8	13	19	16	16	20	21	13	11	10	298
18	10	10	10	11	10	10	10	13	10	17	16	15	13	10	15	20	17	20	16	16	16	13	10	10	318
19	10	10	10	11	10	10	13	11	8	12	20	15	17	18	19	16	17	11	9	11	11	11	10	10	300
20	10	10	10	10	10	10	10	12	17	15	15	13	14	19	17	10	12	12	13	22	16	13	10	10	310
21	10	10	10	10	11	10	14	21	16	16	18	16	15	14	12	12	8	8	12	17	15	13	10	10	308
22	10	10	10	11	10	10	12	14	13	17	16	16	14	16	20	20	18	14	16	14	12	11	11	10	325
23	10	10	11	10	11	11	12	15	13	11	11	8	11	11	17	17	20	17	16	16	12	10	10	11	301
24	10	10	10	11	10	10	12	14	12	8	11	11	9	8	7	12	19	19	14	11	10	11	10	10	269
25	10	10	10	10	10	11	13	14	12	13	15	15	14	9	9	13	17	21	18	17	14	11	10	10	306
26	11	10	10	10	10	10	12	15	10	11	17	11	10	12	11	15	17	14	10	10	11	10	10	10	277
27	10	10	10	11	10	11	9	9	8	7	8	7	8	8	7	10	14	14	14	17	17	13	11	10	253
28	10	10	10	10	10	10	12	16	13	12	12	13	12	18	15	14	14	20	14	21	21	15	9	10	321
29	10	10	9	10	10	10	12	13	10	14	18	18	13	8	8	14	16	16	13	11	10	10	10	9	282
30	10	10	10	10	9	10	10	8	8	14	17	16	12	16	15	13	22	18	15	10	10	10	10	10	293
																					Total				8.997

Table A.10. Hourly consumption in September (in kWh) (© SKANSKA Sverige AB)

October

Day	Time 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
1	10	10	10	10	7	8	8	8	8	12	17	18	19	19	19	18	20	19	20	11	11	11	11	11	316
2	11	11	11	12	8	10	10	10	10	10	10	10	11	10	10	20	24	20	14	16	11	12	11	11	289
3	11	10	11	11	10	10	12	16	14	12	19	16	14	18	17	14	16	14	16	10	18	16	11	11	324
4	11	10	12	10	8	10	13	22	18	14	16	13	13	22	18	18	18	14	16	20	16	14	11	11	347
5	11	10	11	11	8	10	10	8	10	10	10	11	13	19	14	19	23	23	19	16	19	16	11	11	320
6	11	10	11	10	8	10	11	12	10	13	19	11	12	14	14	14	17	11	10	10	10	11	11	11	278
7	11	10	12	10	10	8	11	18	14	14	19	19	16	19	17	16	16	11	16	17	18	13	11	11	335
8	11	11	11	11	10	8	13	19	17	13	18	17	20	14	13	17	24	19	19	20	16	13	11	11	356
9	11	11	11	11	11	10	11	10	8	14	23	20	18	13	11	18	23	22	20	14	12	12	11	11	335
10	11	11	11	11	11	10	12	20	22	20	18	22	23	22	18	17	16	14	20	17	17	16	13	12	382
11	11	12	12	12	11	10	11	10	11	11	13	19	20	20	16	16	25	23	12	17	17	14	12	12	346
12	12	11	12	11	10	10	13	20	16	17	17	18	13	11	11	11	10	11	17	23	23	19	12	12	337
13	12	12	12	11	10	10	13	12	13	17	17	17	16	17	14	13	11	11	18	25	25	17	12	12	347
14	11	12	12	11	11	10	13	16	14	14	17	18	17	20	17	14	22	17	16	17	17	13	12	12	352
15	12	12	11	12	10	11	18	23	16	12	11	12	16	18	19	24	26	18	17	19	26	17	12	12	383
16	12	12	12	12	10	11	11	11	11	14	18	17	16	18	16	12	11	10	14	16	11	12	12	11	307
17	12	11	12	12	12	11	11	12	11	13	24	19	17	19	16	13	11	11	13	16	13	13	12	12	325
18	12	12	12	11	11	10	13	17	16	12	12	11	11	11	11	17	25	25	22	17	12	12	12	12	334
19	12	12	11	12	11	10	11	11	10	11	11	11	19	25	22	19	20	17	16	23	16	16	12	12	347
20	12	12	12	12	11	11	11	12	18	19	17	18	14	18	17	20	22	16	16	19	19	13	12	12	362
21	11	12	12	12	11	11	11	10	11	12	17	13	14	17	17	18	26	19	22	17	11	13	12	12	340
22	12	12	12	12	11	11	13	20	22	24	19	12	16	18	20	22	25	23	18	18	16	12	12	12	391
23	12	11	12	12	11	10	13	19	16	17	19	14	16	18	14	14	25	20	11	11	11	11	12	12	341
24	12	12	12	11	11	10	13	13	16	13	17	18	19	19	16	24	24	20	22	18	13	12	13	12	370
25	12	12	11	11	11	10	13	19	14	12	11	11	13	12	14	13	11	11	11	11	10	12	11	12	287
26	12	12	12	11	11	10	11	10	11	13	17	17	16	11	11	20	26	22	24	19	23	16	13	11	356
27	12	12	12	11	11	10	16	18	16	14	25	14	17	23	19	14	12	11	20	16	14	12	12	11	352
28	11	12	12	10	10	11	11	10	11	10	11	12	11	11	11	13	19	16	16	17	17	13	12	12	295
29	11	12	11	11	10	10	17	19	17	12	10	12	13	17	12	12	16	18	18	11	11	12	11	12	312
30	11	12	11	11	10	11	10	11	11	16	19	23	19	18	14	19	20	17	16	18	17	13	11	12	348
31	11	12	11	11	10	11	10	11	11	15	19	20	19	18	14	19	18	17	15	16	15	12	11	12	337
																					Total				10.449

Table A.11. Hourly consumption in October (in kWh) (© SKANSKA Sverige AB)

November

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
1	13	12	13	12	12	13	13	12	13	13	13	13	17	20	22	22	24	22	18	14	13	13	13	12	364
2	12	13	12	12	12	13	14	19	20	22	18	17	14	13	12	13	16	18	13	13	12	13	13	12	348
3	12	12	13	12	13	12	12	12	14	20	13	12	16	16	19	20	19	13	13	14	12	12	13	12	338
4	12	12	13	12	12	13	16	18	13	13	13	13	16	19	18	16	12	12	13	13	13	12	12	12	329
5	13	12	12	12	13	12	14	13	13	18	23	18	22	26	22	18	17	12	14	13	13	12	13	12	368
6	12	12	12	12	13	12	13	13	12	19	17	17	17	24	23	19	28	28	23	13	13	12	12	13	389
7	12	12	12	12	13	12	11	12	13	19	30	20	18	12	13	14	17	17	13	12	11	12	12	12	342
8	11	12	12	11	12	11	12	13	12	12	12	13	17	20	18	18	17	12	14	13	13	13	13	12	324
9	12	13	12	13	12	12	14	18	17	18	26	20	16	16	19	13	14	12	12	12	13	13	12	13	354
10	12	12	13	13	13	13	12	12	13	12	12	12	16	19	25	22	23	23	17	13	12	13	12	12	356
11	12	12	12	12	13	12	12	13	12	14	19	18	16	20	14	12	12	11	12	12	13	12	13	12	322
12	13	13	13	13	13	12	16	20	18	16	22	18	16	14	13	16	30	23	13	14	13	13	12	13	378
13	12	12	13	12	13	12	12	13	12	12	13	13	16	23	22	23	25	20	13	13	12	13	13	12	355
14	13	12	13	13	12	12	13	12	13	14	19	17	13	12	12	17	26	14	14	19	13	14	13	12	346
15	13	13	13	13	13	12	13	13	12	13	12	12	19	30	24	12	14	17	18	14	13	12	13	12	353
16	12	12	13	12	12	13	12	11	13	16	19	13	16	19	18	17	24	25	16	14	13	13	12	12	358
17	13	12	13	12	13	12	12	12	13	13	12	12	14	18	18	16	29	23	12	12	13	12	13	12	342
18	13	12	12	13	12	13	12	12	12	12	11	12	23	25	19	18	13	12	12	12	12	11	12	12	328
19	12	12	13	12	12	12	12	12	12	13	18	18	13	13	11	20	29	24	14	12	13	11	12	11	342
20	12	11	12	12	11	12	19	25	16	12	11	12	11	12	11	18	31	24	18	11	12	12	12	11	347
21	12	12	11	13	12	12	13	19	16	16	19	18	17	14	11	14	18	20	25	30	12	12	12	12	371
22	11	12	12	12	12	12	16	14	13	14	13	11	17	28	24	19	24	17	13	11	12	12	11	11	350
23	11	12	12	11	12	11	10	11	11	11	11	11	12	11	10	13	18	18	14	11	12	11	11	11	283
24	12	12	11	12	12	11	11	11	11	11	11	11	13	14	13	16	24	18	16	16	13	13	12	12	314
25	11	12	12	11	12	11	16	20	18	17	20	18	22	24	22	18	19	17	17	20	13	12	11	11	383
26	12	11	12	11	11	12	14	28	17	14	18	18	23	23	12	16	23	19	22	18	20	17	12	11	392
27	12	12	12	11	12	11	11	17	19	14	12	11	13	13	11	18	17	11	12	18	14	13	12	11	317
28	12	12	11	12	12	11	18	18	16	14	17	11	16	18	18	14	25	19	18	16	19	13	12	11	362
29	12	12	12	13	12	11	13	18	14	16	18	13	12	11	11	11	11	11	12	20	19	16	12	12	322
30	12	12	12	12	12	11	11	11	12	16	26	23	20	11	12	13	14	13	11	11	11	12	12	12	322
																						Total			10.398

Table A.12. Hourly consumption in November (in kWh) (© SKANSKA Sverige AB)

December

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
1	11	11	12	12	10	11	16	20	16	19	16	13	20	20	18	16	24	18	14	20	24	17	12	11	380
2	12	12	11	12	10	10	11	11	11	13	16	14	17	22	18	17	19	17	19	23	23	18	11	12	356
3	12	11	12	12	11	10	16	23	19	22	11	14	18	18	17	18	22	18	17	19	20	16	12	12	378
4	11	12	12	11	11	10	14	19	18	13	16	19	11	11	11	12	17	13	14	19	18	13	12	12	329
5	11	12	11	12	12	11	13	17	13	12	19	17	13	12	11	13	20	17	19	19	19	16	11	12	342
6	12	12	11	12	12	10	13	18	16	16	17	16	13	19	17	20	23	17	16	18	17	12	12	12	359
7	12	11	12	12	12	10	11	11	11	11	11	11	14	16	17	13	17	16	17	22	24	16	12	11	326
8	12	12	12	12	11	11	17	22	18	12	12	11	11	11	11	16	24	14	12	11	12	13	12	12	319
9	12	12	12	12	12	10	11	11	11	11	11	11	14	20	17	13	14	17	12	10	13	12	12	12	301
10	12	12	11	12	12	10	14	19	16	16	18	16	19	23	24	23	22	25	17	16	13	12	12	11	383
11	12	12	11	12	12	11	11	11	11	16	16	16	14	19	17	19	20	22	19	16	16	13	11	12	347
12	12	13	12	12	12	11	14	19	17	18	20	18	12	11	11	16	20	19	22	19	16	12	12	12	360
13	12	12	13	12	12	11	14	18	14	13	18	18	19	25	18	16	20	17	11	11	12	12	12	12	353
14	12	11	12	12	11	11	11	14	20	20	19	17	16	26	16	23	22	19	16	14	19	14	12	12	379
15	12	12	12	12	12	12	16	12	11	13	18	16	16	12	11	16	20	16	12	14	16	12	12	12	325
16	12	12	12	12	11	11	17	26	19	20	17	17	20	14	18	17	28	20	17	19	18	12	12	12	394
17	13	12	12	13	12	11	14	20	17	14	16	16	17	20	16	18	14	11	11	12	12	12	12	12	337
18	12	12	13	12	12	11	16	26	20	16	19	14	19	20	25	25	24	19	20	23	20	14	12	12	419
19	12	12	12	13	12	11	17	16	18	16	11	11	12	11	12	11	16	16	12	12	13	12	12	12	310
20	12	12	13	12	12	11	13	19	16	13	11	11	14	18	14	13	18	19	16	12	18	19	12	11	340
21	12	13	12	12	12	11	11	11	14	13	17	16	17	24	24	26	19	20	23	20	22	14	12	12	388
22	11	12	11	12	12	11	16	14	11	13	16	18	13	16	16	13	13	12	13	17	17	12	12	12	322
23	12	11	12	12	12	11	11	11	11	13	11	11	11	11	11	16	26	16	13	12	12	12	12	12	300
24	12	12	12	12	12	12	14	19	14	11	12	11	17	18	18	18	16	13	16	18	17	14	12	12	342
25	12	11	12	12	12	11	13	17	11	18	23	22	19	20	17	11	11	11	16	23	17	14	12	12	355
26	11	12	12	12	12	11	16	31	22	13	17	14	14	18	19	18	20	17	19	20	18	13	11	12	383
27	12	12	11	12	12	11	13	18	17	18	23	24	16	16	12	18	28	22	23	28	28	14	12	12	409
28	11	12	12	12	12	11	13	16	13	13	18	12	12	17	19	23	22	23	24	17	18	14	12	12	367
29	12	12	12	13	12	11	11	12	11	10	12	11	17	23	18	18	20	18	22	19	16	13	12	11	344
30	12	12	12	12	12	12	11	11	11	17	12	20	18	20	18	13	19	16	17	13	12	12	12	13	337
31	12	12	12	12	13	12	17	24	16	17	22	22	22	20	13	16	20	23	14	16	16	13	12	12	386
																						Total			10.970

Table A.13. Hourly consumption in December (in kWh) (© SKANSKA Sverige AB)

Next monthly graphs show the evolution of consumption for the whole building group NOPQ throughout the year.

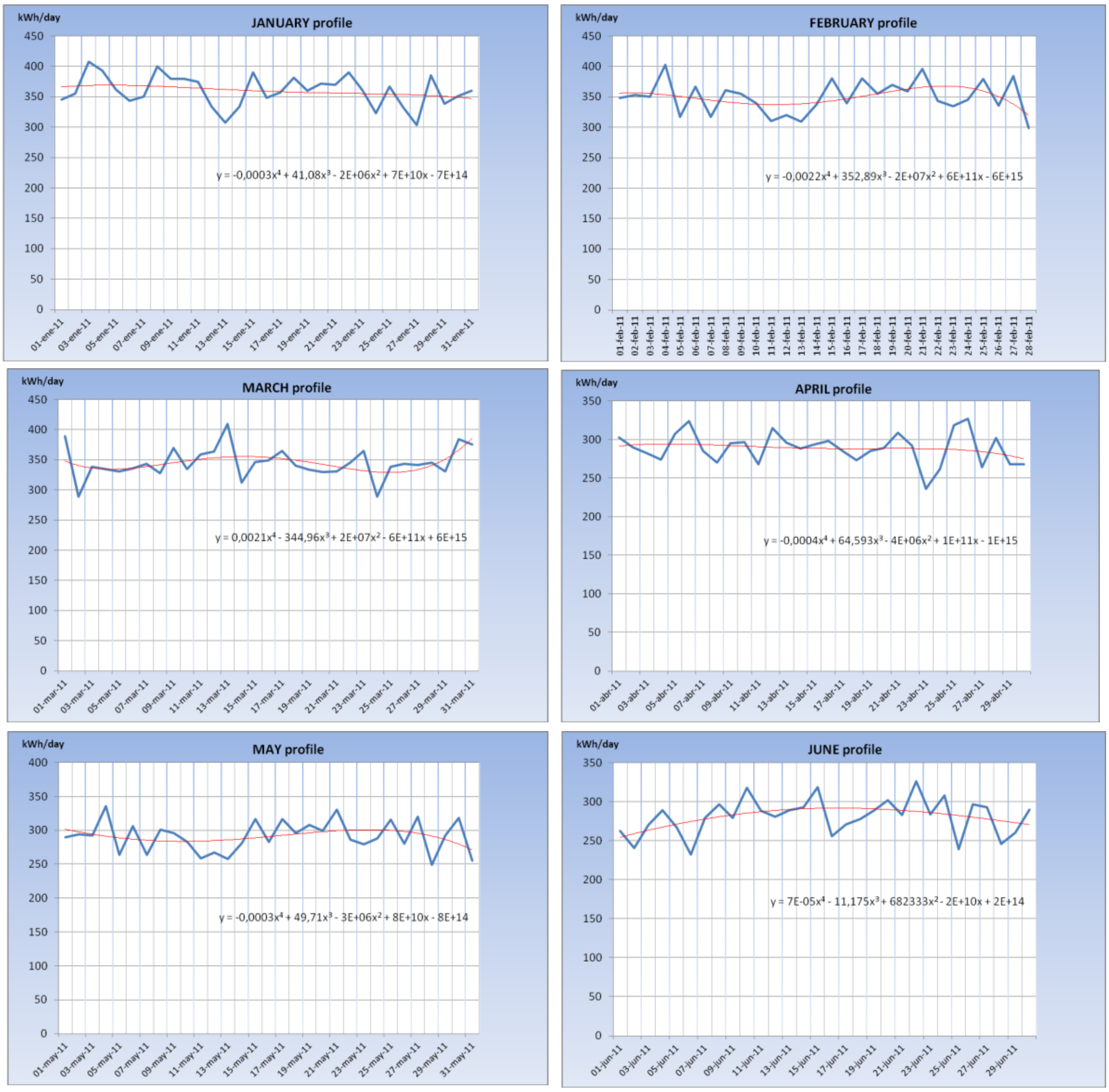


Fig. A.1. Monthly consumption profiles from January to June

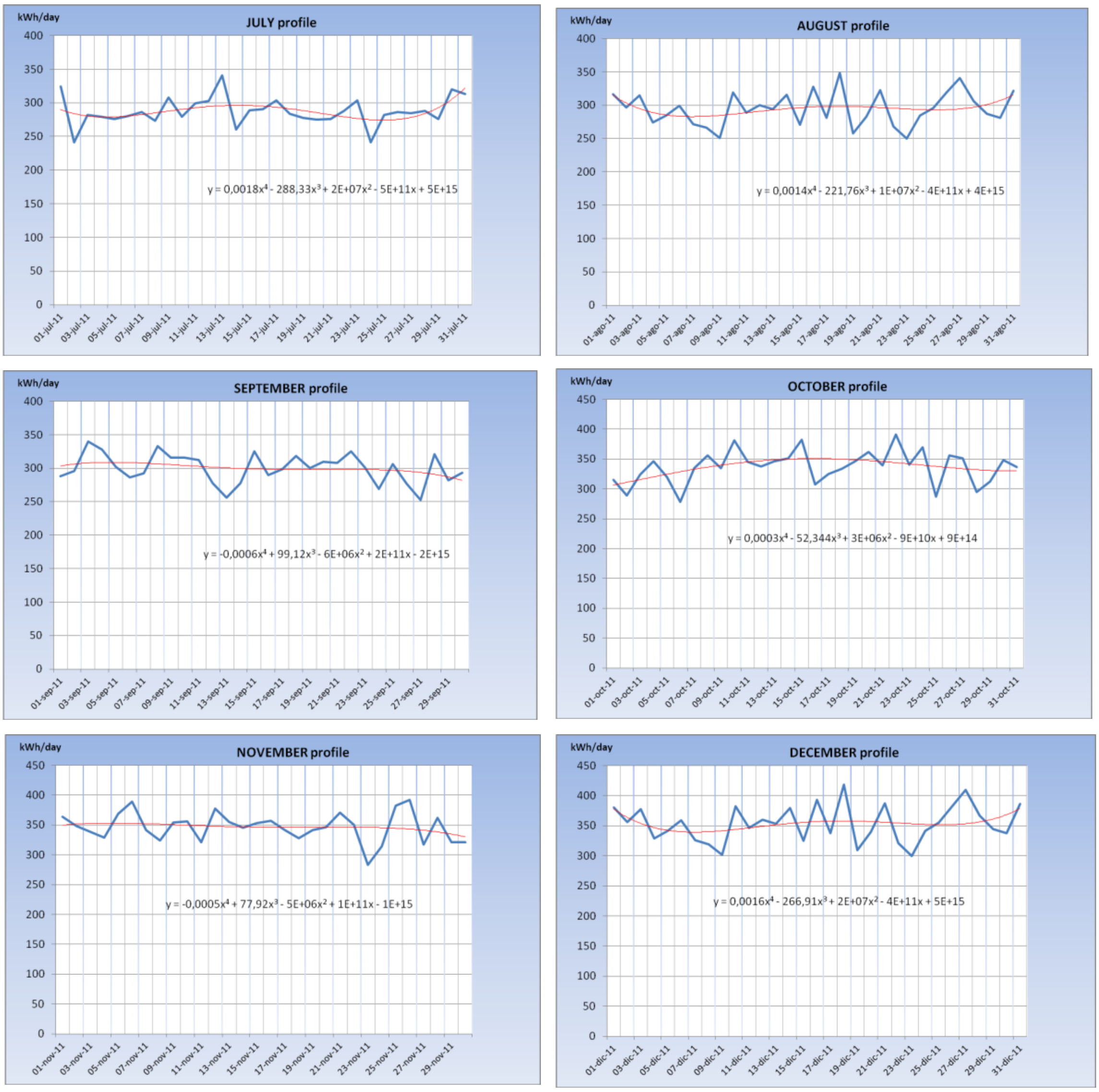


Fig. A.2. Monthly consumption profiles from July to December

Next monthly graphs show the evolution of average consumption throughout the day for the whole building group NOPQ.

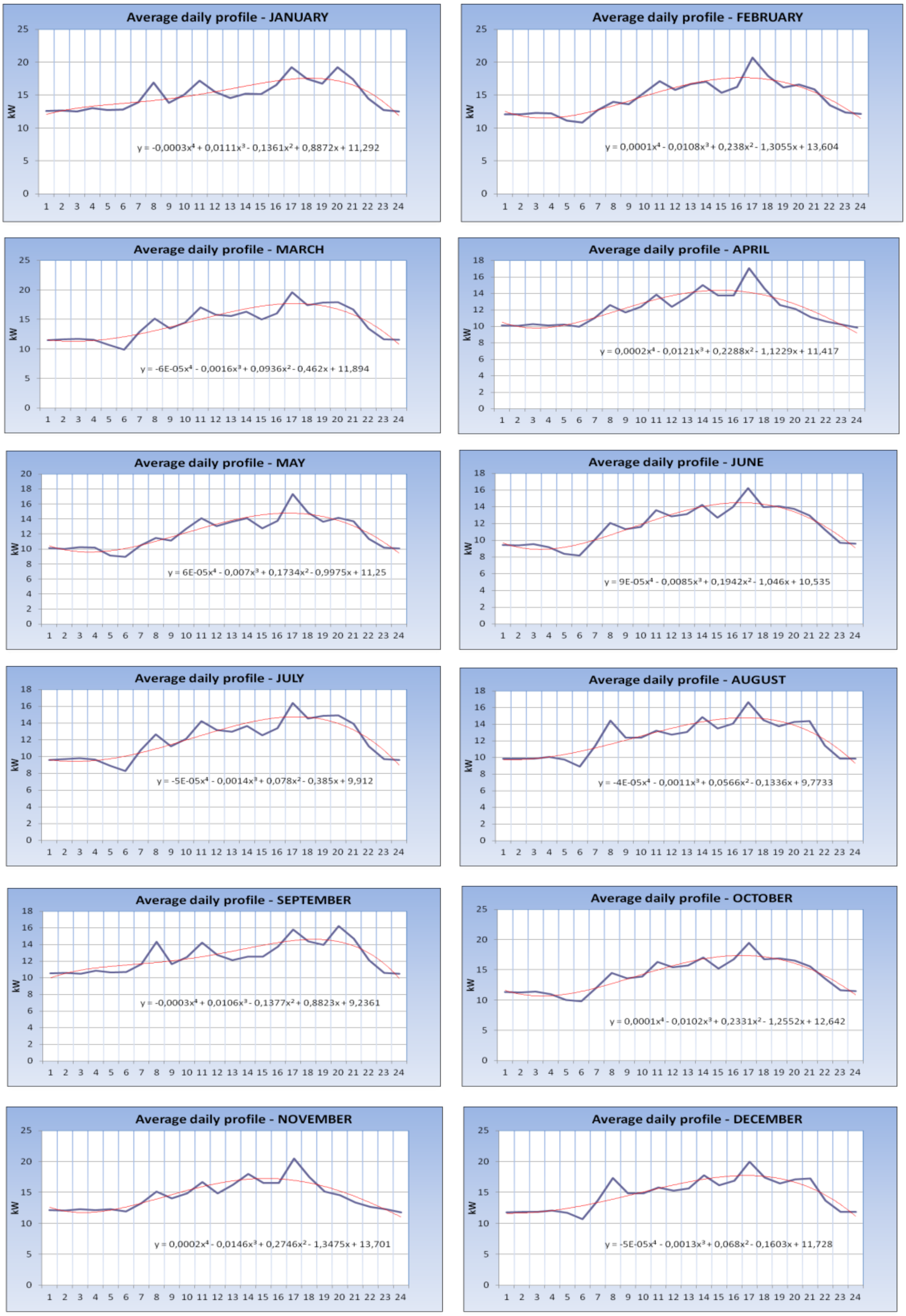


Fig. A.3. Average daily consumption profiles from January to December

A.2 Weather data compilation for Alingsas-Brogården

Next tables show the main meteorological parameters for Alingsas site, extracted from NASA-SSE database. The yellow marked parameters have been referred along the report. The rest of parameters have been included for better understanding of results.

Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface ($kWh/m^2/day$)

Lat 57 Lon 12	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
SSE HRZ	0.50	1.18	2.39	3.74	5.09	5.38	5.21	4.30	2.84	1.40	0.68	0.37	2.76
Diffuse	0.35	0.73	1.37	2.02	2.60	2.76	2.63	2.22	1.51	0.84	0.45	0.26	1.48
Direct	0.96	1.79	2.79	3.67	4.76	4.87	4.85	4.21	3.26	1.92	1.25	0.84	2.94
Tilt 0	0.50	1.17	2.37	3.72	5.11	5.45	5.27	4.31	2.79	1.38	0.67	0.35	2.76
Tilt 42	1.01	1.92	3.15	4.19	5.09	5.11	5.07	4.60	3.53	2.08	1.28	0.78	3.15
Tilt 57	1.10	2.01	3.15	4.00	4.66	4.62	4.60	4.32	3.48	2.15	1.39	0.86	3.03
Tilt 72	1.13	2.00	3.01	3.62	4.12	4.03	4.04	3.88	3.27	2.11	1.41	0.89	2.80
Tilt 90	1.09	1.86	2.64	3.00	3.26	3.13	3.16	3.15	2.81	1.92	1.35	0.87	2.36
OPT	1.13	2.02	3.17	4.21	5.34	5.52	5.39	4.68	3.53	2.15	1.41	0.89	3.29
OPT ANG	72.0	63.0	50.0	34.0	21.0	12.0	18.0	28.0	45.0	59.0	70.0	75.0	45.4

Monthly Averaged Daylight Cloud Amount (%)

Lat 57 Lon 12	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	57.1	61.0	63.4	64.2	59.9	63.0	59.8	61.3	62.5	64.6	60.4	56.0	61.1

Monthly Averaged Earth Skin Temperature (°C)

Lat 57 Lon 12	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	-2.45	-1.71	1.08	5.84	11.7	15.5	17.6	16.9	12.0	7.22	1.72	-1.39	7.07

Monthly Averaged Wind Speed At 10 m Above The Surface Of The Earth For Terrain Similar To Airports (m/s)

Lat 57 Lon 12	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	3.97	3.53	3.68	3.57	3.59	3.48	3.44	3.36	3.79	3.91	3.92	3.91	3.68

Monthly Averaged Relative Humidity (%)

Lat 57 Lon 12	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	82.5	79.1	74.4	69.5	62.2	63.0	64.2	66.4	70.6	77.7	83.0	84.0	73.0

Monthly Averaged Precipitation (mm/day)

Lat 57 Lon 12	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	2.41	1.97	1.65	1.63	1.62	2.56	2.41	2.42	2.74	2.76	2.37	2.38	2.24

Monthly Averaged Surface Albedo (0 to 1.0)

Lat 57 Lon 12	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	0.20	0.15	0.12	0.07	0.08	0.14	0.13	0.13	0.13	0.11	0.18	0.17	0.13

Table. A.14. Main weather parameters at Alingsas site (© NASA-SSE database)

References

[1] Valentin Software Inc., official web site (English version): http://www.valentin.de/en

[2] NASA-SSE, official meteorological data web: http://eosweb.larc.nasa.gov/sse/

[3] SKANSKA Sverige AB, Lin Liljefors, 2010. "*Locally produced renewable electricity for heating at Brogården*". Bachelor thesis in physics, sustainable energy.

[4] METEONORM software, official web site: http://meteonorm.com/

[5] PVGIS tool, official web site: http://re.jrc.ec.europa.eu/pvgis/

[6] RETScreen International, official web site: http://www.retscreen.net/ang/centre.php

[7] Schüco International, official web site (English version): http://www.schueco.com/web/de-en

[8] IET (Institute for Energy and Transport), official web site: http://iet.jrc.ec.europa.eu/

[9] HOMER software, official web site: http://www.homerenergy.com/

[10] PVSYST software, official web site: http://www.pvsyst.com/

[11] GOOGLE EARTH tool, official web site: http://www.google.es/intl/es/earth/index.html

[12] EUROPE´S ENERGY PORTAL official web site: http://translate.google.com/translate?hl=es&sl=en&tl=es&u=http%3A%2F%2Fwww.energy.eu%2F&anno=2

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- SKANSKA, 2011. Real consumption data from Houses AB, CDEF at Brogården site.

Software Tools

- METEONORM Version 6.1 software tool
- PV*SOL Expert Pro Version 5.5 software tool
- RETScreen 4 software tool
- HOMER v2.68 Beta software tool