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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 D4.5: Protocol for integration of electricity generation systems in Brogården

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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 protocol for integration of electricity generation systems in Brogården. This means that the info compiled in this report refers to the specific project at Brogården site, but with a generic character to enable to other future projects to apply this protocol.

Chapter 1 describes the objectives of the report.

Chapter 2 includes an update of several questions or conditions already treated on first deliverable report D4.2 but in the meantime between writings of both reports have changed.[1]

Chapter 3 discusses the Swedish electrical supply company review, including information related to National situation in Sweden, local situation at Brogården and massive market uptake.

Chapter 4 presents detailed information and results for application in Brogården site. This chapter describes how the selected PV installation is, what size it has, the specific questions and solutions for mounting PV panels on Balconies, Facades and Roofs, a brief energy balance for the selected solution and an economical estimation of investment.

Chapter 5 shows the main aspects and considerations about how a common GERES design should be treated. This chapter also includes the simplification made in GERES design for applying to specific Brogården site.

Chapter 6 presents the main findings from the report.

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Chapter 1 Objectives

The aim of this report is being a basic reference for showing the main guidelines of the procotol to carry out the integration of a PV installation to produce electricity at Brogården.

This report can be seen as a generic reference for similar future BEEM_UP projects located at other sites.

The specific results showed in this report referred to Brogården site can help to a better understanding of the questions treated in the different stages of the protocol.

The main stages in a general protocol could be split in the following points:

- Assessment of the PV installation
- Electrical supply companies review
- Application of the PV installation selected at the site
- Design of the specific GERES
- Economical estimation of the investment

The **assessment of the PV installation** consists of a comprehensive approach to electrical network of the building. It identifies the real electrical energy demanded by the loads and estimates the renewable electrical energy produced by the sources. From these data, the energy balance is obtained which is important to know the detailed evolution of the system throughout the time.

The production of energy is calculated taking into account different possible alternatives (for example, assessing several places or surfaces for locating PV panels, or assessing if a energy storage system can be included, ..).

This work was made at the first deliverable report D4.2.[1]

The review of the electrical supply companies let knowing the current and nearby future situations, helps to identify and know the agents implicated in the system (electrical supply companies, grid owners, clients, etc.), and other things (like european, national and local regulations). As a consequence of this analysis, it can be defined what bussiness model is the best to apply to the project, and which are the main economical parameters (electricity tariffs, fundings, other restrictions about bought or sold electricity, etc.).

This issue is completely treated on Chapter 3 at the present report.

After that, with all prior information and results in mind, a discussion has to be made to decide which is the best alternative to integrate at the specific site. The **application of the PV installation selected for the specific site** defines the final configuration of the system (PV panel models and quantities, installation surfaces, ..), compiles the mounting or installation problems and solutions applied for solving them. Furthermore, it includes a final energy balance of the system.

This issue is completely treated on Chapter 4 at the present report.

Figure 1.1. below shows a flow diagram with the main stages to cover for integrating a PV system.

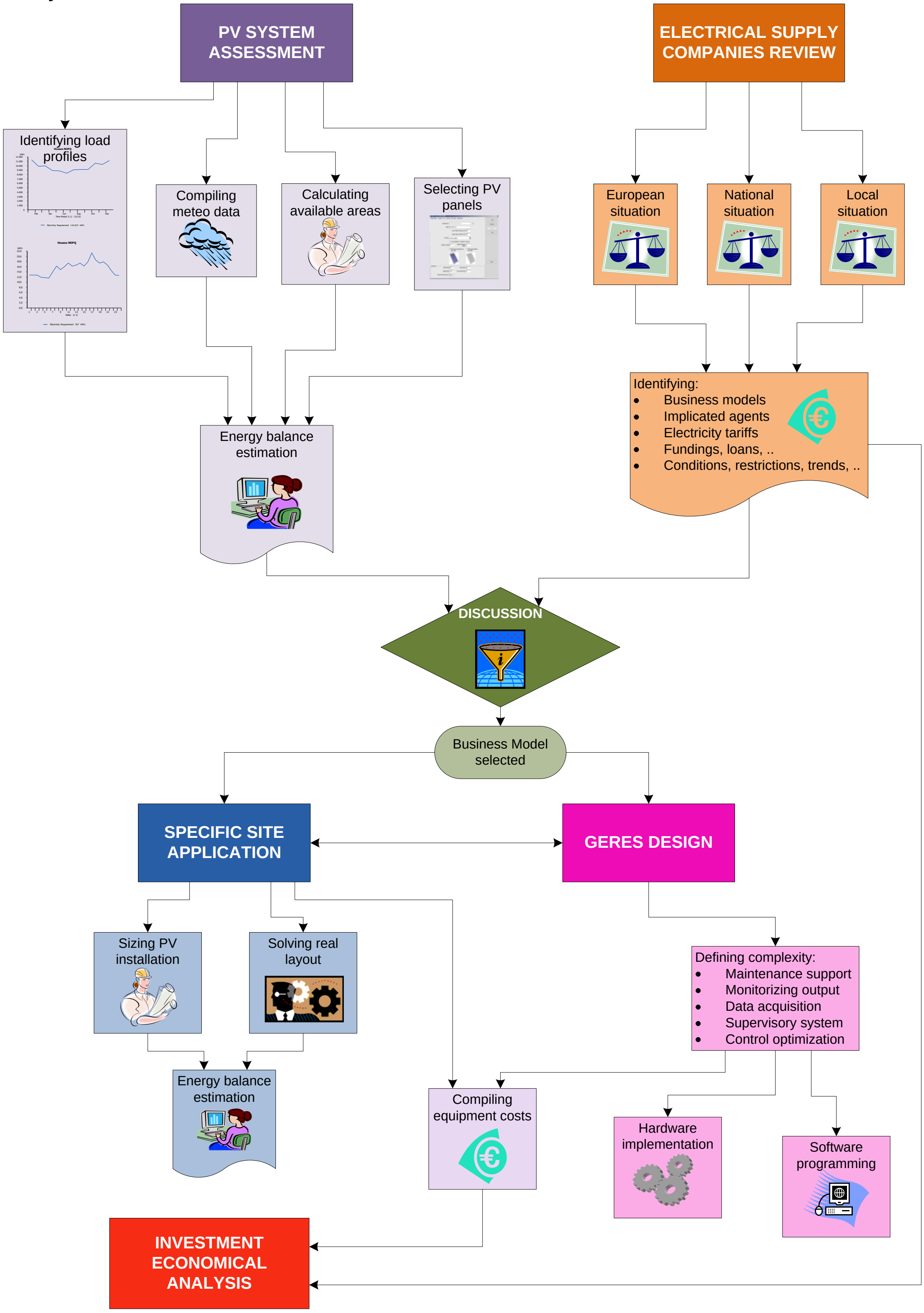

Fig. 1.1. Main stages in a general protocol for integrating a PV system

The **GERES design** can be widely different in complexity depending on the bussiness model selected and the definitive configuration at the specific site.

In general, it could consist of a supervisory and control system, which includes the integration of the corresponding hardware and software to carry out the monitoring and control tasks.

These kind of supervisory and control systems let from keeping an appropriate maintenance of the installation (the most basic situation) to controlling the energy production of the PV panels in real time. Furthermore, they give lots of information to compile and analyze the time evolution, or to compare the simulated production with the real one, for example.

This issue is completely treated on Chapter 5 at the present report.

In the end, the definitive **economical estimation of the investment costs** is made taking into account all the hardware equipments and software components, the mounting and installation costs, and the eventual maintenance costs. Also, other issues can be included as the possibility of getting funding, bank loans needed, ..

Chapter 2 Deliverable D4.2. update

From the finalization of the first report there have been some conclusions, modifications and changes about some items of the project refered to Brogården site. These questions are to be showed in this chapter.

2.1 Loads

The main difference is the idea of considering the group of four Houses NOPQ as only one load for the energy balance calculations.

In the first deliverable report D4.2[1], the consumptions of the Houses were considered on independent way because its high flexibility in the ulterior design of the hardware layout, but due to the residential electricity at Brogården is measured at only one point it is more real to consider it as only one load.

Moreover, the definitive consumption loads included are going to be the residential electricity (electricity for fans and pumps, stairwell lighting, elevators) and also the electricity for laundry rooms.

As a consequence of these slight modifications, the expected demand for the four Houses NOPQ is estimated to **8,500 kWh in June**.

Another slight correction refers to the correlation factor for consumptions among summer and winter periods used in the estimations in the first deliverable report D4.2[1], which was 1.2, and new analysis have revealed a better approximation value of **1.1** (10%).

From these modifications the yearly energy demand will be approximately **108 MWh**.

Figures 2.1. and 2.2. below show the yearly and daily profiles of the total consumption taking into account mentioned modifications:

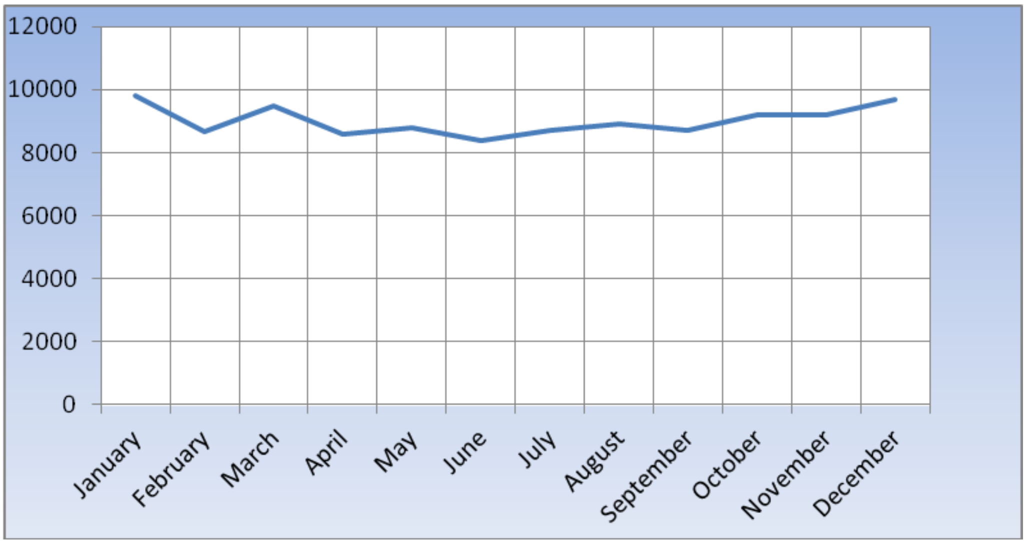

Fig. 2.1. Yearly profile of the total consumption for Houses NOPQ (in kWh)

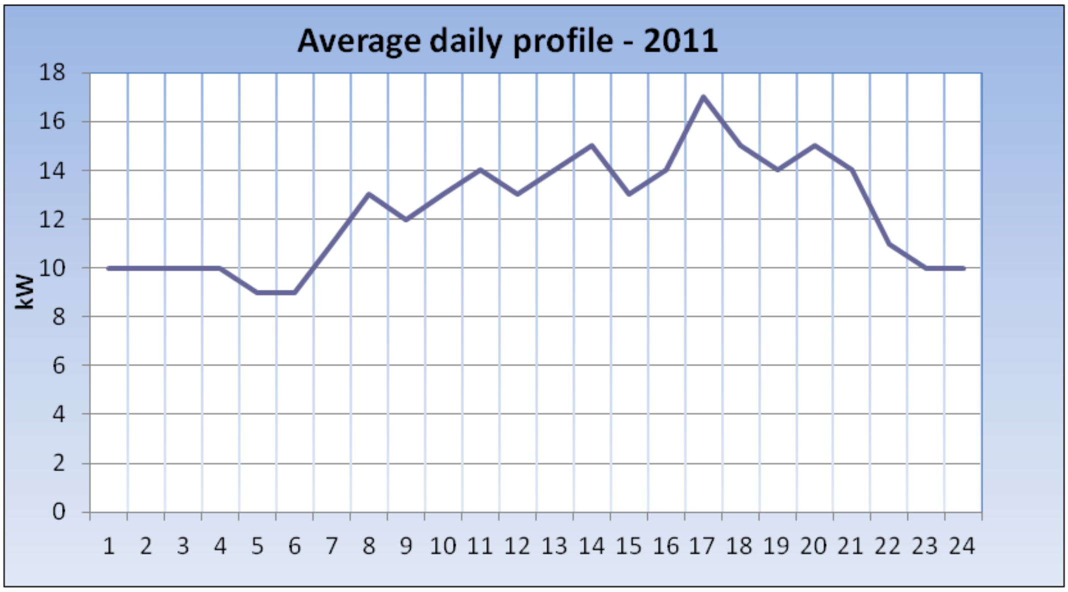

Fig. 2.2. Average daily profile of the total consumption for Houses NOPQ in 2011

As it can be seen the profiles keep the same behaviours, but with values a little bit lower.

2.2 Electricity tariffs

The tariff for bought electricity in Sweden was assumed to be 1.82 SEK/kWh on the first deliverable report D4.2. [1]

After carrying out a more detailed review of the Swedish electrical supply companies, this value has demonstrated to be too high. In next Chapter 3, this question is treated in depth, and economical calculations under new conditions are included in Chapter 4.

2.3 Funding conditions

The funding conditions to apply for integrating solar installations put in the first deliverable report D4.2[1] were up to 55% of the investment cost, or a maximum of 2,000,000 SEK per solar cell system, as well as the maximum cost per installed kWp was around 75,000 SEK.

The current figures for funding conditions are limited to **45% of the investment cost**, or **1.5 million SEK per installation**. In Brogården an application for funding is made in spring 2011, but whether it will be granted or not will probably not be known until the end of 2012. The possibilities to get similar funding during 2013 are still unknown.

2.4 Regenerative elevators

This point was treated at a workshop held in Brogården 6th of April 2011, with 11 participants were representing Skanska, Alingsåshem, MP-Lifts and RC-hiss (a local actor in the elevator business) to study and analyze the optimal options for elevator systems to be installed in those buildings of Brogården associated to BEEM-UP project.

More information about this workshop can be consulted in the report "*Report from Skanska to be included in Deliverable D1.4. Three workshops per site for the integration of industrial solution*", written by Skanska in 2012/03/19. [2]

2.4.1 MPLIFTS initial proposal of lifts for Brogarden site

The general features (and requirements) of buildings in Brogården are:

- 3 or 4 floors
- 3 dwellings each floor
- residential use (private)
- no previous lift shaft (complete modernization)
- shaft location to be determined
- special dimensions for headroom and pit (small height)
- maximum energy consumption for Brogården: 13 kWh/m2
- expected vertical traffic: very low, VDI cat1 (0.2 hrs/day or 48 travels/day)
- predominant energy consumption: standby

According to the above requirements, MP Lifts proposed to install gearless traction lifts (which are the elevators with the highest energy efficiency). More precisely the lift model proposed for the typical Brogården building was the **MP GO Evolution**. Their features are presented below:

- Machineroom-less elevator
- 2:1 roping with centred point of car suspension
- Rated load, Q, 630 kg (8 passengers)
- Rated speed, v, 1.0 m/s
- Car dimensions, 1100 x 1400 x 2100 mm3
- Door type, 2-panel automatic side opening
- Power supply 3-phase, 400 Vac
- Rated power, 4.2 kW
- Rated current, 10.5 A
- Shaft dimensions, 1600 x 1700 mm2
- Minimum pit depth, 650 mm
- Minimum headroom height, 2900 mm
- Energy efficiency options:
    - intelligent car lighting system (LED with programmable switch-off)
    - standby mode

The pictures below show the plan drawings of MP Go Evolution Lift.

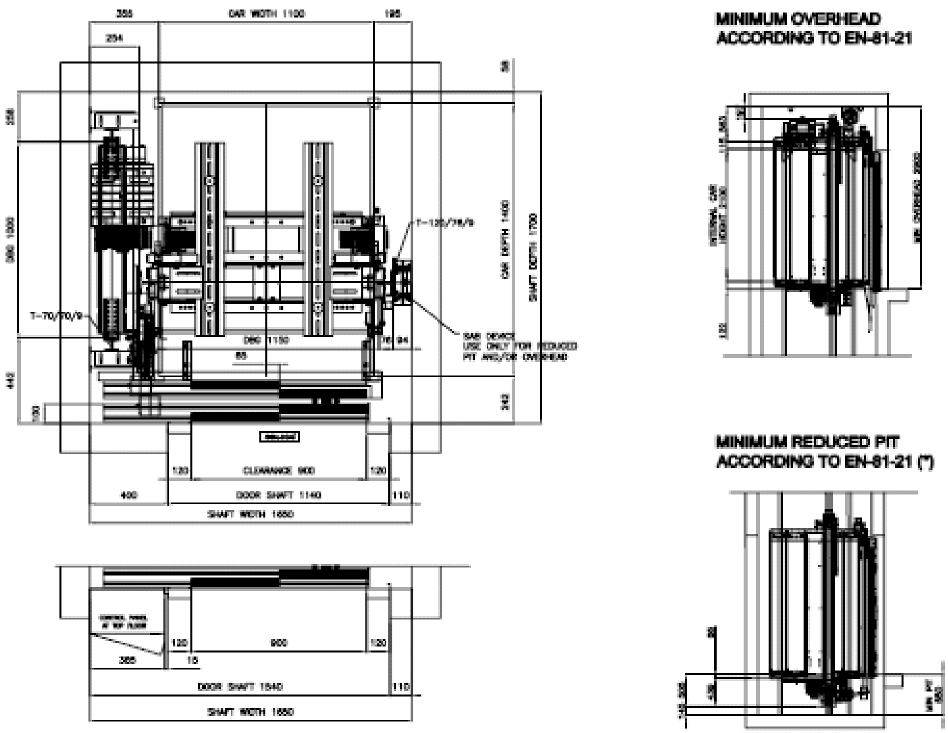

Fig. 2.3. Plan drawings of the MP Go Evolution Lift model

The REGEN system was rejected due to the lack of conditions for the system to be efficient and economically feasible. These conditions are:

- Long car travel, to get enough generation time
- High rated load, to get power
- Intense traffic, to get repetitiveness of the generation process
- Lift grouping, to reduce the amount of investment

2.4.2 Comparative Energy Performance among different lift technologies (in Brogården site)

After extensive and detailed studies carried out by MPLIFTS, based on reliable data achieved from a large amount of lift installations in different building types, we have concluded that the break-even point for the REGEN system is determined by the following minimum parameters:

- 1000 kg (10 passengers) rated load
- 25 m travel (or 10 building levels)
- 1440 travels/day (60 starts/hour)

The next figures show how this break-even point is calculated for a 1000 kg lift under VDI-5 traffic conditions:

Daily traffic 1440 trav/day (**usage category 5**, as per VDI 4707)
Residential bulding
Elevator main features: Gearless traction lift 1000 kg, 1.0 m/s, 7.5 kW, DUPLEX arrangement
Price of kWh: 1,26 SEK (tax included)
Annual increase Price of Energy 5,00 %

Nº stops		8 stops		10 stops		12 stops		14 stops		16 stops	
Energy-efficiency options		BASIC	REGEN	BASIC	REGEN	BASIC	REGEN	BASIC	REGEN	BASIC	REGEN
Lighting		161	161	161	161	161	161	161	161	161	161
Stand-by		416	613	416	613	416	613	416	613	416	613
Working		2838	1035	3359	1225	3877	1414	4398	1604	4919	1794
TOTAL		3415	1809	3936	1999	4454	2188	4975	2378	5496	2568
Energy saving	(%)	0	47,03	0	49,21	0	50,88	0	52,20	0	53,28
	kWh		1606		1937		2266		2597		2928
Money saving	SEK		2023,56		2440,62		2855,16		3272,22		3689,28
	Pay-back (yrs)		13,12		11,41		10,12		9,09		8,25

Energy-efficiency options:
BASIC Intelligent car lighting + Standby mode
REGEN Intelligent car lighting + Standby mode + REGEN sys

Relation stops-travel
8 stops 21 m
10 stops 27 m
12 stops 33 m
14 stops 39 m
16 stops 45 m

Break-even Point is achived when the investiment recovery is equal or less than 10 years (30% of the whole elevator's life)

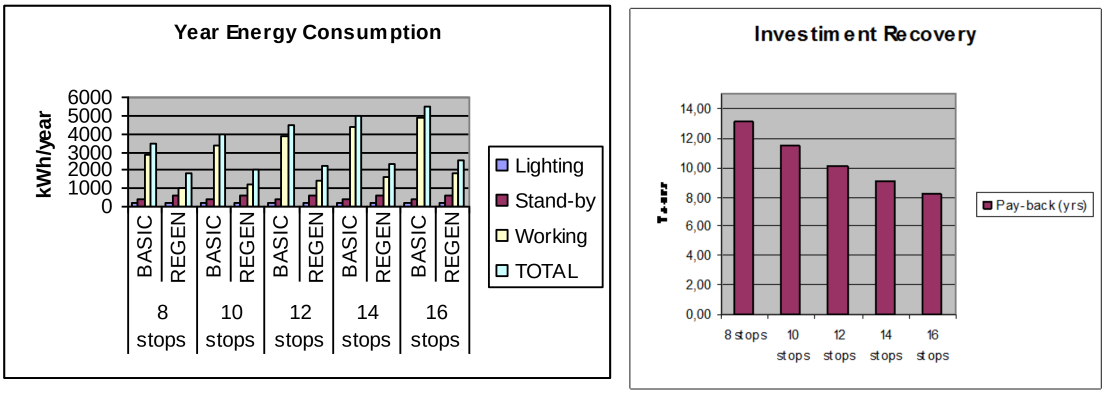

Fig. 2.4. Calculation of the break-even point for a 1000 kg lift under VDI-5 traffic conditions

Residential bulding 4 levels
Daily traffic 48 trav/day (usage category 1, as per VDI 4707)
Elevator main features: Gearless 630 kg, 1.0 m/s
Price of kWh 1,26 SEK (tax included)
Year increase price of energy 5,00 %

Electric Consumption		Elevator Technology	
		Gearless	REGEN gearless
Lighting		72	72
Stand-by		573	865
Working		63	9
TOTAL		708	946
Energy saving	%		-33,62
	kWh	0,00	-238,00
Money saving	SEK	0,00	-1190,00

Energy-efficiency options:
Gearless Intelligent car lighting + Standby mode
Gearless REGEN Intelligent car lighting + Standby mode + REGEN sys

Fig. 2.5. Calculation of the energy savings for a 630 kg lift under VDI-1 traffic conditions

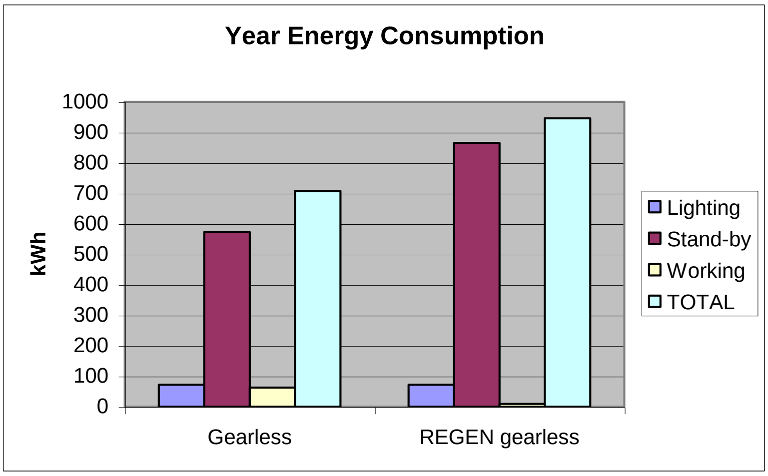

Fig. 2.6. Yearly energy consumption for a 630 kg lift under VDI-1 traffic conditions

Finally the graphs below show a comparative performance among the possible technologies able to be installed in Brogården:

Residential bulding 4 levels
Daily traffic 36 trav/day (usage category 1, as per VDI 4707)
Elevator main features: Hydraulic 630 kg, 0.63 m/s
Gearless 630 kg, 1.0 m/s

Electric Consumption	Elevator Technology		
	Hyd 3VF	Gless	Gless REGEN
Lighting	72	72	72
Stand-by	483	573	865
Working	397	63	9
TOTAL	952	708	946

Energy-efficiency options:
Hyd 3VF Intelligent car lighting + Standby mode + Electronically controlled Valve & Drive
Gless Intelligent car lighting + Standby mode
Gless REGEN Intelligent car lighting + Standby mode + REGEN sys

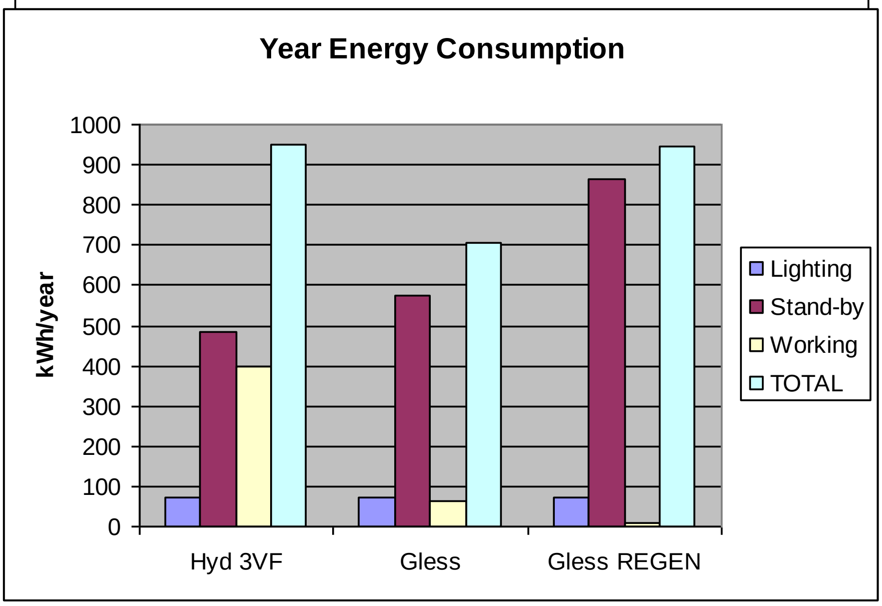

Fig. 2.7. Break-even point and yearly energy consumption comparative among different lift models available in Brogården site

As it can be seen from the graphs, under these conditions (630 kg-lift and VDI-1 usage category), the gearless lift has a small advantage in terms of energy consumption. Gearless+REGEN lift has no advantages at all and shows the same total level that the hydraulic 3VF lift. Although the Gearless+REGEN has a negligible consumption in working (travelling) mode, its consumption in standby mode is by far the greatest of the three solutions. This is due to the own consumption of the REGEN system in the running periods when it is not generating power. This fact combined with the very low traffic level (predominance of standby periods) offsets the worse running performance of the hydraulic lift.

2.4.3 Description of the technical solution adopted in Brogården

After developing the LCC study by SKANSKA and MP Lifts (see graphs below), a hydraulic solution was adopted.

Residential building 4 levels
Daily traffic 48 trav/day (usage category 1, as per VDI 4707)
Elevators main features:

Gearless: 630 kg, 1.0 m/s, intelligent car lighting, standby mode
Hydraulic: 630 kg, 0,63 m/s, intelligent car lighting, standby mode, electronically controlled valve and drive

Price of kWh 1,26 SEK (tax included)
Year increase price of energy 5,00 %

Electric Consumption		Elevator Technology	
		Hydraulic	Gearless
Lighting		72	72
Stand-by		483	573
Working		397	63
TOTAL		952	708
Energy saving	%	0,00	25,63
	kWh	0,00	244,00
Money saving	SEK	0,00	307,44
	Pay-back (yrs)		49,46

Fig. 2.8. Energy savings comparison among hydraulic and gearless lifts under VDI-1 traffic conditions

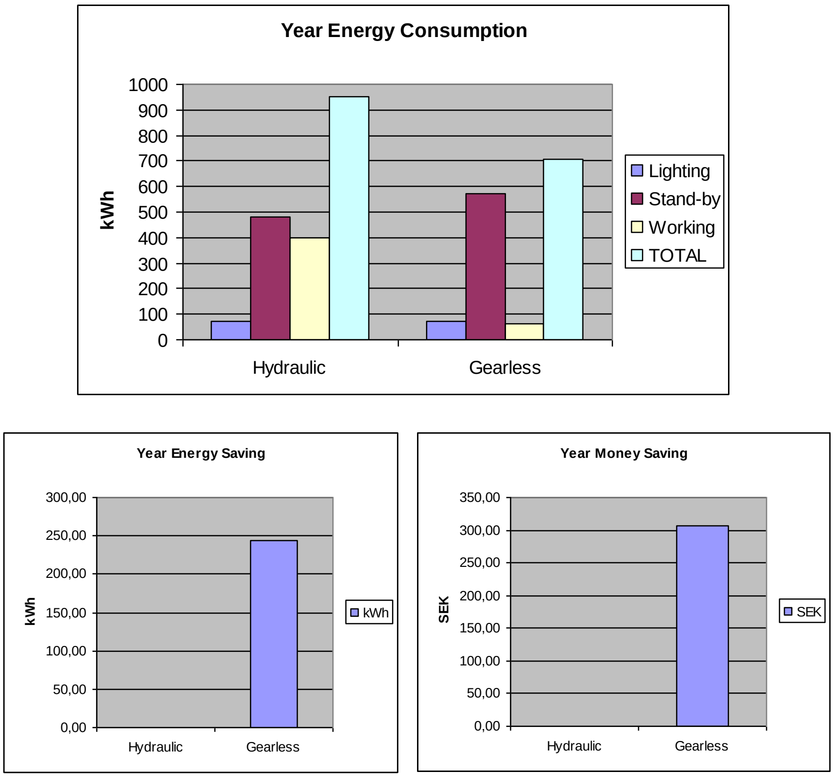

Fig. 2.9. Yearly energy consumptions and savings comparison among hydraulic and gearless lifts under VDI-1 traffic conditions

Despite the smaller energy consumption of REGEN gearless lift (about 25%), the bigger investment needed gives a payback period of more than 49 years (longer than the estimated life of an elevator, about 30 years).

So the solution finally adopted is an electronically controlled hydraulic elevator, model **MP H-01**. The main features of this model are presented below:

- Machineroom-less elevator
- 2:1 roping with rucksack arrangement
- Rated load, Q, 630 kg (8 passengers)
- Rated speed, v, 0.63 m/s
- Car dimensions, 1100 x 1400 x 2100 mm3
- Door type, 2-panel automatic side opening
- Power supply 3-phase, 400 Vac
- Rated power, 9.5 kW
- Rated current, 16.0 A
- Shaft dimensions, 1600 x 1700 mm2
- Minimum pit depth, 200 mm
- Minimum headroom height, 2900 mm
- Energy efficiency options:
  - Intelligent car lighting system (LED with programmable switch-off)
  - Standby mode
  - Electronically controlled valve
  - Pump motor controlled by frequency converter

The following lines give a more detailed description of the energy efficiency options.

i) **Intelligent car lighting**: The system is based on LED technology (longer life, smaller power for the same luminosity) and is switched off every time the car has stopped and the passengers have left without decreasing the whole life of the lamp.

ii) **Standby mode**: This electronic system allows all no-needed electrical items to be switched off when the lift is expected to be still for a long period of time (for instance, night periods). Just the electrical items that make up the security system of the lift are permanently “awake”.

iii) **Electronic valve**: This device controls the hydraulic flow from pump to the ram and has smaller power losses than the traditional solenoid-actuated valves.

iv) **Frequency converter**: It is a solid state power electronics device directly connected to the motor that saves energy adjusting smoothly the power supplied to the car speed.

In the graphs below is showed a comparative among the different energy-efficiency options for hydraulic lifts. The main features of each energy option is briefly described below:

- Basic: hydraulic lift with soft-start system
- ENE-1: Soft-start + Intelligent car lighting
- ENE-2: Soft-start + Intelligent car lighting + Standby mode
- Elec/Valv: Intelligent car lighting + Standby mode + Electronically controlled Valve
- 3VF: Intelligent car lighting + Standby mode + Electronically controlled Valve and drive

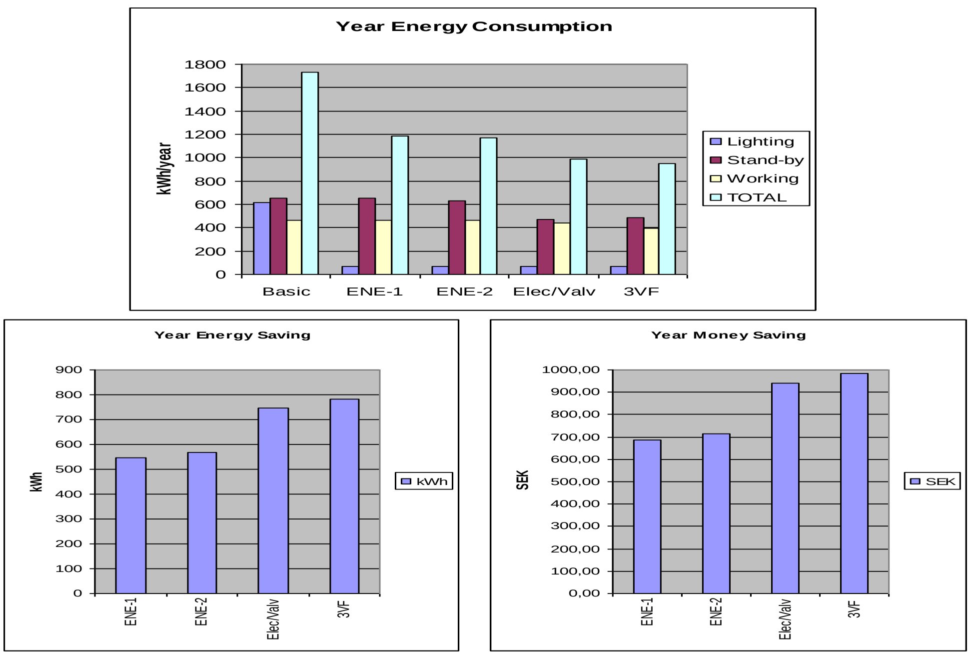

Fig. 2.10. Yearly energy consumptions and savings comparison among different energy efficiency options

The plan and construction drawings of the **MP H-01** lift are presented below:

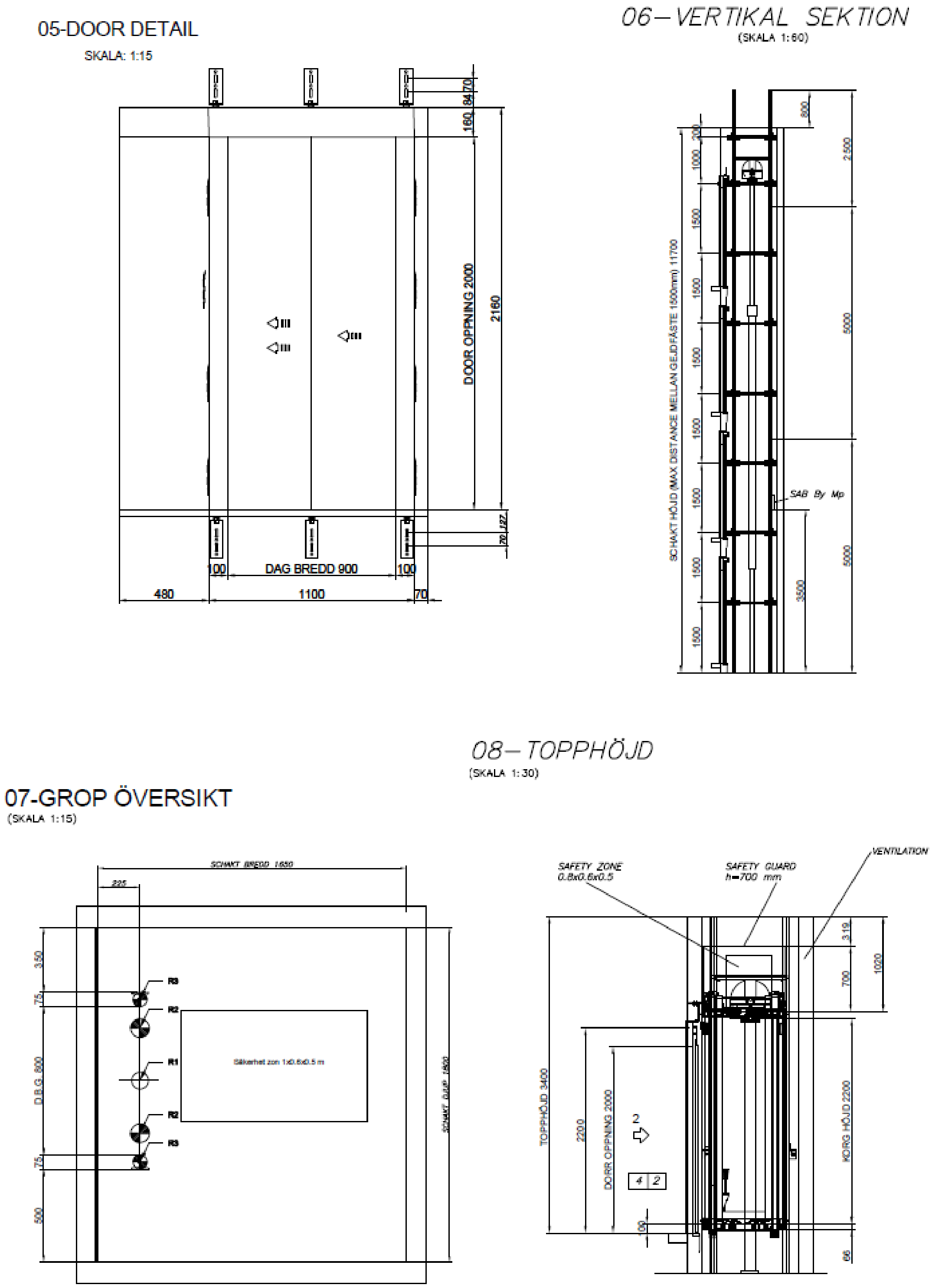

Fig. 2.11. Plan and construction drawings of the MP H-01 lift

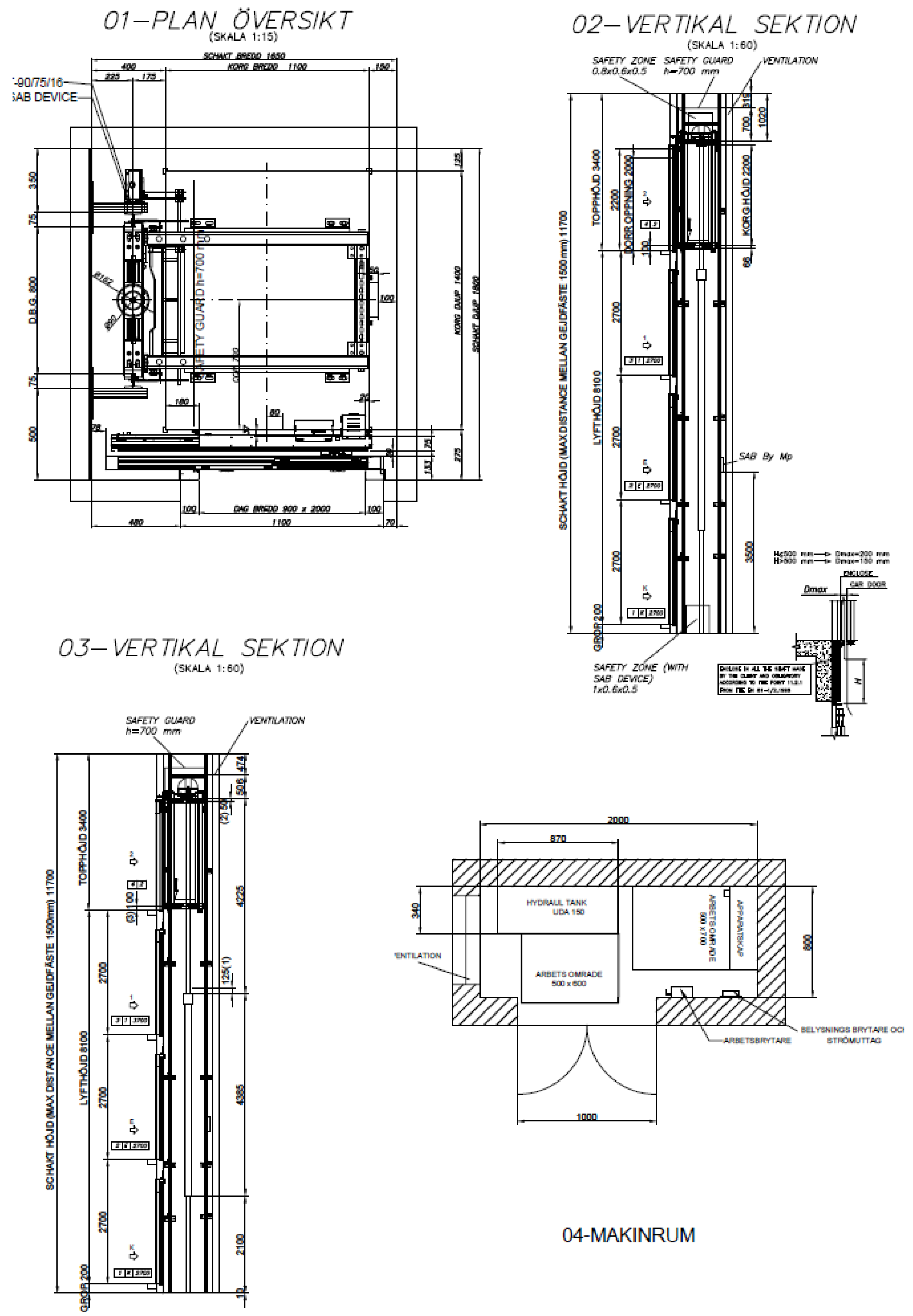

Fig. 2.12. Plan and construction drawings of the MP H-01 lift

Chapter 3 Swedish electrical supply company review

3.1 National situation in Sweden

The Swedish power production is to a very large extent CO_2 neutral and is based on four major production categories with the following approximate shares: Nuclear power (38%), Hydro power (45%), Combined heat and power/ back pressure (Biofuel based 9% and fossil fuel based 4%) and wind (4%), see Fig. 3.1. The total Swedish power production in 2011 was 147 TWh, an increase with 1,4% from 2010. In terms of installed power wind is the fastest growing category.

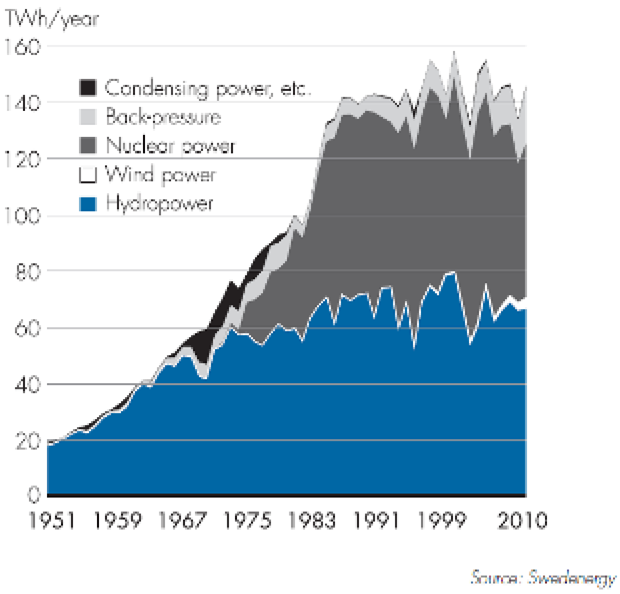

Fig. 3.1. Wind power is now becoming visible in the Swedish energy mix whereas solar PV power is still below 0.01 %.

Installed capacity in grid connected solar PV is approximately 9 MW with an annual production of 8 GWh i.e. around 0,01% of total production. Nevertheless it is considered as what may be the only realistic option for local electricity production i.e. production within your own building. This is one reason to why solar PV is attracting increasing interest in Sweden. Figures 3.2. and 3.3. below show how PV installations are distributed on sizes and on single family houses and other installations for the period 2009-2011.

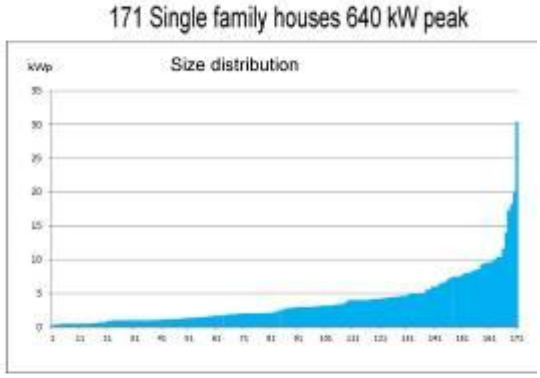

Fig. 3.2. Grid connected PV in Swedish private buildings has been supported by governmental investment grants since 2009.

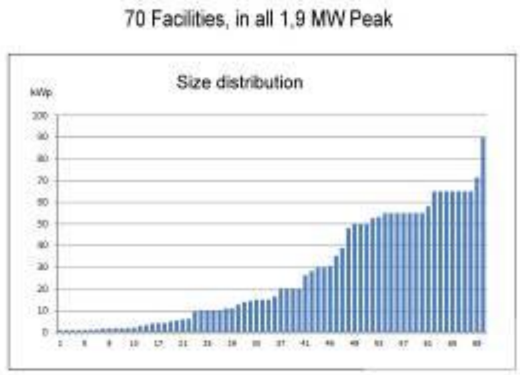

Fig. 3.3. All building types except single family houses are in this category. Source: Elforsk Rapport 11:76

3.1.1 National regulations

The only remuneration for delivered energy a micro producer of electricity in Sweden is entitled to according to the law is that from the grid owner who compensates the producer for having reduced his distribution losses. The distribution losses in the Swedish electricity grid is approx. 7% of the total electricity production, partly due to long distances between for example the hydropower in northern Sweden and the main Swedish population who lives in southern Sweden. The costs of the distribution losses are carried by the grid owners, depending on the amount and source of transferred electricity in the grid. Locally produced electricity lowers the total amount of the distribution losses, so when feeding locally produced electricity into the grid you will be compensated for this by the grid owner. The size of the compensation depends on where in Sweden the producer is located. In southern Sweden the compensation, ranging from 0.04 to 0.08 SEK/kWh, is often larger than in the north.

Three basic options for supporting small scale power production, in this context PV power production, are discussed in Sweden.

- Green certificates
- Feed in tariffs
- Net metering

Out of these, the green certificates have been chosen as the Swedish “patent solution” and are part of Swedish law. It has been successfully applied to support large scale bioenergy and wind power installations but in the case of e.g. solar PV it is not enough powerful to make a difference. One reason for this is that you only get certificates for your surplus production unless you install an additional meter and get a metering subscription at your own cost. The annual cost for this would be the same as what the certificates from a 5 kWp installation would give back i.e. for an installation smaller than 5 kWp the costs would exceed the payback in certificates. Another reason to why the certificates will not make a difference for PV is that the price of PV power is still too far from grid parity. The value of the certificates vary but currently they are worth around 20 €/ MWh.

Neither feed in tariffs nor net metering are thus regulated in Swedish law but in particular the latter has been intensely discussed and subject to several government inquiries in the past five years. Several electricity companies have therefore taken own initiatives and a large variety of offers based on these two measures are now available, each company having their own requirements, price structure etc, see 3.1.2.

The Swedish legislative support for small scale power production has thus been and still is weak but some improvements have been made quite recently. Since 2010 the owner of a PV installation have the right to connect to the national grid and the costs for connections and (compulsory) metering shall then be carried by the grid owner. Conditions are that the installed power is not more than 43,5 kW (63 A) and that the owner of the installation is a net user seen over the year.

Another supportive measure introduced in 2010 is that producers of electricity can apply for public “guarantees of origin” for each MWh produced. The idea is that these guarantees shall be possible to trade on an open market but no one really knows if this system will work as expected and it’s not expected to make any significant difference.

Two legislative requirements are presently hindering the further development of the Swedish PV market by indirectly making net metering “illegal”. According to the most recent government inquiry, net metering on a monthly or annual basis would be against the tax legislation since no VAT would be paid on the surplus power being transferred into the grid and back again. This actually wouldn’t have been a problem in the case of monthly net metering if it wasn’t for another requirement saying that the power fed into the grid has to be measured every hour. It has been proposed by Swedenergy, the Swedish interest organization for companies involved in the supply of electricity that this requirement should be taken off from micro producers.

3.1.2 Electricity companies

In general, Swedish power consumers have two business agreements, one with the distributor/ grid owner and one with a producer or with a trader of power. In the case that a consumer has an own power production that from time to time exceeds the consumption, he has the right to feed the surplus into the grid. However the business deals can vary within a wide range, from no compensation at all to monthly net metering or tariffs in the range of 50 to 250 €/ MWh. As previously mentioned a number of voluntary initiatives supporting small scale power production have been announced by electricity companies the past two years. These are either attempting to introduce some form of net metering (e.g. the company Mälarenergi) or to offer a feed in tariff to the producers (e.g. Telge energi). A third variant is the “Sala Heby concept” where individuals are offered membership (by buying shares) in an association building and operating PV installations.

The progressive initiatives have come from smaller actors whereas the major players still appear to be cautious. It is still a common understanding within the solar energy business in particular but also in the power business in general, that net metering on a monthly basis would be the preferable option.

3.2 Local situation at Brogården

Alingsåshem, the proprietor at Brogården, have no solar PV installations in their building stock at present and even if it's planned for Brogården there haven't been any discussions around the issue of surplus electricity so far. In Alingsåshem and in Brogården, Alingsås Energi Nät is the grid owner and the power producer is Telge Energi. The latter in November 2011 presented a new program where they offered 250 €/ MWh to solar PV power producers. As it turned out that the demand for solar PV power however did not meet their expectations they're not signing any new purchase agreements but putting new producers on a waiting list. Telge Energi still supply "green power" to Alingsåshem, according to their current agreement but it is produced from hydro and bio fueled CHP.

3.3 Massive market uptake

In terms of regulatory measures supporting small scale renewable power production Sweden does not have much to offer as a role model for other countries in Europe. The green certificates' system is considered as a success but this has only been true for large scale installations such as biofuel in CHP or large windmills. It has not been an efficient means of supporting e.g. small scale wind or solar PV where costs are still relatively far from grid parity.

3.3.1 Influence on electricity grid

Since the accumulated quantity of grid connected PV in Sweden is still so small it has not been possible to perform practical studies of the impact on the electricity grid from large scale distributed solar PV. However the impacts of large-scale distributed solar PV generation on low-voltage grids and on the national power system has been theoretically studied. Power flow studies showed that voltage rise in the grids is not a limiting factor for integration of distributed solar PV generation. Variability and correlations with large-scale wind power were determined using a scenario for large-scale building-mounted PV. Profound impacts on the power system were found only for the most extreme scenarios.[3]

A recent practical study made by Sandia laboratories on a 1,2 MW installation occasionally covering 50% of the load on the Hawaian island of Lanai came to similar conclusions. "The PV system has had a negligible effect on voltage and frequency on Lanai, despite the fact that most days are partly cloudy". https://solarhighpen.energy.gov/article/first_irradiance_sensor_network

In another Swedish study, it was concluded that the buffering capacity of the Swedish hydro power would set an upper limit to the installed PV power capacity at 6-7 GWp. The same report estimates the Swedish technical potential for building mounted PV to be 60 TWh/year.[4]

3.3.2 Fire safety

During the past three years there has been a strong interest in risks related to Solar PV and fire. The reason is partly that there have been some incidents where firefighters were exposed to unforeseen risks of electric shocks and partly that several independent field studies showed alarmingly high shares of faulty installations. The latter was seen in the light of risk for fire caused by electric arcs. Studies were carried out in Germany, in the US and in the UK, focusing on three main aspects:[5][6]

- Electrical arcing – fires from within the PV system
- Resistivity of PV against external fires
- Safety Issues for rescue squads and fire fighters in relation to PV

The main conclusion in terms of firemen's safety is that there is no fundamental difference between a PV installation and many other electrical installations. Thus the most significant risk lies in the fact that a fireman does not know that there's a power source on the roof which is easily overcome by appropriate marking of buildings with PV attached.

Regarding the risk of arcing, the remedy lies in using appropriate materials in cables and contacts and that the installations are carried out according to up to date safety standards.

Chapter 4 Application in Brogården

4.1 PV installation in Brogården

In this chapter a complete solar cell system will be designed for houses N, O, P and Q at Brogården. To demonstrate the different design possibilities in areas like Brogården, this system will include three different applications, covering BIPV (Building Integrated Photo Voltaic) in balconies, BIPV in facades and BAPV (Building Applied Photo Voltaic) on the roofs. The solutions are associated with different issues, which will be treated in this report.

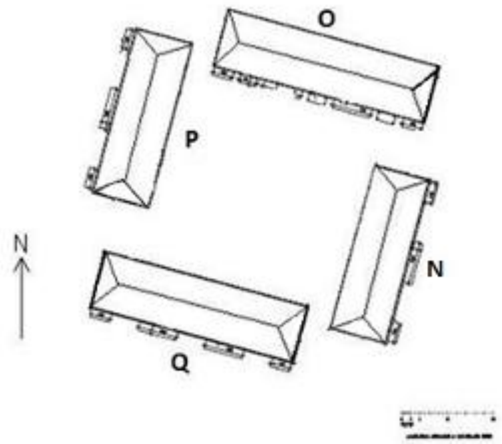

Fig. 4.1. Situation plan over the four buildings N, O, P and Q in Brogården

4.2 Sizing of PV installation

The sizing of a solar system can be done by several different methods, see Report D4.2 for more details on this subject. In this report the detailing in the suggested method is based on the specific conditions at Brogården, and in any other project a new analysis has to be done to find the best fitting design. [1]

For calculating the energy output the free software Solelekonomi 1.0 is used[1]. The software is developed within the Swedish Solar Electricity Program, an applied national development program for solar cell systems, financed in cooperation between the Swedish Energy Department and the industry. The program is simple, and adapted to the Swedish conditions. The solar data used in the program is from the solar data base STRÅNG, and have been developed by SMHI – the Swedish Meteorological and Hydrological Institute.

4.2.1 Regulation concerning small scale production/business model

Due to great uncertainty considering possibilities to get paid for the excess electricity by Telge Energi according to their business model mentioned in chapter 3, this profitable scenario will not be assumed in this analysis. It is though reasonable to believe that the political obstacles for net debit in Sweden will be solved in near future, and the most likely scenario is that a monthly basis model will be implemented.

The suggestion for sizing the installation is to seek an energy balance on a month basis. Since the production can be assumed to occur around June, this is the chosen dimensioning month.

4.2.2 Consumption

The residential electricity for the houses N, O, P and Q at Brogården are all measured together at one point. In addition to the residential electricity according to the definition in the Swedish Building Regulations, also the electricity for laundry room is included in the measuring. Due to this, the proposed system will be dimensioned to respond to values expected to be measured at the common node for N, O, P and Q.

Based on measured data from the buildings in the area in combination with calculations, the expected demand in the mentioned node is estimated to 8,500 kWh in June. This sum includes electricity for fans and pumps, stairwell lighting, elevators and laundry rooms. According to measured data the residential electricity demand is approximately 10 % higher in the winter than in the summer. This gives a yearly energy demand at approximately 108 000 kWh.

[1] http://www.solelprogrammet.se/Projekteringsverktyg/Berakningsverktyg/

4.2.3 Areas suitable for PV panels

The most appropriate surfaces from a strict energy efficiency perspective are as shown in report D4.2 the roofs sloping towards east and south. [1] Considering other aspects such as architectonical, educational and communicative, other surfaces such as balconies and facades can also be suitable. There is great demonstrative potential in integration of solar cells in the buildings at Brogården, and this is taken into account in the system design process.

This analysis will approach a total system solution by first optimizing a solution for the facades and balconies, and then complement with dimensioning a roof system, adding up to an expected production equal to the expected demand in June. The balconies chosen are situated on the south façade of house Q, which has no external shadings. The balconies of house O is by low standing sun shaded by both vegetation and surrounding buildings, and is therefore not included in the primary choice. The façade chosen is the south gable of house N, which also has very little external shading. For the roof installation the southern roofs of O and Q will be the primary choice, and if not sufficient for the suggested dimensioning the areas will be complemented with the east roof areas of house N and house P. The following chapters will go into further detail of the design on the specific surfaces.

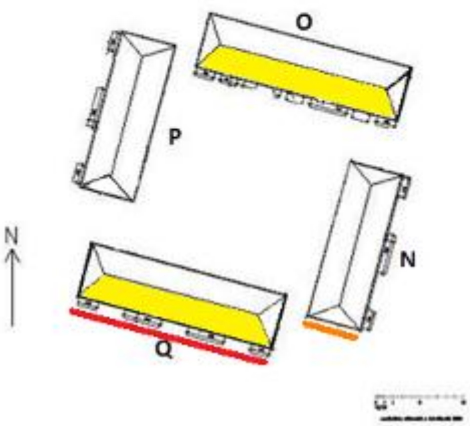

Fig. 4.2. Primary suggested areas for solar installations at Brogården. Red: BIPV balconies, Orange: BIPV facade, Yellow: BAPV roofs

4.3 BIPV Balconies

Fig. 4.3. Left: Satellite picture over houses N, O, P and Q. Right: Refurbished balconies at house E

House Q will have 24 balconies towards south, 6 of them at ground floor. To minimize the risks of sabotage it would be convenient to install solar cells only from floor 2 and up. This gives 18 balconies suitable for the design.

4.3.1 Design suggestion

For economical reasons it is convenient to use standard sizes as far as possible. The cutting process of the modules and the waste produced increases the cost significantly. The module used for this design is a black thin film module with the size 1100*1300 mm from Schüco.[7]

The balcony fronts will be 4200 mm wide. From the balcony floor to the top of the lintels the maximum height is 1200. To keep the view conditions it is recommended to cut the height of the modules to 1000 mm, and to keep a strip of transparent glass between the modules and the lintel. This can be done by the solar cell supplier, and leads only to a decrease in power output, linearly corresponding to the amount of solar panel surface cut away. A part of the balcony front will also be transparent, see figure 4.4. below. The suggestion here is to use two modules of solar cell at the width, combined with a glass-plate, transparent or dye laminated.

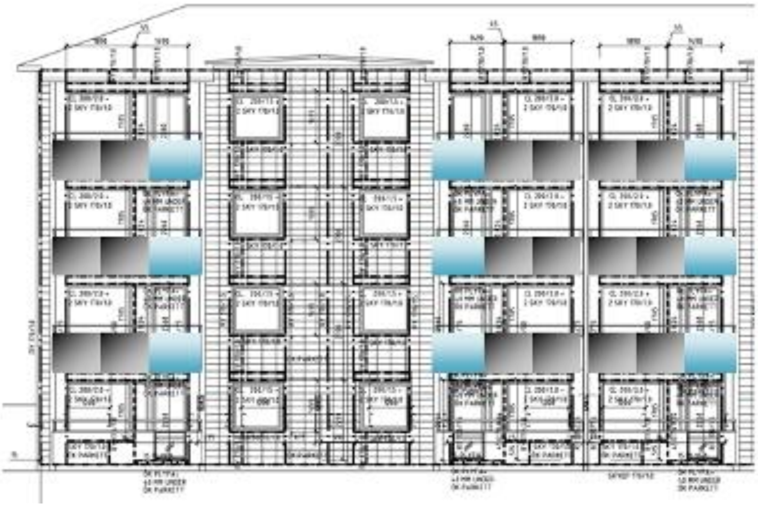

Fig. 4.4. Illustration of design for balconies. Blue is glass, black is solar cells. Only half of the building is seen here, 36 solar panels totally suggested for the buildings balconies

4.3.2 Technical specification of system, including requirements

The suggested solar panel is a 3.2 aSi:H/_µc-Si float glass (microcrystalline) from Schüco. The panel consists of 4 mm tempered safety glass with a 1.52 PVB-foil. Schüco is at the writing moment running tests in Sweden for safety class 2(B)2 for these panels, and the plan is to be finished by summer 2012. This means that the panel will meet the legislation for safety glass at balconies. [7]

The panels will be cut to the size of 1300*1000 mm to fit the design, and have the maximum output of 85 Wp/module. Totally there will be 36 modules at the total size of 46.8 m^2. The total maximum output will be 3.06 kWp.

The balcony supplier Vika Balkong AB will deliver the balconies to Brogården and their aluminum profile system is compatible to the modules suggested. The electrical installations can be hidden in the profile system. For specification of the surrounding electrical system, see the end of this chapter.

The figure 4.5 below shows a detailed view of the construction draft of the suggested balconies at Brogården. This picture gives some information about fixing methods of the different elements of the balcony.

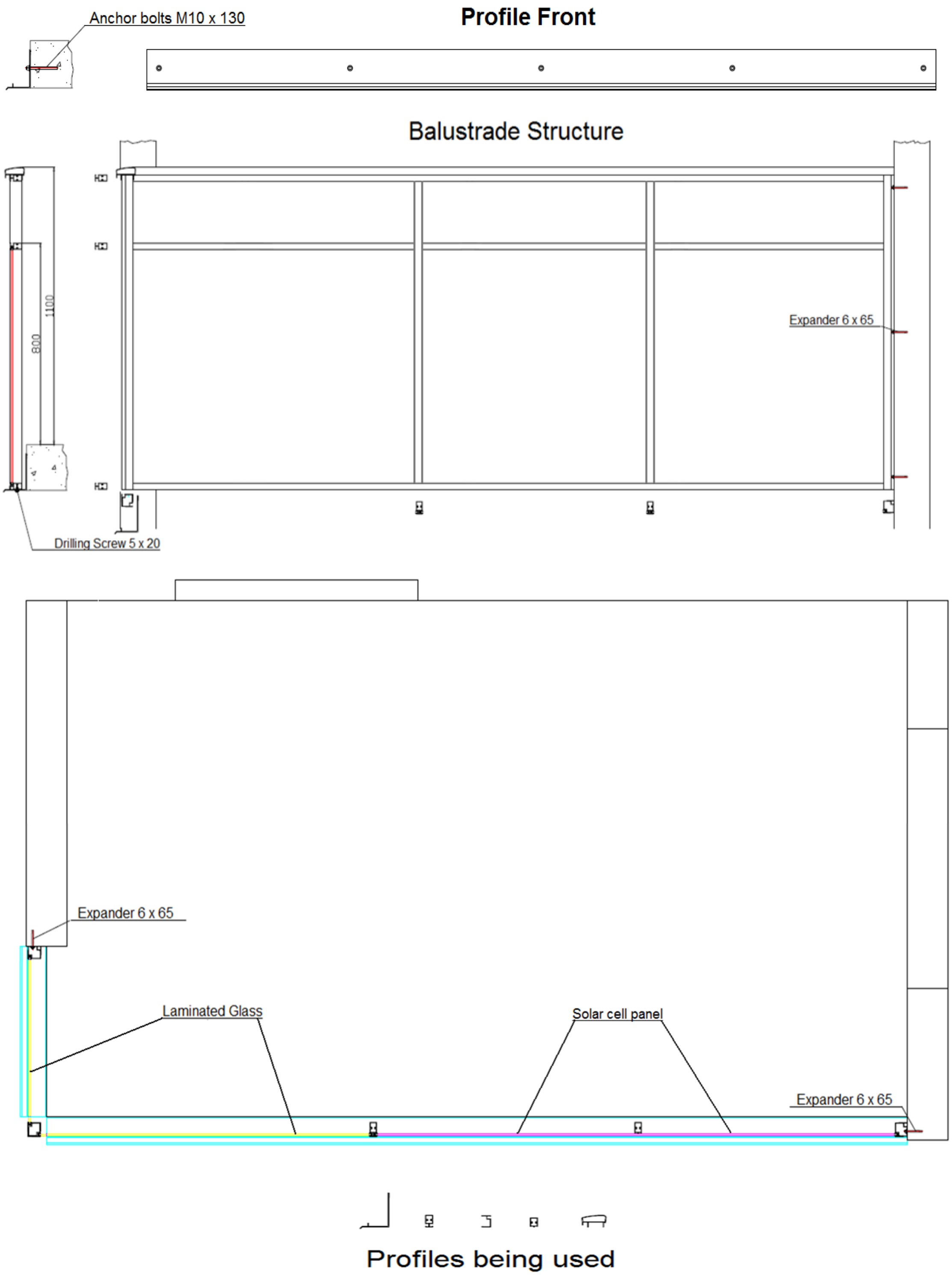

Fig. 4.5. Illustration of detailed design for balconies

4.3.3 Electricity production

The simulation of the electricity production is based on the data described above. The results on month and year basis are shown in the table below.

January	120
February	124
Mars	277
April	366
May	261
June	264
July	209
August	265
September	219
October	232
November	159
December	35
Sum	**2529**

Table 4.1. Calculated electricity production from BIPV balconies

The production in June is calculated to approximately 264 kWh, and on the full year 2529 kWh.

4.3.4 Cost

The module cost is approximately 4,035 SEK/module (excl. VAT). The material used for the balconies at Brogården is a colored plywood plate to the cost of approximately 2,000 SEK/m^2. This gives a saving potential of 2,600 SEK/module, or a cost increase at 1,435 SEK/module compared to plywood. The total cost increase for the 36 modules is 51,660 SEK (excl. VAT) compared to plywood.

For installation and inverter cost etc see summary, as this is calculated for the total system.

4.4 BIPV Facades

The gable of house N has eight windows. An option considered in early stage was covering the complete facade with solar cells, but since this would mean much cutting and puzzling this would also be a quite costly solution. The suggestion is instead to make a simple design with only standard sized modules, places in two rows along the parapets. The panels should replace the facade mounted ceramic plates.

4.4.1 Design suggestion

The module suggested for the facade solution at the gable of house N is an aluminum framed black thin film module for cold facade systems from Schüco. [7] The size of the module is 1100*1300 mm, frame included. The parapets at the gable are 1300 mm high, and the gable is 12.8 m long. The facade mounted ceramic plates has the size 400*200 mm. Leaving one column of bricks on each side gives 12 m for solar cells, or 10*1100 + 1*1000 mm. This means that there will be two rows of 11 modules each, from which one is cut to a width of 1000 mm.

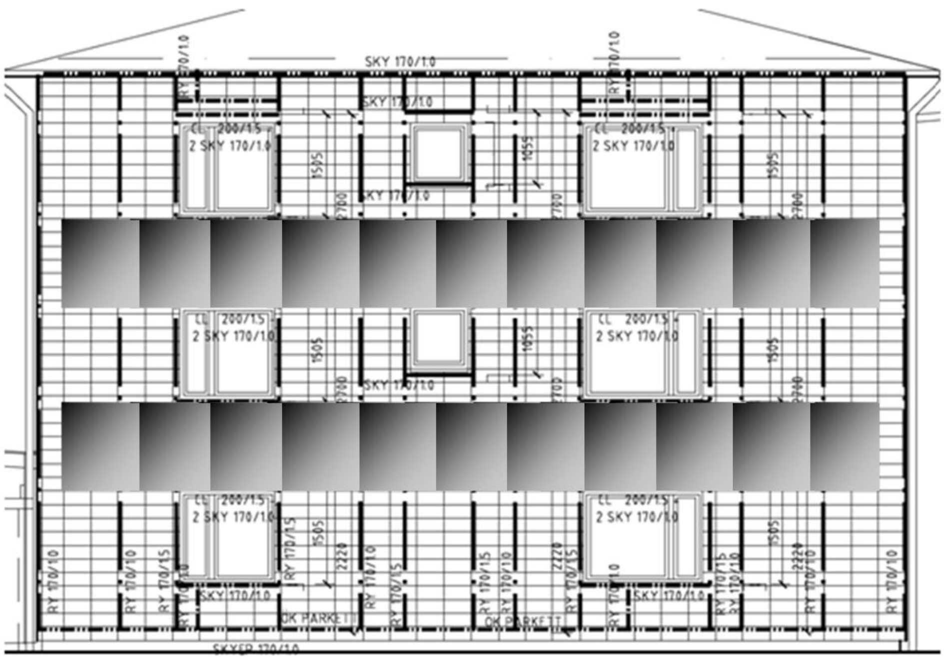

Fig. 4.6. Illustration of design for facade

4.4.2 Technical specification of system, including requirements

The module suggested is a Schüco SCC 50 Cold Façade with Prosol Black Thin Film. [7] Since the glass can move and swallow with temperature changes, there must be some space between the glass panels for them not to build up tensions. The façade must be weather tight, so there may be no uncovered gaps between the modules. The aluminum frame is used to cover the required gaps between panels.

The standard modules have a maximum output of 85 Wp/module, and the cut modules 77 Wp/module. 20 standard modules and two cut once gives a total of 1.85 kWp.

According to Schüco the same mounting system can be used for the modules as for the façade bricks, with only little modification. [7] The cables etc. can be hidden behind the façade bricks.

For specification of the surrounding electrical system, see the end of this chapter.

4.4.3 Electricity production

The simulation of the electricity production is based on the data described above. The results on month and year basis are shown in the table below.

January	73
February	76
Mars	169
April	224
May	159
June	161
July	128
August	162
September	134
October	142
November	97
December	21
Sum	**1546**

Table 4.2. Calculated electricity production from BIPV facade

The production in June is calculated to approximately 161 kWh, and on the full year 1546 kWh.

4.4.4 Cost

The module cost is approximately 2,185 SEK/module (excl. VAT). The façade bricks costs approximately 500 SEK/m^2, which gives a saving potential of 715 SEK/module. The cost per module, minus the saving potential, is 1,470 SEK. Costs for cutting two of the modules are negligible in the context. The total cost increase for the 22 modules is 32,340 SEK (excl. VAT) compared to bricks.

For installation and inverter cost etc see summary.

4.5 BAPV Roof

The roofs are hipped with hipped ends, consisting of roofing felt on top of 100 mm mineral wool on toughed and grooved board. The large roof areas have an inclination of 14 degrees, and the hipped ends 20 degrees. The hipped ends are though very small compared to the pitched roof areas, and the difference in inclination is not significant. To reach simplicity in the installation, the suggestion in this report will be to only focus on the pitched roof areas. The sizing starts with the south roof of house Q, followed by south roof of house O, and then the east roofs of house P and N if needed to reach the aimed production in June.

The suggestion is to use crystalline PV on the roofs. The prices for crystalline cells are relatively low, and the efficiency high. Since the location will not be as visible as the balconies and facade, the aesthetics are not of the same importance. The modules have a quite distinct pattern, with a look characteristic to conventional solar cells.

4.5.1 Electricity production

To size the roof system according to the suggestion of energy balance during June, the first step is to decide the production demand. The expected production from the balconies and facade during June is 425 kWh. This leaves a demand of 8,075 kWh in June for the roof system design.

4.5.2 Design suggestion

The module suggested for the roof system is the mono crystalline module MPE 240 PS 02 from Schüco, which measures 1639*893 mm. [7] To reach the aimed production during June, around 222 such panels with an azimuth at 15 degrees and an inclination at 14 degrees are needed. The expected production distributed over the year would be as followed:

January	1118
February	1460
Mars	4628
April	7692
May	6968
June	**8077**
July	5840
August	6535
September	4302
October	2988
November	1580
December	380
Sum	**51568**

Table 4.3. Calculated electricity production from BAPV roofs

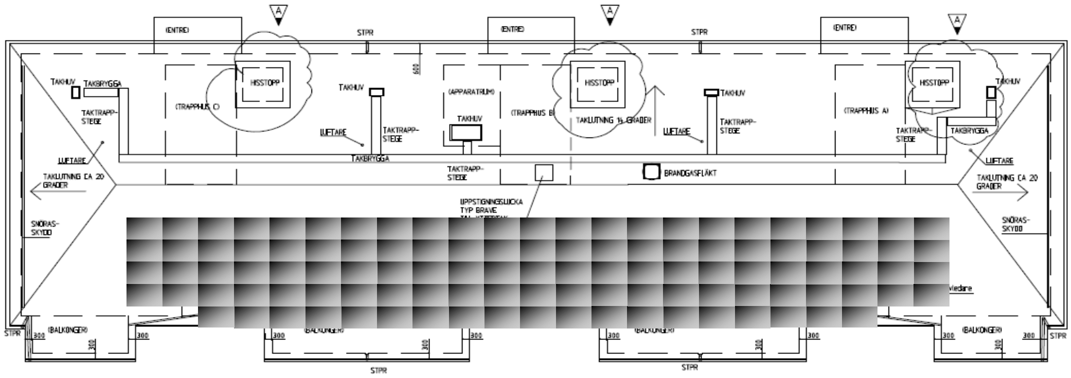

Fig. 4.7. Illustration of design for roof systems. Two similar systems are suggested, one for house Q and one for house O

The schematic picture Fig. 4.7. above shows that 111 modules fit in at the south roof of house Q without any problem. Most of the cowls etc. are conveniently located at the north side of the roof at house Q. In house O at the other hand a few cowls etc. are located on the south side. It would be preferable to move these to the north side, to make the solar installation simpler, and the risks of shading smaller. If not possible, the panels must be restructured to fit in on the roof, but simple calculations have shown that the areas are still with margins sufficient for 111 panels. If needed, some of the panels could be moved to the south roof of house Q instead, so the conclusion is that these two roof areas are sufficient for the suggested sizing of the roof system. To concentrate the system to only two roof areas will simplify the installation, and optimize the costs of the surrounding equipment.

4.5.3 Technical specification of system, including requirements

The module MPE 240 PS 02 has a peak performance at 240 Wp/module. The total of 222 modules gives a performance of the system at 53.28 kWp. The weight of the modules is 20 kg, so the total of 111 modules weights 2220 kg. Calculations for the roof construction have to be made, to ensure load capacities for this weight in addition to the snow loads.

The modules are mounted on rails, according to the Schüco system MSE 210. [7] To prevent moisture problems due to water retention along the rails, these should be mounted along the slope of the roof, and not horizontally. This results in that the modules also have to be in horizontal position. 24 rails are needed for the installation, and the rails have to be fastened into the roof. Approximately four connections per rail are needed, depending on the results from load calculations. This gives a total of approximately 100 connection point through the roof, for the installation. The connections need to be done with care for moisture issues.

4.5.4 Cost

The prices for crystalline cells have radically dropped the last couple of years. Modules are sold on daily price, and to predict future prices is not easy. In these calculations the current prices of 2,215 SEK/module are used. Totally for the 222 modules the price is approximately 491,730 SEK. For installation and inverter cost etc see summary.

4.6 Summary

4.6.1 Technical specification of system, including requirements

The top performance of the total system will be approximately 58.2 kWp.

4.6.1.1 Electricity DC

All outdoor cables must be UV- and weather resistant, and follow Swedish standard regarding colour codes. At the DC-side of the inverters there shall be a DC-switch, and the installation shall have an adequate lightning protection.

4.6.1.2 Electricity AC

Number of inverters should be planned and decided by installer. The Inverters must be CE-labelled. Meters for logging the produced AC shall be positioned after each inverter. There shall be an AC-switch at each inverter, in case of service demand. There shall also be an adequate protection towards electrical feed in to the grid in case of grid power failure.

4.6.1.3 Data collection and presentation

The electricity production should be collected after every inverter, and added for presentation in a display system where both instantaneously power output in W and accumulated AC-production in kWh since operation start is presented. The display should be positioned well visible for the inhabitants as well as visitors, to reach a high pedagogical value. The data should also automatically be communicated to Alingsåshem.

4.6.2 Total cost

Costs are calculated in consultancy with Schüco. [7]

The module cost for the total system is estimated to 575,730 (excl. VAT), including the savings of alternative material in BIPV-systems. Costs for inverters and cabling etc. for solar cell system varies with the size of the system, and is here set to 3 SEK/Wp. For the complete system this gives 174,600 SEK. The installation job costs about 6.70 SEK/Wp, regardless the type of installation, which gives 389,940 SEK for the complete system.

The total cost for the system will approximately be 1,140,000 SEK (excl. VAT).

4.6.3 Total production

The total production of the systems is calculated by adding the three different simulation results from chapters above.

January	1311
February	1660
Mars	5074
April	8282
May	7388
June	8502
July	6177
August	6962
September	4655
October	3362
November	1836
December	436
Sum	**55643**

Table 4.4. Calculated electricity production from complete system

The yearly production is calculated to approximately 55,600 kWh. Since the expected yearly residential electricity demand is 108,000 kWh, this means that approx. 50% of the demand will be covered by solar electricity.

4.6.4 LCC

To analyze the economical picture an LCP-analysis is made (Life Cycle Profit). The analysis will give a picture of the economical saving potentials of the solar installation over the lifetime, taking into consideration the price development of electricity, real cost of capital, inflation and present value calculations. All calculations are VATs excluded. The input is presented in the table below.

Investment cost	1,140,000 SEK
Real interest rate	5 %
Inflation rate	2 %
Real electricity price increase	5 %
Current electricity price	1,400 SEK/MWh
Lifespan	30 years

Table 4.5. Input for LCP-analysis

Another assumption made is the business model of net debit on a monthly basis, according to chapter 4.2.1. This means that every produced kWh economically equals a bought one. No eventual funding is taken into account, due to the big uncertainty associated with it.

The analysis results are presented in the table below.

Amortization	1,140,000 SEK
Interest	1,616,000 SEK
Total energy cost savings	7,873,610 SEK
Net profit	5,117,555 SEK
Net profit, present value	1,197,006 SEK

Table 4.6. Output from LCP-analysis

The conclusion drawn from this analysis is that under given conditions the present value of the saving potential of the installation is approx. 1,200,000 SEK.

To get a deeper understanding or the economical conditions, it is appropriate to have a closer look what happens with the net profit (present value) if changing the different parameters. (By looking at the present value of the profit, it is taken into account that future savings are less worth than savings in near future.) The following analyses will show the sensitivity of the different parameters one at a time. The red dot represents the assumed scenario in the LCP-analysis above.

4.6.4.1 Investment cost

As mentioned earlier the prices of the panels have dropped radically the last years. This analysis shows what happens if the prices decreases further.

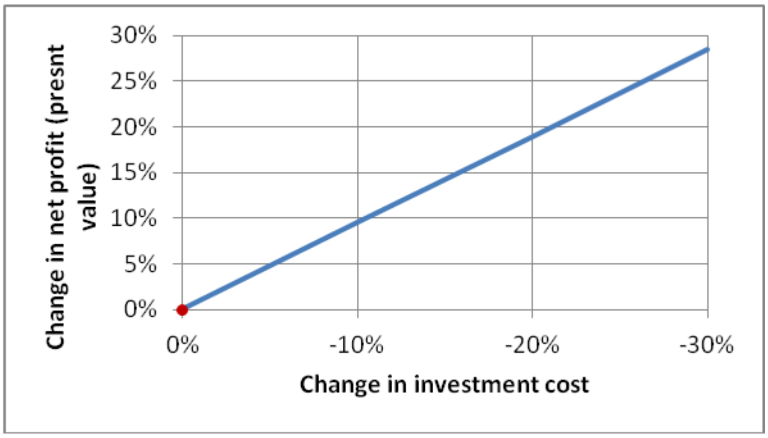

Fig. 4.8. Relation between change in investment cost and change in expected net profit

The diagram Fig. 4.8. shows that the decrease of the system cost of 10 % leads to an increase of 9.5 % of the net profit (present value). The correlation is linear, so a cost decrease of 20 % will give an increase of 19 %, etc.

4.6.4.2 Real electricity price increase rate

To predict the electricity price increase in the future is related to great uncertainty. There are many different ways to analyze statistics, and depending on method the historical price increase can differ significantly. The following analysis aims to shine some light over the influence the chosen increase rate has on LCP results.

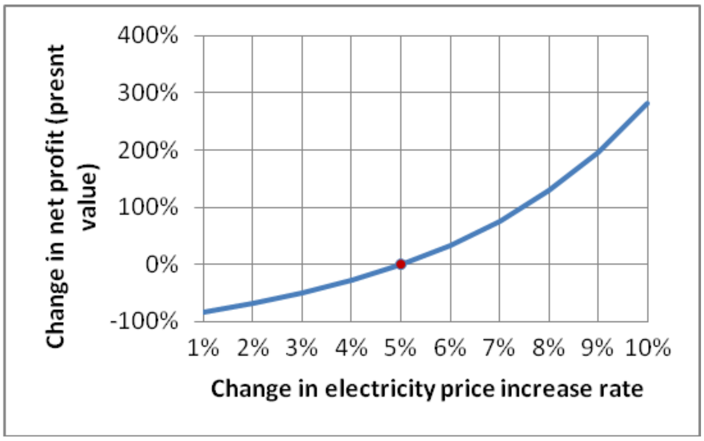

Fig. 4.9. Relation between change in electricity price increase rate and change in expected net profit

The diagram Fig. 4.9. shows that the influence of the chosen electricity price increase rate is significant. The higher rate chosen, the higher sensitivity will be experienced, since the change is exponential. In the LCP-analysis a change rate of 5 % is used. If 3 % is used instead, the net profit will decrease to the half. If 7,5 % is used, the net profit will double.

4.6.4.3 Lifespan

The lifespan of the installation can be hard to predict. Solar cell plants are still a quite modern phenomenon, and the experiences of old installations are therefore few. Anyhow the few old existing solar cell installations show that the lifespan can be longer than expected, due to the fact that the installation does not include any moving parts. Suppliers often offer guaranties of 20-25 years, but the installations can just as well keep in running many years past this limit. The following analysis shows the relation between calculation time span and expected net profit.

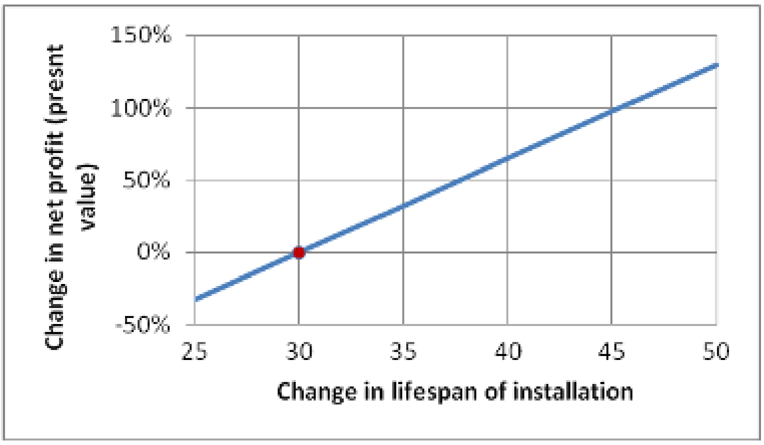

Fig. 4.10. Relation between change in expected lifespan of installation and change in expected net profit

The graph Fig. 4.10. shows that if the lifespan of the installation is increased from 30 to 45 years, the calculated net profit will double. If 25 years is used instead, the expected net profit will be approx. 30 % less than if 30 years is used.

Chapter 5 GERES design

This chapter includes a comprehensive approach for designing a global GERES system related to any current or future application belonging to BEEM-UP project.

So, for this reason, the chapter 5.1. is going to have a general point of view, not specific to Brogården site. Later, in chapter 5.2. the specific application to Brogården is treated in detail.

5.1 Global approach

The residential building sector have begun to look more seriously at new technologies to save energy. For that purpose, in residential buildings there is a definite trend towards upgrading electrical systems with new ones that allow to save 25 to 30% of electrical energy. The GERES system will help to achieve such goal.

The GERES system is a distributed energy system for residential building that is capable to optimize the electrical energy generated and consumed in residential buildings with renewable energy installed.

The idea is to recover the exceeded energy produced by the renewable energy sources installed in the building and use it to power any auxiliary equipment (lights, etc) located in the same building at any time of the day or night. This system will control the energy flow among the different components of the buildings (energy sources and sinks).

The GERES system should be designed to optimize the balance between the produced and demanded energy in the building. For that purpose, it is necessary to develop an interface (storage energy device + power converter) to control the energy flow among auxiliary components of the building.

This “optimal and global“ energy design will save an important amount of energy and decrease the peaks of power demanded by the building during the peak power consumption times of the day. This second effect will allow to optimize the design of the power network of building because it allows to storage energy during the power consumption valleys and use it during the power consumption peaks of the day.

As result a more uniform demanded energy of the building is presented which may be used for the electrical power companies to predict better the power demanded and adjust better the strategy of the power network.

The main difficulty lies in the fact that the energy generation has to be instantaneously consumed or stored to be used later. For that purpose it is crucial to adapt or uniform the power and energy demanded by the building.

Therefore a recovery system has to be designed based on a more accuracy building energy demand and generation patterns. For this reason an hourly time basis should be selected to define the size of the GERES system. The energy balance based on monthly time bases may be not good enough for that purpose. One of the biggest limitations will be the storaged energy, which defines the rate of the battery installed as energy buffer of the system.

The most important components of any energy recovery system for buildings applications are:

- Energy sources
- Energy storage devices
- GERES system

Energy Sources

The local energy sources available for distributed energy systems installed in buildings can be mainly originated from PV solar energy and wind power. These systems have advanced rapidly in recent years.

They can operated alone or combined. The energy sources selection will depend on a number of factors, as they can be energy efficiency, economic efficiency, pedagogical values, aesthetics, and so on. Each of these variables should be analized for each energy source.

Photovoltaic (PV) systems are very flexible and modular. They can be sized to give power ranging from few watts to few hundreds of kilowatts; however they can be very expensive for large power ratings. For building applications, in general they are sized for power ratings of some kW.

The power available from PV systems fluctuates depending on the weather and is completely unavailable at night. Therefore, they are operated with energy storage devices or connected to the grid to ensure continuous power supply to the load.

Normally, to increase the efficiency, a maximum peak power tracker (MPPT) is used to track an operating point such that maximum power can be extracted from the PV arrays.

Wind turbines are gaining popularity due to their clean energy and lower cost. The power ratings of wind turbines can range from kilowatts to a few megawatts. For building applications, in general they are sized for power ratings around few kW.

Wind turbines can be found either in fixed speed or variable speed applications. The most common types of generators used in variable speed wind turbines are the induction and synchronous generators.

As in the previous type of energy source, due to the intermittent nature of the wind, for a continuous power supply to the load, connection to the grid or the use of ESD is necessary.

Energy storage devices (ESD)

One of the most important things is to define the bussiness model to apply in the project. The bussiness model gives answers about the best way to buy and sell the electricity from and to the grid. This means, for example, to know if a energy storage system can be necessary or not.

Energy storage devices are required in some cases to uniform the energy flow during the day in standalone systems as well as in areas in which there is no possible to obtain any profit selling energy to the power grid.

The type and the size of these units will be defined by financial and operational conditions. There are a few types of ESD that are being used and researched in power system applications:

- Batteries
- Flywheels
- Ultra-capacitors

The most common is the Batteries technology. In particular, the lead–acid batteries, are widely used in power system applications due to their low cost, high energy density and capability, and their established and mature technology.

Flywheel technologies and ultra capacitors are gaining popularity and have been applied in wind turbine technologies. However, they are more focused on low-energy, high peak power applications, which does not fit BEEM_UP applications (high energy and low power). They have been used in drive systems to improve ride-through capability during voltage sags.

5.2 Global Energy Recovery System (GERES)

The acronym GERES means **Gl**obal **E**nergy **Re**covery **S**ystem, so it refers to a system that is able to manage the produced electricity from local sources (normally renewable sources) and consumed electricity on its own loads in an optimal way (both from energy efficiency and economical points of view). For this purpose, depending on the specific case of each project site (stand-alone/grid-connected without feeding into the grid/ grid-connected with feeding into the grid), it can be necessary to use an additional energy storage system to optimize the performance of the produced energy.

5.2.1 Architecture description

Diagram Fig. 5.1. below shows a global view of the internal architecture of a GERES. This diagram is mainly focused on managing renewable energies applied to buildings. Interfacing with the GERES there can be several kind of electricity sources, building loads, a grid connection and different communication equipments to remotely monitor the system.

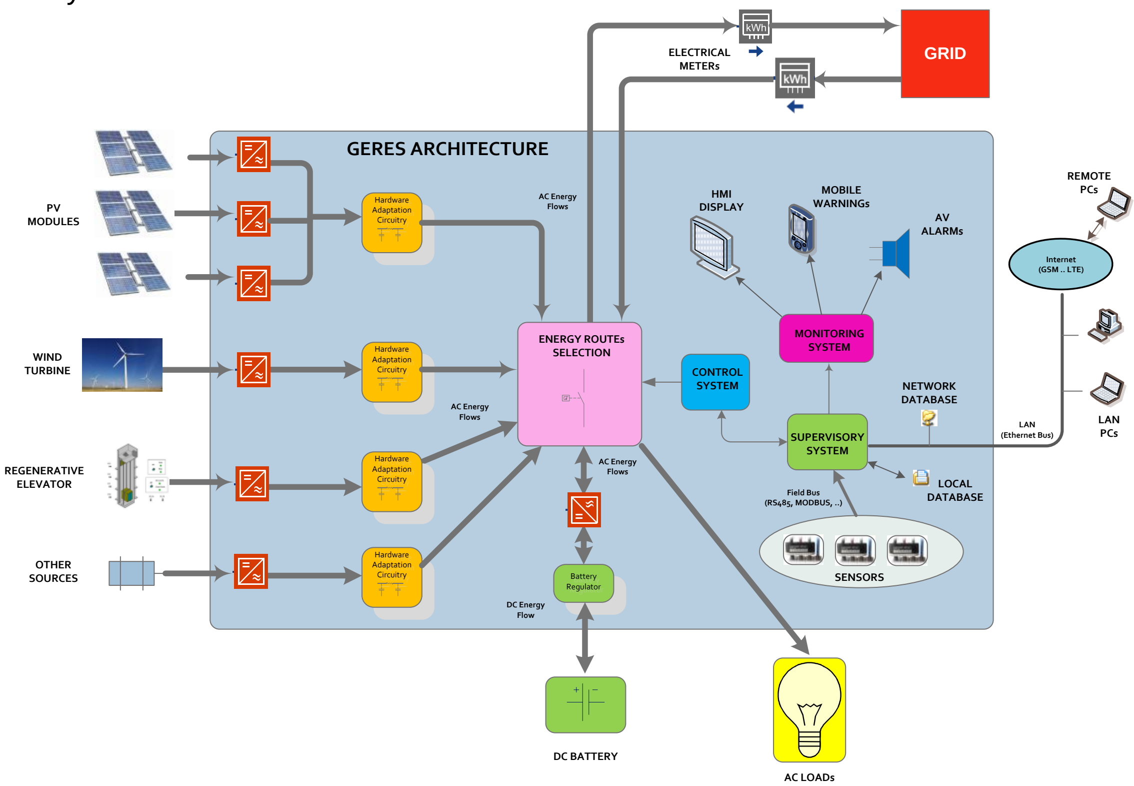

Fig. 5.2. Global GERES architecture

So, the internal architecture of a generic GERES could consist of:

- The power hardware interface (electronic power converters plus adaptation circuitries) for managing the produced electricity from the local sources and the charged/discharged electrical energy from ESDs
- An smart system to supervise and control the energy flows inside the building. This system should include additional power hardware to flow the energy in selected routes. Moreover, it would be necessary to integrate sensors to

measure the energy in different points. After knowing the produced energy, the load behaviour and the ESD state of charge, the control system should take the appropriate decissions in real time for the best optimization of the installation

- Furthermore, it would be recommendable to integrate a monitoring system to display relevant information about the installation. This information could help to the maintenance tasks and keep informed to the tenants or visitors at the project site, among other things

The final configuration of the electronic power converters depends on the topology of the system and energy sources available, which define operational requirements of energy charging and discharging processes. In some cases, more than one energy source may be required. In that case, each type of power source (PV or wind-turbine) will use a different power converter to connect the GERES with the energy source.

The energy flow between the grid or load and GERES system is done by inverters, which can be operated in voltage or current controlled modes. The energy flow between ESDs and GERES is generally controlled by a DC-DC regulator, which must be of bi-directional power flow type to enable charging and discharging of the storage devices.

Alternatively, the power electronics can also be used to supply power to the DC loads in which case, a DC-DC converter (bi-directional power flow, if required) may be needed to convert the DC voltage level appropriately. If the ESDs have to be re-charged using the grid, the inverter will be operated in rectification mode and possibly with unity power factor.

The power electronics must be:

- Capable of providing a continuous supply to the load with acceptable power quality
- Capable of managing the power flow between the energy sources, ESDs, the grid and the load for maximum energy utilization. For example, it must be capable of determining the optimum sources of energy (either from the grid, energy sources or ESDs) that can be used to supply the load at any particular time, to give maximum efficiency and minimum cost. It must know when to re-charge the ESDs – whether to use the grid or the energy sources, or the combination of both, for optimum cost and efficiency
- When connected to the grid, the power electronics must maintain the unit power factor within the permissible value as seen by the grid by controlling the active and reactive power flow. The amount of harmonics injected to the grid must be within the limits as imposed by the standards

In reference to the supervisory, control and monitoring systems, there can be a great difference from the simplest to the most complex case. Next chapter 5.2.2. includes a more detailed overview about these systems.

5.2.2 Supervisory and Control systems

5.2.2.1 General overview

A supervisory system is a set of electronic equipments and software components to be included in a existing system with the purpose of acquiring and monitoring the main system parameters and warning to the installation manager about alarms or events.

This kind of supervisory systems can be completed with control functionalities of the installation. The global system is normally accepted to be named SCADA, which means “Supervisory Control and Data Acquisition”.

These control functionalities can be made automatically or manually by the installation manager, or even a combination of both. It depends on the user needs. In order to carry out the control operations over the process it is necessary first to compile information from the process, analyze this information and finally act over the parameters that afect to the process.

SCADA systems refer to a type of application and it is not related to an specific technology. In fact, an SCADA system can be implemented in a number of different hardware platforms (PCs, PLCs, other programmable devices, ..), communication protocols (MODBUS, PROFIBUS, ..) or even hardware interfaces (Ethernet, RS-485, Wireless interfaces, ..).

In general, any application getting data of a process in order to control it can be considered as a SCADA application. A complex SCADA can be built using several technologies or communication protocols at the same time.

SCADA systems are valid for applying in most of industrial processes which would be difficult to manage directly by people, due to process speed or duration or hazardous conditions.

The range of application fields of SCADA systems is truly huge, for example in electric power treatment, water utilities, smart building systems, any manufacturing process, control systems in smart cities and so on.

The final architecture of a SCADA system depends on the specific application, so there can be applications without control requirements, or others without monitoring requirements to show the state of the system in real time, or even others without the need of data logging in order to generate historical trends in the future. So, in each case the specific hardware and software requirements will be different.

For example, diagram Fig. 5.2. below shows a possible architecture of a SCADA system applied to building solutions. There can be different energy sources like a PV installation, there can be multiple loads like household appliances or residential loads, even there can be equipments which behaviour is as source and as load at the same time like a regenerative elevator, and so on.

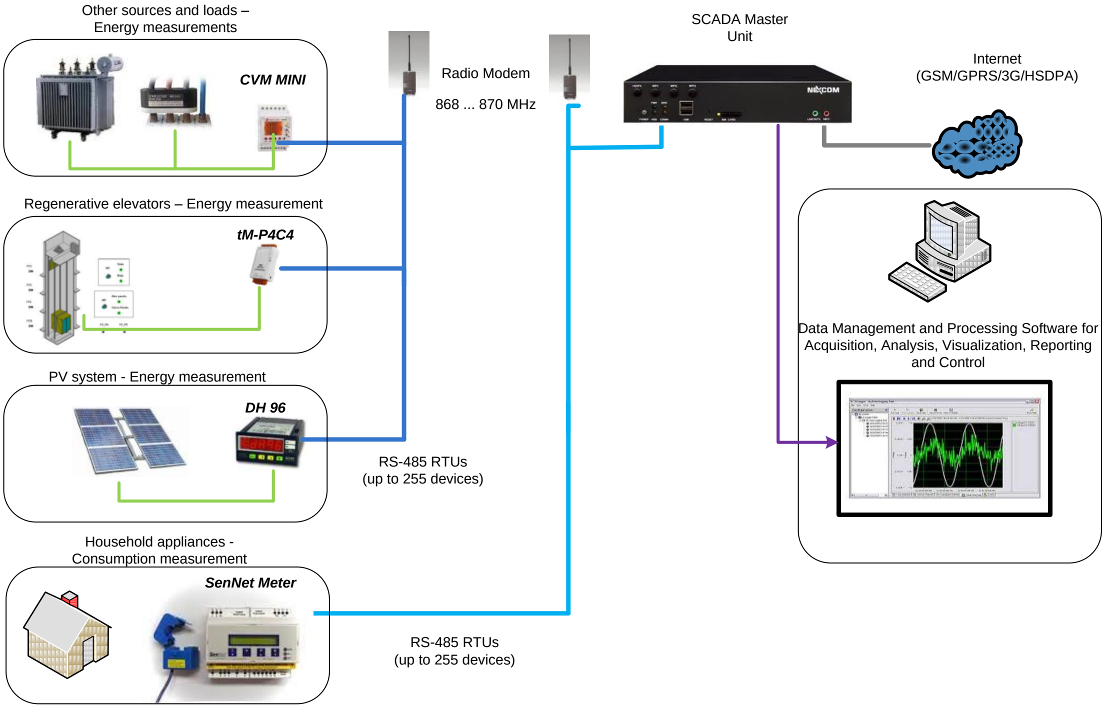

Fig. 5.2. Example of SCADA system applied to a building project

A SCADA system can manage huge quantities of data, process them in real time and show the results in a comfortable way to the user.

With this resulting information the installation manager can take decissions about the specific process or system to stop it, modify it or speed it up. Of course, it is also possible to program the SCADA system with the appropriate decission algorithms for applying the control in real time.

A SCADA system can storage all the acquired data for ulterior revision, generating timely graphs for analyzing the evolution and measuring trends over time. It can help to discover inefficiencies in the system or in the process.

Another important advantage is that they are flexible and scalable systems, they can be increased in size adding new sensors or measurement points. It is also possible to combine devices from different manufacturers without losing the communication compatibility between them.

Furthermore, a SCADA system gives to the installation manager the necessary information to carry out the maintenance works in a easy and quick way, so the SCADA system warns to the manager just in the precise instant that an event ocurrs, even by sending messages to a smartphone, for example.

For consulting all the registered and storaged information about a process, users can access to these data via online connection with the web server. Logically this kind of service must be secured with the corresponding security measures.

Basically, a SCADA system can perform four main functions:

1. Data acquisition
2. Networked data communication
3. Data presentation

4. Control

For these operations, a SCADA system uses different equipments:

1. Digital and analog sensors to capture the wanted parameters
2. Control relays to enable/disable the system processes and leading the energy or information flows
3. Remote telemetry units (RTUs), which are small smart components to compile and send to the master the sensors information and commanding the control relays. They are delivered in the field at necessary locations to cover all the processes
4. SCADA master units. The simplest SCADA system must have one at least. They are in charge of compiling and analyzing the global information of all the RTUs and sending the corresponding commands to the control relays in base to the decissions taken by the manager or by themselves. It usually also gives a visual output to display the state of the system in real time
5. The communications network that connects the SCADA master unit to the RTUs in the field

Communication protocols used by SCADA systems can be closed proprietary or open protocols. Maybe, the most recent trend is to use open and standard ones. The RTU modules read the sensor signals and encode them over the selected protocol to send them to the master unit. In turn, RTU modules receive the corresponding commands from the master unit over the protocol format, they decode them and act over the relays or sensors.

The master unit of a SCADA system displays the system state in real time through a screen (like a PC monitor). This functionality is usually named HMI (Human Machine Interface). Furthermore, the HMI shows the configured alarms or warnings in a visual way, so the manager can quickly act to fix the problem.

5.2.2.2 Energy flow control

Depending on the selected topology to apply in the specific application, there will be different control alternatives.

The first topology division is referred to the physical connection in the application area, which can be stand-alone or grid-connected.

Stand-Alone Mode

The GERES unit consists of several power converters, depending on the type of available energy sources. The energy sources can be from PV, wind turbine or the combinations of these sources.

Furthermore, it will be necessary a energy storage system, because of lack of the grid connection. In this case, the optimization of the energy storage system is probably the most important task of the control system. This is due to ESDs are a bidirectional device, they can act as an energy source and as a load, depending on the specific conditions at all times. Furthermore, the ESDs are the equipment with the worst performance of the installation, so it is very important to manage their state of charge in depth.

In stand-alone mode, the inverters in the GERES will be generally operated in voltage-controlled mode supplying power to the loads.

Grid-Connected Mode

A second topology division is referred to the interconnections of GERES to the grid. It can be categorized into two types:

- Interconnections with power only drawn from the grid
- Interconnections with power drawn and supplied back to the grid

It is the second category of interconnections that concerns the utility, especially with regard to the power quality and safety of personnel or equipment connected to the grid. In this mode of operation, assuming that the grid voltage is stiff, the inverter of the power processor will be normally operated in current-controlled mode.

The grid-connected mode may or may not include ESDs, with several factors that determine this choice. If the grid is intended as a backup supply to the load, ESD may not be required. Then the power is obtained from the grid when the energy sources are unavailable. In this case, the power required for a sudden load change or during peak power demand is obtained from the grid and the energy sources.

However, a power outage on the grid will result in the power supplied to the load being totally dependant on the energy sources. Thus, due to slow response of the energy sources to react to an instantaneous sudden load demand, the quality of the power supplied to the load will be impaired.

In the worst case, when the energy sources are not generating power, a power outage on the grid will result in no power available on the load. If the energy sources are sized to supply the load only during average power usage, then during the power outage on the grid, peak power demand cannot be fulfilled.

There are a few possible sources of energy from which the load can obtain the power, i.e. from the energy sources, from the ESDs, from the grid or from the combinations of these sources. The choice of source or combination of sources used to supply the loads in real time has to be made carefully to ensure maximum and efficient energy utilization.

This depends on several factors, such as the instantaneous power available from the sources, state of charge of the ESD, load characteristics, price of energy from the grid at that moment and the desired power factor.

This decision has to be made by the Master Unit for optimum energy utilization and cost. During a power outage on the grid, the energy sources and the ESD supply power to the loads therefore instantaneous peak power demand can be fulfilled.

The ESD can be charged-up either by the grid or energy sources depending on the instantaneous power available and the load demand. The sizing of the ESD has to be determined based on the load and energy sources characteristics. The ESDs are used to compensate the high transient power demanded by the loads that cannot be delivered by the energy sources due to their slow response.

5.2.2.3 Commercial solutions in the market

There are a wide range of Scada systems manufacturers in the market. They can give both closed as customizable solutions to a specific application.

These Scada systems are normally configurable and adjustable by the user to its application, but in the case of complex situations the manufacturers can implement a individual development on demand.

Table 5.1. below shows a number of more currently extended manufacturers and distributors of Scada systems and their web site pages:

MANUFACTURER	WEB SITE
National Instruments	http://www.ni.com/
Schneider Electric	http://www.schneider-electric.com/site/home/index.cfm/ww/
ABB	http://www.abb.com/
Siemens	http://www.siemens.com/entry/cc/en/
Omron Industrial Automation	http://www.omron.com/
Rockwell Automation	http://www.rockwellautomation.com/
Iconics	http://www.iconics.com/Home.aspx
Logitek	http://www.logitek.es/
PLC Automation	http://www.plcintegrator.com/index.htm
General Electric	http://www.ge.com/
Indusoft	http://www.indusoft.com/
Circutor	http://www.circutor.com/inicial.aspx

Table. 5.1. Compilation of some SCADA system manufacturers and distributors

Some of these softwares are slightly described in this chapter.

NATIONAL INSTRUMENTS

Maybe one of the most famous softwares for implementing Scada systems in the market nowadays is Labview.

Labview has a graphical development environment, which is modular, making it easier for users to configure a package just for them. Every project starts with a development system and then can add application tools or deployment targets depending on requirements. This flexible packaging enables LabVIEW functionality to grow as projects become more complex.

At the beginning, the users can choose between three software versions, depending on their needs:

LabVIEW Base	***LabVIEW Full***	***LabVIEW Professional***
• Graphical user interface developments • Data acquisition • Instrument control • Reporting and file I/O	• More than 700 math/analysis functions • External code integration (.dll) • Web connectivity • Advanced user interface development	• Application distribution (create .exe) • Development management • Source code control • Network communication

Table. 5.2. Labview software versions

Thanks to the modular and flexible design of the Labview application, there are a huge quantity of different independent packages to complement the user needs for the specific application. The next list shows some of them related to BEEM_UP projects.

LabVIEW Datalogging and Supervisory Control Module
LabVIEW Report Generation Toolkit for Microsoft Office
LabVIEW Database Connectivity Toolkit
LabVIEW Real-Time Module
LabVIEW Mobile Module
LabVIEW Touch Panel Module
LabVIEW Wireless Sensor Network Module
LabVIEW Internet Toolkit
WLAN Measurement Suite

Even third-party partners software packages can be added.

SCHNEIDER ELECTRIC

Schneider Electric gives support to an extensive products and services portfolio.

Between them, as an example related to renewable energies, it is recommended to consult the project carried out in France (work ended in past June 2010) where a 8.9 MW PV Power Plant was built.

The link to this project info is :

http://www.schneider-electric.com/solutions/WW/en/ref/4663671-solarezo?application=17140415

ABB

The specific software application from ABB is named the Network Manager SCADA/EMS system. It enables a secure and efficient operation of the electric power system and also an energy information system that provides the decision makers with reliable process information.

It´s based on a open and versatile platform that allows for easy integration with other utility information systems. Furthermore, it´s a recommended platform for building control solutions. It has a modular architecture which can help for future expansions, if needed.

OMRON INDUSTRIAL AUTOMATION

Omron provides a full lineup of configuration and programming software to integrate Supervisor Control And Data Acquisition systems in a high range of projects, both for small supervisory and control tasks as for the design of the most sophisticated applications.

One of the Omron´s products is CX-Supervisor, which let the user rapidly create simple applications with the aid of a large number of libraries and functions. But, it also let build a much more complex applications by using custom scripting and ActiveX® components. Among other functionalities, CX-Supervisor includes data log viewer, data analyzer, graphics library in order to include actions, animations & associated points, secure web based remote maintenance.

Omron Industrial Automation is also an official partner of InduSoft, Inc (also included in the table). Together, Omron and InduSoft provide a joint-venture product which includes the InduSoft Web Studio v7.0 SCADA development and runtime software.

This collaboration provides additional power when communicating with Omron products, multiple databases, when accessing systems remotely, highest data integrity and reliability though redundant server technology and extensive graphic library and graphical tools for user-customization.

PLC AUTOMATION

This company supply all the major brands of this kind of applications, including Wonderware, Intellution, Allen Bradley, GE Fanuc, ..

Wonderware created the InTouch® HMI software for visualization and industrial process control, which offers outstanding ease of use and simple-to-configure graphics. Customized applications can be easily and quickly developed and can connect and deliver real-time information. It´s based on a flexible architecture which ensures scalable projects. It also let be accessed from mobile devices, computer nodes and over the Internet.

Intellution´s IFIX SCADA software is a widely-respected HMI/SCADA application by the industry. Among its benefits it can be mentioned powerful distributed Client/Server architecture, faster system development and deployment, simplified application integration, enhanced security and accountability.

LOGITEK

Logitek is another distributor in Spain for the Wonderware´s software.

CIRCUTOR

Circutor´s SCADA software is named Power Studio, which is a powerful and simple software with a friendly environment that can be used for energy studies at a high level. It allows the complete energy supervision of power analyzers and the complete control of different magnitudes in the industrial process field.

Among its features:

- Built-in web server (multi-user)
- Real time display of all electrical parameters or process signals
- Energy graphs display
- Table of data display
- Historic display (day, week, month, etc.) in high resolution
- Zooms and print outs of any area
- Option to export historical in Excel or XML format
- Option to export parameters in real time using XML server to link in with other external applications
- Maximum connectivity internally (Intranet) and externally (Internet)

5.3 Application to Brogården site

This chapter includes the specific GERES design applied to Brogården site. At first place, it is described the internal architecture of the GERES design. It can be verified that the specific GERES for Borgarden is a simplified version regarding to the complete architecture in chapter 5.1.

Afterwards, the complete PV system design is calculated and described. This chapter adds the power hardware necessary to manage the produced energy from the PV panels. This power hardware mainly refers to the inverters to convert the DC electricity to AC electricity.

At last, the Supervisory and Control systems design that could be applied to Brogården site are described.

5.3.1 Architecture design

This chapter describes the specific application of the GERES design to Brogården site. From the general GERES diagram (Figure 5.1.), some simplifications are taken into account. Picture Fig. 5.3. below shows the simplified schematic.

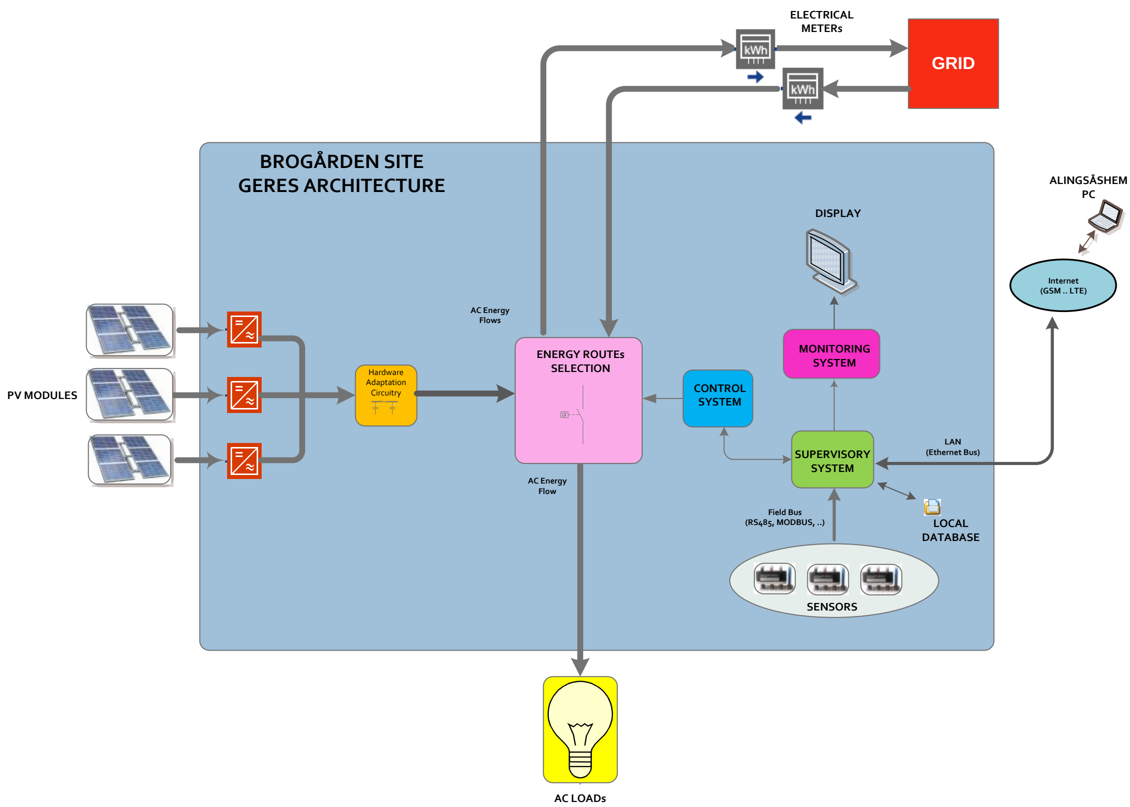

Fig. 5.3. Simplified GERES architecture design applied to Brogården site

The main differences between the universal GERES design and the specific to Brogården site one are compiled below:

- ✓ In reference to electrical energy sources, only the PV energy source is applied to this project site. Wind power, regenerative elevator aren´t taken into account
- ✓ In reference to the selected bussiness model, a net debit model in monthly basis is applied, where feeding into the grid the surplus energy is feasible. In this situation, the energy storage system is not necessary
- ✓ The supervisory and monitoring systems functions are referred to:
  - Data acquisition from several sensors distributed over the buildings, acquiring data through a field bus (RS485, MODBUS, ..) connected to the corresponding RTUs which manage the sensors
  - Small data analysis and treatment to calculate the instantaneous power and accumulative produced energy
  - Display the results of the power and energy values in a visible place at the buildings for knowledge by the tenants and visitors
  - At the same time, communicate these power and energy values to Alingsahem
  - Additionally, it could log the real time data and the made calculations in a database for future analysis. This would let extract trends and behaviours of the system
  - It is suggested to include an interface for connecting any local or remote PCs, through USB/Ethernet port or wireless modem (GSM, GPRS, 3G, HSDPA, LTE) or WiFi router
- ✓ The control system functions depend on how the produced energy is managed:
  - In the case of feeding in to the grid all the energy production at any time, then the Control System won´t be necessary, because the circuitry for the output energy (originated by PV modules and ended into the grid) will be totally independent from the circuitry for the input energy (from the grid and consumpted by the building loads). In addition, the box for Energy Routes Selection won´t be necessary, because there will only be two routes, one for input energy and another for output energy. This is the most basic topology for connecting to the grid. At the moment, **it is the selected topology for Brogården site**
  - Alternatively, in the case of consuming the produced energy for the own use to satisfy the building load, then both the Control System and the Energy Routes Selection box would be necessary. This box would mainly consist of switches or relays managed by the Control System to configure the appropriate routes for flowing the energy between the inputs and outputs. The route selection should be made in real time depending on the energy produced and the required load on each instant. This topology would be more complex in hardware and software than the prior one, and it only would make sense if the bought electricity was more expensive than the sold electricity as for compensating the additional investment costs

In order to know the specific reasons used for these simplifications, please refer to the first report Deliverable D4.2.[1] and also to the prior chapters of this report itself (mainly chapters 2, 3 and 4).

The design of the specific PV system is described in more detail in the next chapter *5.2.2. PV system design*. And the design of the specific Supervisory, Monitoring and Control systems are described in more detail in the chapter *5.2.3 Supervisory and Control system design.*

Furthermore, the schematic Fig. 5.3. above also shows two electrical meters, the global building load and the connection to the grid. One of the meters counts the electricity bought from the grid and the other one counts the electricity sold to the grid.

5.3.2 PV system design

In this chapter the system is going to be designed taking into account the main power hardware related to the PV installation. It´s not the aim of this report to define the installation at the lowest implementation level. The proposed design shows the calculated inverters to convert the generated electrical power from DC to AC, and at the same time shows one possible configuration of PV modules connection between them and the inverters.

The PV system design has been made with the help of the simulation software PV*SOL Expert Pro v5.5 and the Meteonorm application software v6.1. These are the same softwares used in the report D4.2 to show application examples of different topologies related to PV installations[1].

The design is going to be completed following the sizing described in chapter 4 of this report for Brogården site. The main parameters of this sizing are:

SURFACE	Modules	Wp/module	Model reference[7]
Southern Balconies House Q	36 PV	85 Wp	Schüco 3.2 aSi:H/_µc-Si float glass (microcrystalline)
Southern Facade House N	22 PV	85 Wp	Schüco SCC 50 Cold Façade with Prosol Black Thin Film
Southern Roof House O	111 PV	240 Wp	Schüco MPE 240 PS 02
Southern Roof House Q	111 PV	240 Wp	Schüco MPE 240 PS 02

Table. 5.3. PV system sizing applied to Brogården site

The installed power of the installation, the electricity production in June of the configuration above and the electricity consumption of the Houses are:

Total installed power	=	**58.2 kWp**
PV solar power production in June (from Chapter 4)	=	**8,502 kWh**
Electricity demand	=	**108,000 kWh/y**
Electricity demand in June	=	**8,500 kWh**

The estimation of electricity production in chapter 4 doesn´t include the influence of considering the inverters and their connection with the PV modules, separated on arrays or strings.

The feasible combinations to connect these strings is normally high, depending on the specific parameters of each installation. In this chapter only one of these feasible combinations is going to be shown, and it is highly possible that it isn´t the optimal one. So, the system designed in this chapter has to be taken only as an example.

Due to the fact that including more hardware equipments and more connection restrictions between them, the electricity production will be lower than the calculated one in chapter 4. So if the condition for sizing the system is to balance demand and production in June, then the PV installation should be increased with more PV panels to rise the installed power of the system. These new PV panels could probably be mounted on eastern roofs of Houses N and/or P. This additional calculation will not be included on this report.

The picture Fig. 5.4. below shows the four Houses NOPQ with the PV modules configuration proposed fitted at the corresponding surfaces. These pictures only show the basic structure of the buildings with the PV configuration distributed in the selected surfaces.

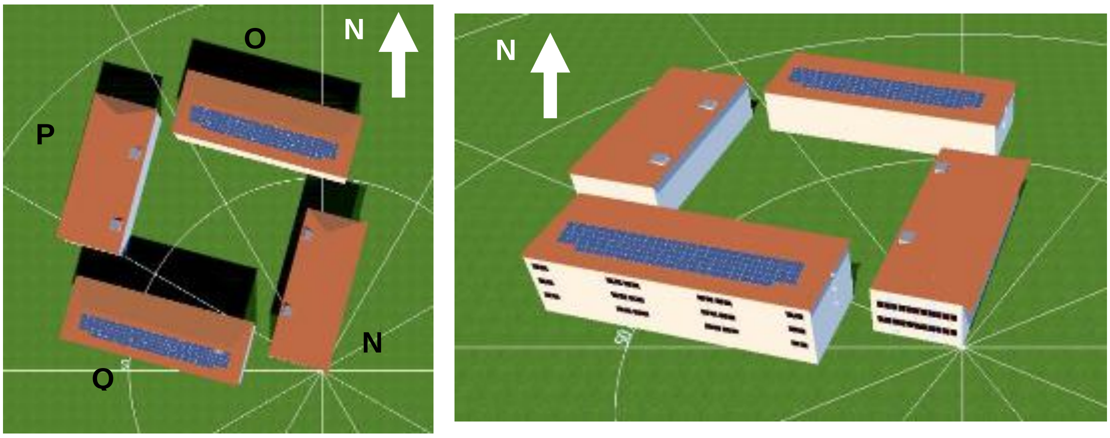

Fig. 5.4. Solar cell panel layouts on Houses NOPQ (Pictures done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

The first one shows the top view of the four Houses set. It can be seen that the Houses set are slightly oriented to the West, approximately 15º. On it, only the PV modules installed on the roofs can be seen.

The second one shows the southern view of the Houses, where it is possible to verify the PV panels installed in balconies and facade.

The facade PV installation on House N can be seen in more detailed in the picture Fig. 5.5. below. It is composed by two rows of eleven panels each.

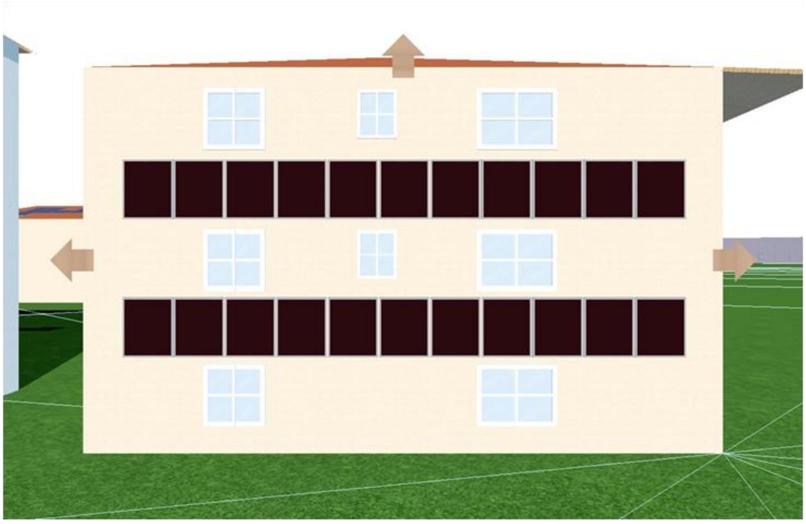

Fig. 5.5. Solar cell panel layout on Facade of House N (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

5.3.2.1 PV system simulation results

Based on the mentioned parameters above, the global results of the simulation are showed in the table 5.4. below. The installed power is the same, 58.21 kWp, which represents approximately 444 m^2 PV area, distributed in four zones (balconies, facade and roofs).

The nominal solar irradiation of the PV installation is around 435 MWh/y, but taking into account the reduction due to the shading effect, the real solar irradiation of the PV installation is around 420 MWh/y. With the graph Fig. 5.6. below the shading effect over the PV array irradiation can be seen. It´s mainly significant during the summer time when the sun power is the biggest over the year.

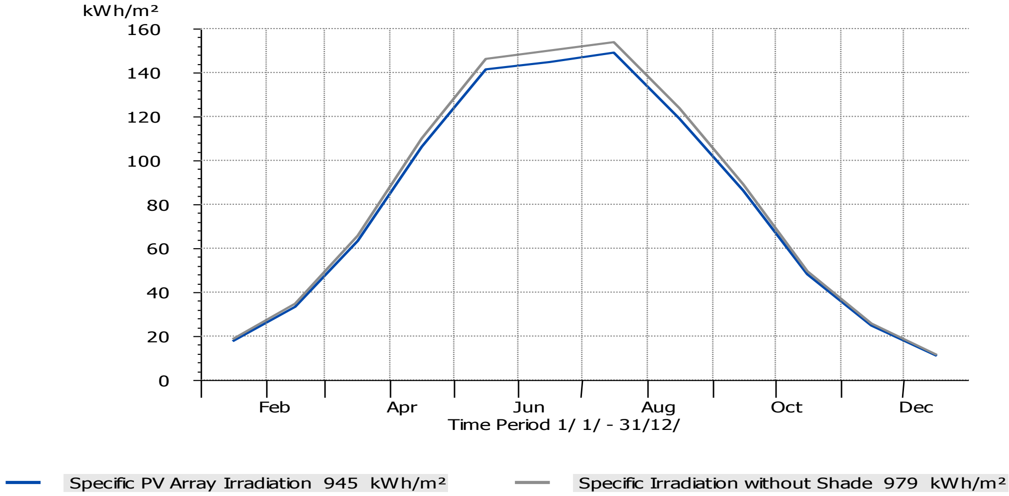

Fig. 5.6. Solar irradiation values applied to Brogården site throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

The PV installation is able to produce almost 50 MWh/y of DC electricity, which are converted in around 47 MWh/y of AC electricity, ready to use by buildings AC loads or to feed in to the grid. The graph Fig. 5.7. below shows the difference between the energies produced by PV array in DC and AC modes.

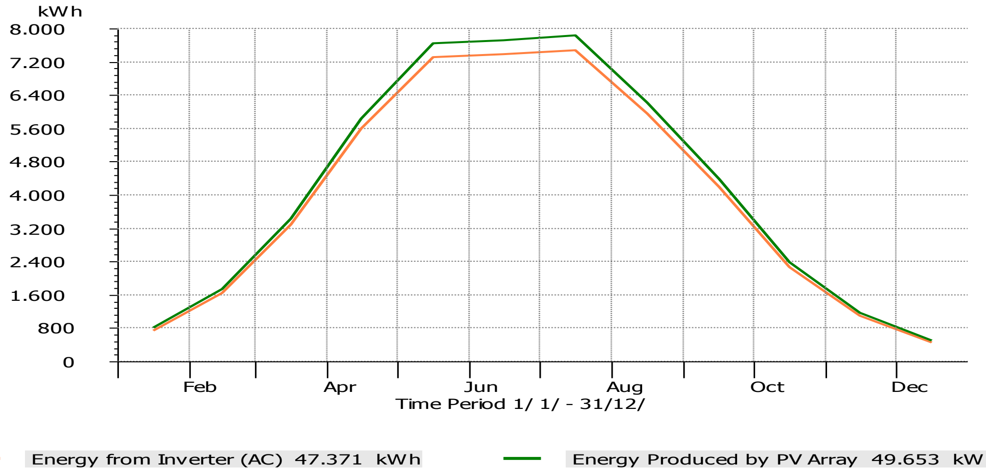

Fig. 5.7. DC and AC electrical energy production throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

The resulting system efficiency is 11.2%, calculated from the *AC Energy Produced (47,371 kWh/y)/PV Array Irradiation (420 MWh/y).*

The consumption requirement throughout the year is 108 MWh, more than the double of AC produced energy (47 MWh), which distribution can be seen on graph Fig. 5.8. below.

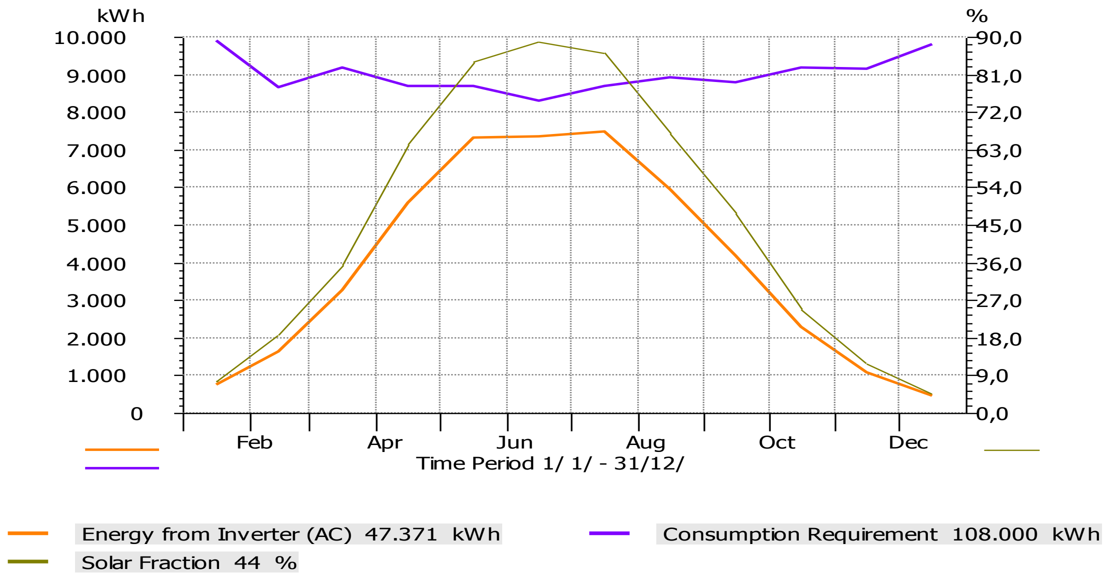

Fig. 5.8. Global electrical energy balance (Consumption vs Production) throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

Focused on June, it is possible to verify that the required balance between consumption and production is around 85-90% covered. The average solar fraction throughout the year is around 44%, but in summer time almost reaches 90%.

There is a portion of the AC produced electricity (15.6 MWh/y) that cannot be used by loads in real time and it must be feed in to the grid. And there is another portion (almost 32 MWh/y) that can be used directly by buildings loads or feed in to the grid, depending on the choice of how the connection to the grid is made. Graph Fig. 5.9. below shows the energy distribution in the case of choosing loads directly consume the corresponding portion of energy (32 MWh/y).

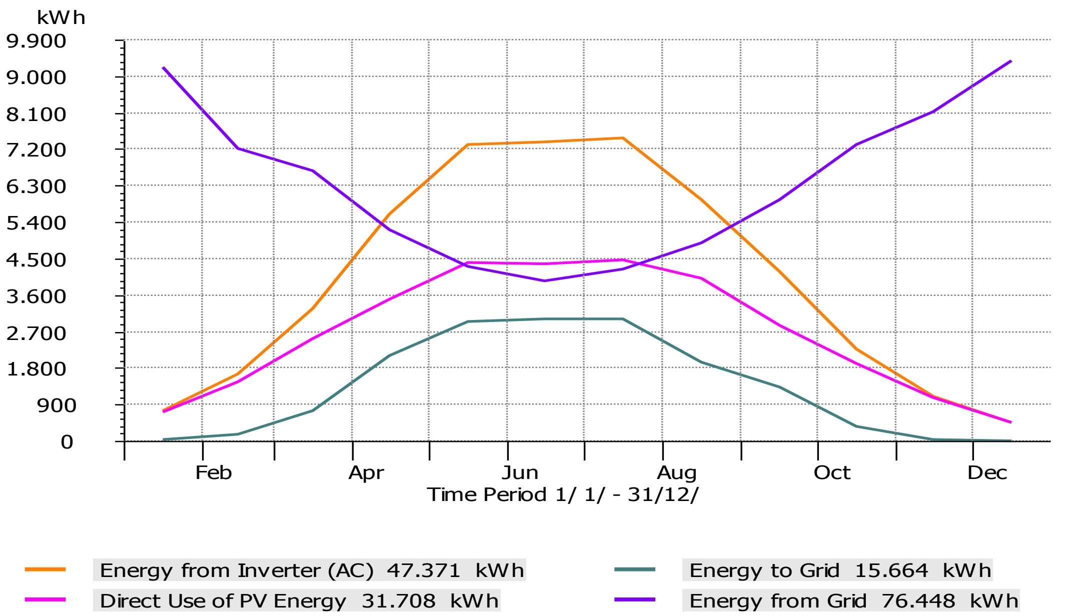

Fig. 5.9. Distribution of AC electrical energy production throughout the year (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

If the choice is to feed in to the grid all the production, then *Energy from Grid* parameter will match with the *Consumption Requirement*, 108 MWh, and the graph Fig. 5.9. above will not be used.

Table 5.4. below compiles all main data calculated by the simulation software, some of them detailed in graphs above.

PV Output:	**58.21** kWp
Active PV Surface Area:	444.15 m²
PV Array Irradiation without Shade:	434,689 kWh/y
PV Array Irradiation:	419,923 kWh/y
Energy Produced by PV Array (DC):	**49,651** kWh/y
Energy Produced by PV Array (AC):	**47,372** kWh/y
Energy to Grid:	15,664 kWh/y
Consumption Requirement:	**108,000** kWh/y
Direct Use of PV Energy:	31,708 kWh/y
Energy from Grid:	76,448 kWh/y
Yield Reduction due to Shading:	1 %
Solar Fraction:	43.7 %
System Efficiency:	**11.2** %
Specific Annual Yield:	811.1 kWh/kWp/y

CO2 Emissions Avoided:	33,451 kg/y

Table. 5.4. Gloabl simulation results of the PV system (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

One interesting parameter which also indicates the system performance is the *Specific Annual Yield* parameter (around 811 kWh/kWp). This value is calculated from the relation between the AC produced electricity (47 MWh/y) and the PV power of the installation (51.28 kWp).

The shading effect over the installation yield reduction is 1%. In addition, the quantity of CO_2 emissions avoided to the atmosphere is almost 34 Ton/y.

The last graph Fig. 5.10. below shows the contribution of each surface to the toal AC energy production. The green and purple bar charts correspond to the roofs production, and the grey and pink bar charts correspond to balconies and facade productions.

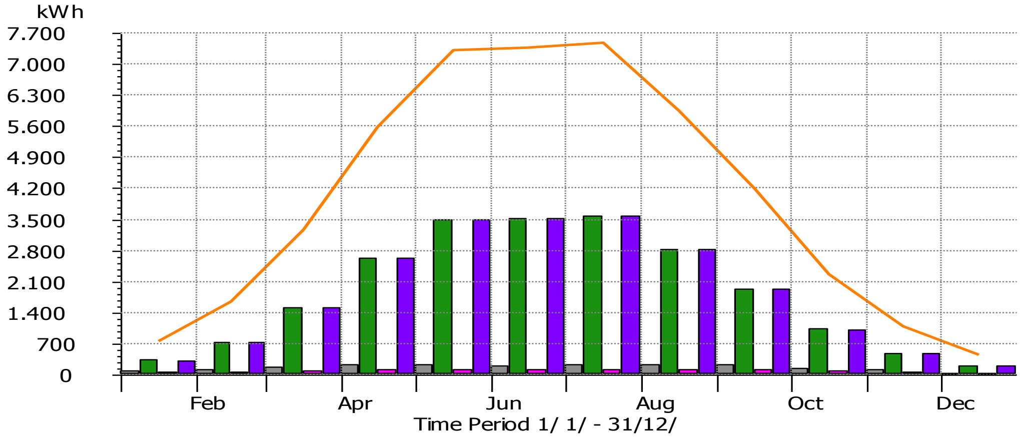

Fig. 5.10. Comparison of AC electrical energy production from the four surfaces throughout the year (Green-House Q Roof / Purple-House O Roof / Gray-House Q Balconies / Pink-House N Facade) (Graph done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

5.3.2.2 Components description

Each surface selected for installing PV panels is covered by one set of panels. Each set of panels consists of several strings of PV modules. A string consists of several panels connected between them in a serial way, so the final voltage is the sum of each panel one and the resulting current is the same for all them.

It´s important to associate the inverter design with the PV modules design, because each inverter works efficiently in a narrow power band. In these conditions, the inverter inputs must match their electrical capabilities with the generated strings connected to them. So, it is not enough to select an inverter which nominal power can satisfy the installed power of the panels, in addition each inverter input must satisfy each PV string characteristics. But it is also important not to oversize the inverter capacity, because its efficiency will significantly decrease.

The diagram Fig. 5.11. below shows the main components configuration calculated for this system. This is only one of the multiple existing combinations.

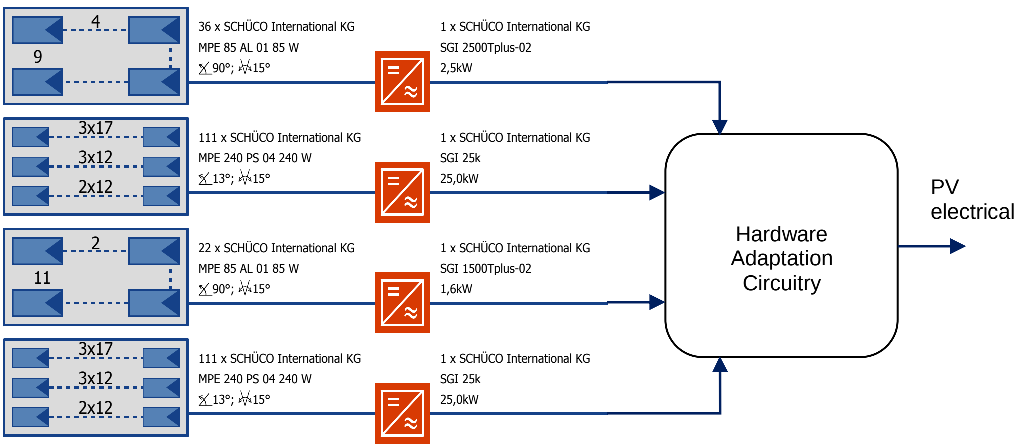

Fig. 5.11. PV system components schematic (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

The inverters normally integrate the appropriate electrical interface to feed in the electrical power to the grid connection, so the four inverter outputs could be slightly adapted by hardware circuitry in order to get only one energy output.

The southern balconies of House Q integrate 36 panels connected in 9 strings of 4 panels each. The nine strings are connected to only one 2.5 kW inverter Schüco SGI 2500Tplus-02. [7]

The southern roofs of Houses O and Q have the same implementation. They integrate 111 panels each connected in 8 strings (three strings with 17 panels each, and five strings with 12 panels each). The eight strings are connected to only one 25 kW inverter Schüco SGI 25k. [7]

In the end, the southern facade of House N integrate 22 panels connected in 11 strings of 2 panels each. The eleven strings are connected to only one 1.6 kW inverter Schüco SGI 1500Tplus-02. [7]

5.3.2.3 Southern Balconies House Q layout

Table 5.5. below shows the specific parameters for southern balconies configuration of House Q in more detail.

Output:	**3.06 kW**		
Active Solar Surface Area:	**53 m²**	**Inverter**	1 x
PV Module	**36** x	Manufacturer:	SCHÜCO International KG
Manufacturer:	SCHÜCO International KG	Model:	SGI 2500Tplus-02
Model:	MPE 85 AL 01	Output:	2.50 kW
Nominal Output:	**85 W**	European Efficiency:	**94 %**
Efficiency (STC):	**5.9 %**	No. of MPP Trackers:	1
No. of Modules in Series:	4	MPP Tracking:	200 V To 510 V
MPP Voltage (STC):	291 V		
Orientation:	15 °		
Inclination:	90 °		

Table. 5.5. PV system components related to Southern Balconies House Q (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

Most of them are already known. The nominal efficiency of each PV module is less than 6%, and the inverter one is 94%.

The inverter design is compatible with multiple string configurations. The main condition is that the total voltage per string (this is the sum of all panel voltages in serial connection) must be inside of the MPP Tracking value (ranged 200 .. 510 VDC). For verifying this issue, it is necessary first to know the MPP voltage of each PV panel. This parameter can be obtained from the data sheet and also it can be obtained from the graph Fig. 5.12. below. This is the characteristic curve Power vs Voltage at nominal conditions. The maximum value of the curve signs the voltage for getting the maximum power (MPP voltage parameter).

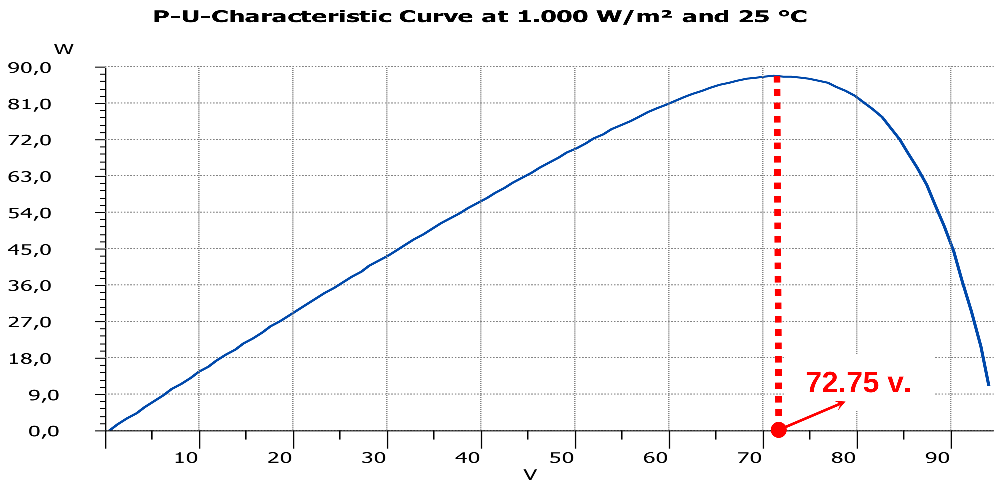

Fig. 5.12. Power vs Voltage characteristic curve of Schüco MPE 85 AL 01 PV panel (Screenshot done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

So, if each panel voltage is 72.75 volts, then the MPP voltage for the string composed by 4 PV panels will be 291 volts, which value complies with the specified range of the inverter input.

Picture Fig. 5.13. below shows the shading effect over the PV panels located in southern balconies of House Q.

Fig. 5.13. Solar cell panels on Balconies House Q showing the shading effect (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

It can be seen that the reduction on the solar irradiation is lower than 0.7% in all cases.

On the other hand, picture Fig. 5.14. below shows the strings configuration calculated by the simulation software. The PV panels are grouped in 9 strings of 4 modules each. The panels connected at the same string have the same colour. This layout is not the only one solution, in fact at a real implementation there would be other factors that they could modify this layout (cable lenghts, aesthetics, mounting feasibility, ..).

Fig. 5.14. PV strings layout on Balconies House Q (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

The specific energy balance results are compiled in Table 5.6. below.

Array Irradiation:	40,499 kWh/y	Energy Produced (DC):	**2,079 kWh/y**
Energy Produced (AC):	**1,909 kWh/y**	System Efficiency:	**4.7 %**
Inverter Efficiency:	91.3 %	Array Efficiency:	5.1 %

Table. 5.6. Main energy balance results related to Southern Balconies House Q (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

It can be verified that the System Efficiency parameter related to the balconies array is 4.7% (1,909 kWh/y got from 40,499 kWh/y irradiated), and also it can be verified the Balconies Array Efficiency is 5.1% (2,079 kWh/y got from 40,499 kWh/y irradiated).

Furthermore, it can be seen that the corresponding real efficiencies of PV array and inverter are lower than the nominal values.

5.3.2.4 Southern Roofs Houses Q/O layout

Table 5.7. below shows the specific parameters for southern roofs configurations of Houses Q and O in more detail.

Output:	**26.64 kW**		
Active Solar Surface Area:	**179 m²**	**Inverter**	1 x
PV Module	**111** x	Manufacturer:	SCHÜCO International KG
Manufacturer:	SCHÜCO International KG	Model:	SGI 25k
Model:	MPE 240 PS 04	Output:	25.00 kW
Nominal Output:	**240 W**	European Efficiency:	**97 %**
Efficiency (STC):	**14.9 %**	No. of MPP Trackers:	3
No. of Modules in Series:	17 | 12 | 12	MPP Tracking:	330 V To 600 V
MPP Voltage (STC):	517 | 365 | 365 V		
Orientation:	15 °		
Inclination:	14 °		

Table. 5.7. PV system components related to Southern Roofs Houses Q/O (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

The nominal efficiency of each PV string is almost 15%, and the inverter one is 97%.

The inverter design is compatible with multiple string configurations. In this case, the inverter has three independent MPP Trackers, so this means that three different string configurations can be connected to the inverter at the same time. The three inverter inputs must be ranged 330 to 600 volts. So the condition is that the total voltage per each different string (this is the sum of all panel voltages in serial connection) must be inside of the MPP Tracking value. For verifying this issue, it is necessary first to know the MPP voltage of each PV panel. This parameter can be obtained from the data sheet and also it can be obtained from the graph Fig. 5.15. below. This is the characteristic curve Power vs Voltage at nominal conditions. The maximum value of the curve signs the voltage for getting the maximum power (MPP voltage parameter).

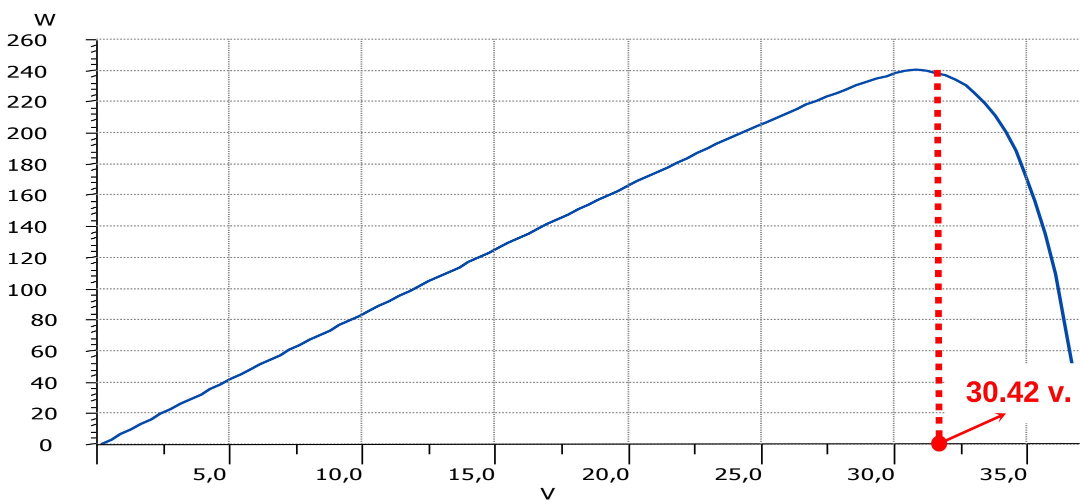

Fig. 5.15. Power vs Voltage characteristic curve of Schüco MPE 240 PS 04 PV panel (Screenshot done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

So, if each panel voltage is 30.42 volts, then the MPP voltage for the string composed by 17 PV panels will be 517 volts, and the MPP voltages for the strings composed by

12 PV panels will be 365 volts, which values comply with the specified range of the inverter input.

Picture Fig. 5.16. below shows the shading effect over the PV panels located in southern roof of House O. This shadow over roof of House O is due to the House Q. This is the reason why the southern roof of House Q is not affected by any shadow projected by other buildings (a more detailed analysis should include the solar horizon effect as well).

It can be seen that the reduction on the solar irradiation is lower than 0.4% in all cases.

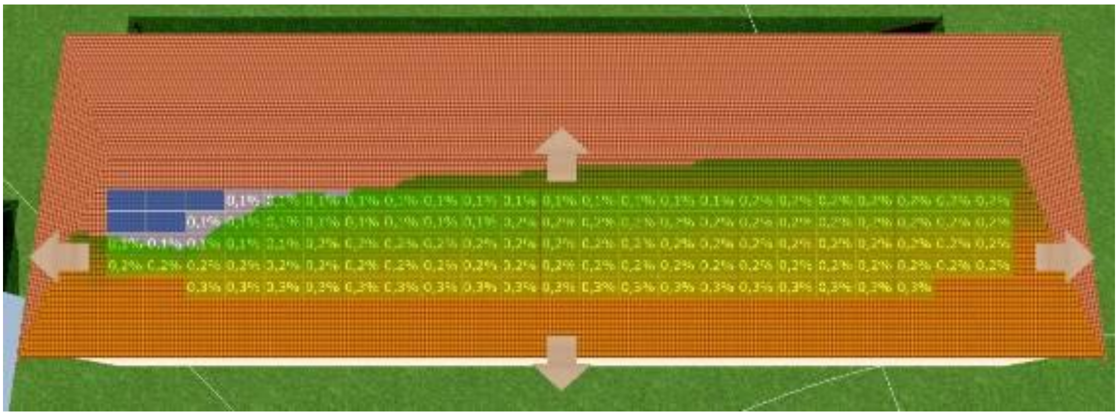

Fig. 5.16. Solar cell panels on Roof House O showing the shading effect (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

Picture Fig. 5.17. below shows the strings configuration calculated by the simulation software, both roofs have the same layout. There are 5 strings of 12 PV panels each, which are located at the highest rows, while the 3 strings of 17 PV panels each are located at the lowest rows. The panels connected at the same string have the same colour. This layout is not the only one solution, in fact at a real implementation there would be other factors that they could modify this layout (cable lenghts, aesthetics, mounting feasibility, ..).

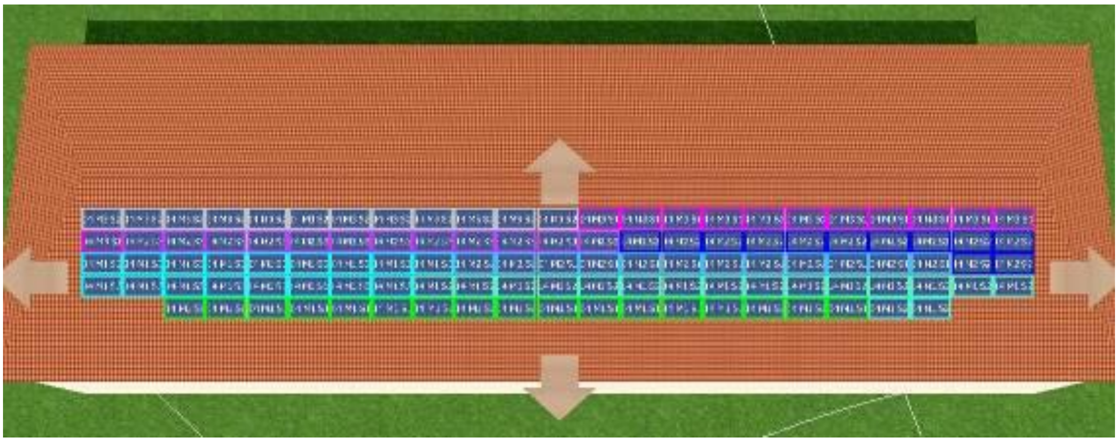

Fig. 5.17. PV strings layout on Roofs House Q/O (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

The specific energy balance results are compiled in Table 5.8. below (House Q).

Array Irradiation:	178,370 kWh/y	Energy Produced (DC):	**23,245 kWh/y**
Irradiation without Shade:	183,630 kWh/y	System Efficiency:	**12.4 %**
Energy Produced (AC):	**22,250 kWh/y**	Array Efficiency:	13 %
Inverter Efficiency:	95.4 %		

Table. 5.8. Main energy balance results related to Southern Roofs House Q (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

It can be verified that the System Efficiency parameter related to the House Q roof array is 12.4% (22,250 kWh/y got from 178,370 kWh/y irradiated), and also it can be verified the Array Efficiency is 13% (23,245 kWh/y got from 178,370 kWh/y irradiated).

The specific energy balance results are compiled in Table 5.9. below (House O).

Array Irradiation:	178,143 kWh/y	Energy Produced (DC):	**23,156 kWh/y**
Irradiation without Shade:	183,630 kWh/y	System Efficiency:	**12.4 %**
Energy Produced (AC):	**22,163 kWh/y**	Array Efficiency:	13 %
Inverter Efficiency:	95,4 %		

Table. 5.9. Main energy balance results related to Southern Roofs House O (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

It can be verified that the System Efficiency parameter related to the House O roof array is 12.4% (22,163 kWh/y got from 178,143 kWh/y irradiated), and also it can be verified the Array Efficiency is 13% (23,156 kWh/y got from 178,143 kWh/y irradiated). Furthermore, it can be seen that in both cases, the corresponding real efficiencies of PV array and inverter are lower than the nominal values.

5.3.2.5 Southern Facade House N layout

Table 5.10. below shows the specific parameters for southern facade configuration of House N in more detail.

Output:	**1.87 kW**		
Active Solar Surface Area:	**33 m²**	**Inverter**	1 x
PV Module	**22** x	Manufacturer:	SCHÜCO International KG
Manufacturer:	SCHÜCO International KG	Model:	SGI 1500Tplus-02
Model:	MPE 85 AL 01	Output:	1.65 kW
Nominal Output:	**85 W**	European Efficiency:	**93.3 %**
Efficiency (STC):	**5.9 %**	No. of MPP Trackers:	1
No. of Modules in Series:	2	MPP Tracking:	125 V To 510 V
MPP Voltage (STC):	146 V		
Orientation:	15 °		
Inclination:	90 °		

Table. 5.10. PV system components related to Southern Facade House N (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

The nominal efficiency of each PV string is less than 6%, and the inverter one is 93%.

The inverter design is compatible with multiple string configurations. The main condition is that the total voltage per string (this is the sum of all panel voltages in serial connection) must be inside of the MPP Tracking value (ranged 125 .. 510 VDC). For verifying this issue, it is necessary first to know the MPP voltage of each PV panel. This parameter can be obtained from the data sheet and also it can be obtained from the graph Fig. 5.18. below. This is the characteristic curve Power vs Voltage at nominal conditions. The maximum value of the curve signs the voltage for getting the maximum power (MPP voltage parameter).

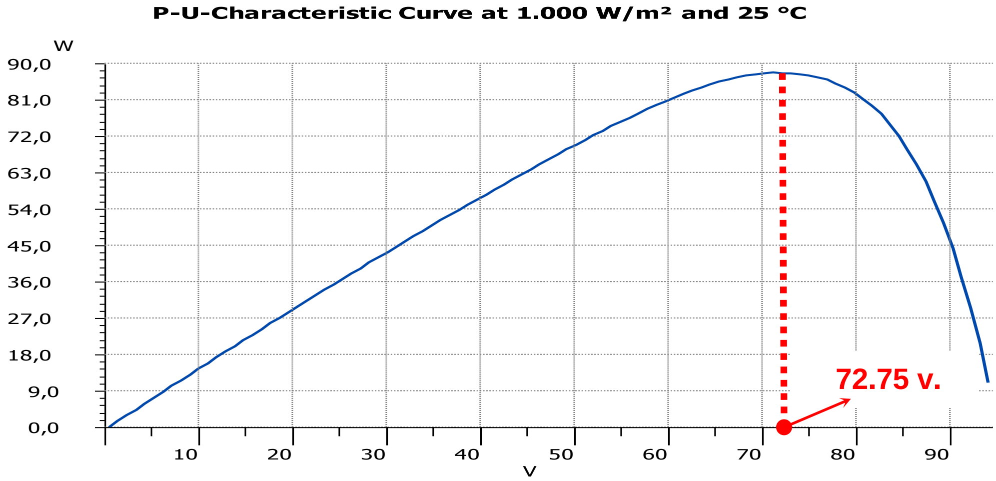

Fig. 5.18. Power vs Voltage characteristic curve of Schüco MPE 85 AL 01 PV panel (Screenshot done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

So, if each panel voltage is around 73 volts, then the MPP voltage for the string composed by 2 PV panels will be 146 volts, which value complies with the specified range of the inverter input.

Picture Fig. 5.19. below shows the shading effect over the PV panels located in southern facade of House N. In this case the shading effect is more significant than prior surfaces. Now, the reduction in the solar irradiation rises up to 15% in the worst case that is the panel located at the left lower corner. The shadow is mainly projected by the House Q when the solar beams comes from the West direction.

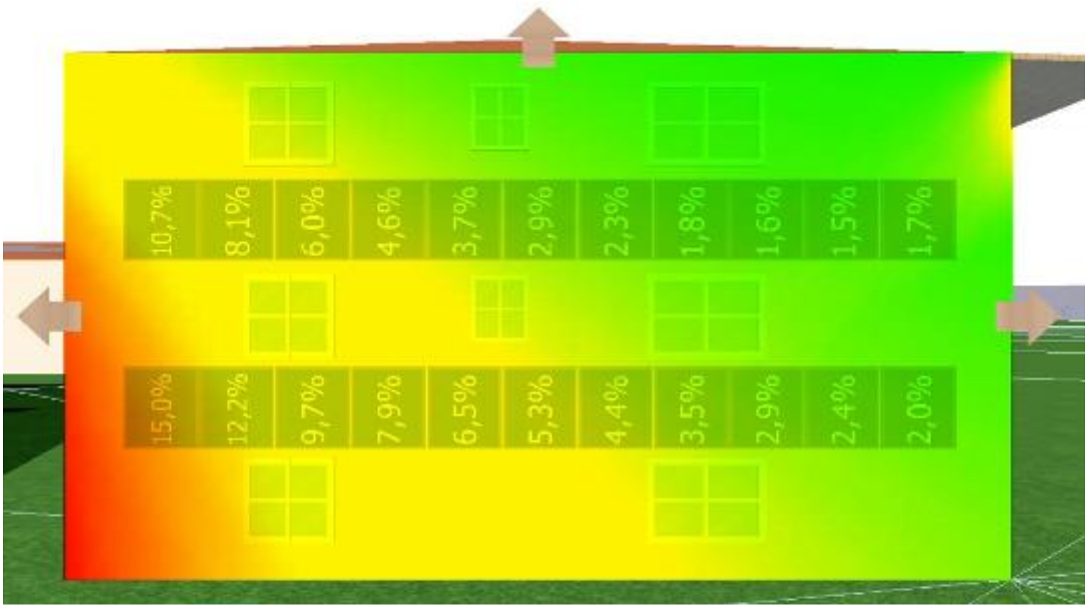

Fig. 5.19. Solar cell panels on Facade House N showing the shading effect (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

Picture Fig. 5.20. below shows the strings configuration calculated by the simulation software. There are 11 strings of 2 PV panels each. The panels connected at the same string have the same colour. As in the prior cases, this layout is not the only one solution, in fact at a real implementation there would be other factors that they could modify this layout (cable lenghts, aesthetics, mounting feasibility, ..).

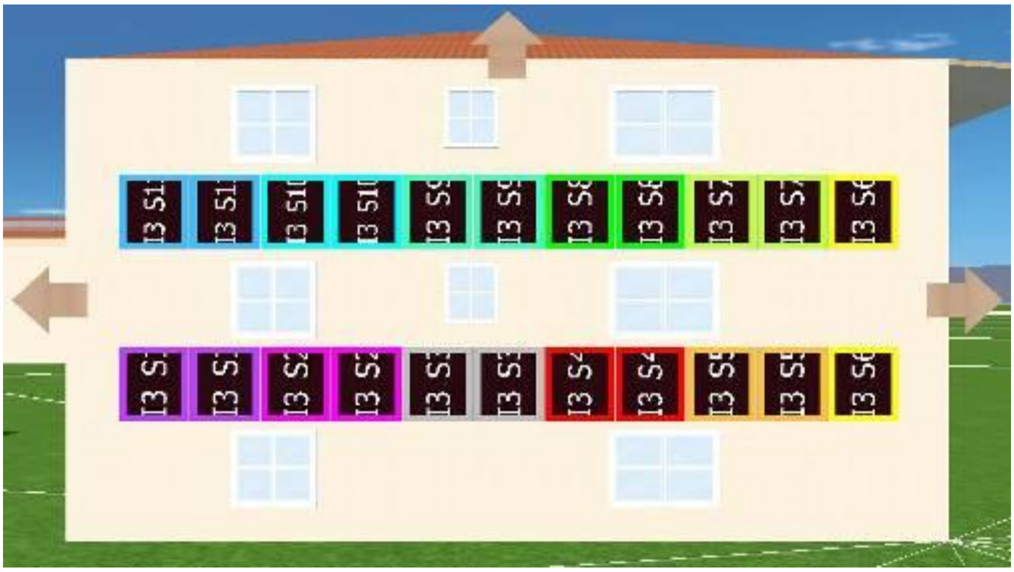

Fig. 5.20. PV strings layout on Facade House N (Picture done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

The specific energy balance results are compiled in Table 5.11. below.

Array Irradiation:	22,911 kWh/y	Energy Produced (DC):	**1,171 kWh/y**
Energy Produced (AC):	**1,048 kWh/y**	System Efficiency:	**4.5 %**
Inverter Efficiency:	88.7 %	Array Efficiency:	5.1 %

Table. 5.11. Main energy balance results related to Southern Facade House N (Report done with PV*SOL Expert Pro 5.5, © Valentin Software[8])

It can be verified that the System Efficiency parameter related to the facade array is 4.5% (1,048 kWh/y got from 22,911 kWh/y irradiated), and also it can be verified the Facade Array Efficiency is 5.1% (1,171 kWh/y got from 22,911 kWh/y irradiated). It can be seen that the corresponding real efficiencies of PV array and inverter are lower than the nominal values.

5.3.3 Supervisory and Control systems design

The definitive GERES design to apply in Brogården site is showed in schematic Fig. 5.21. below:

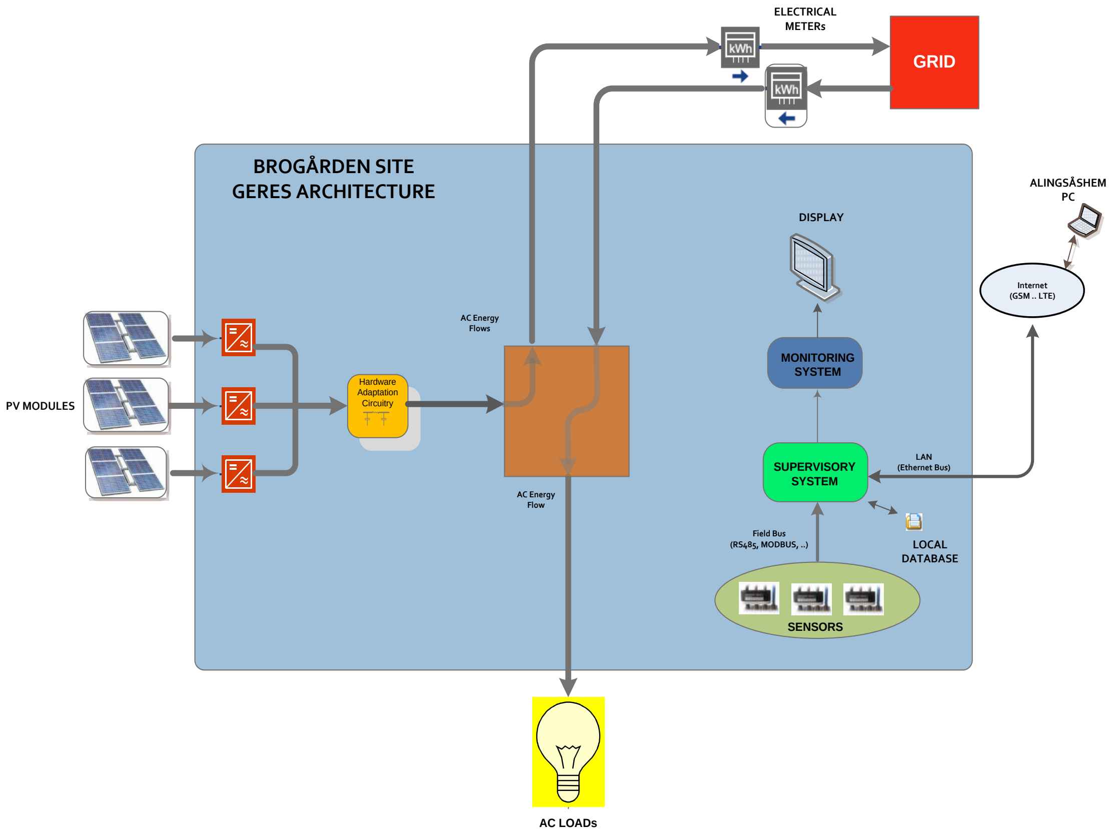

Fig. 5.21. GERES architecture design applied to Brogården site

As it can be seen the Control System has disappeared, and the box for selecting the energy routes doesn´t have any function, because there are only two possible energy flows, one for the incoming electrical energy and another for the outgoing electrical energy.

According with the schematic Fig. 5.21., the generated electricity by PV modules integrates a totally independent system, connected to the grid through the output meter. On the other hand, the energy inputs from the grid and it is directly connected to the AC loads through the input meter.

This scenario has an implementation and maintenance easier than any other one, because the current connections for consuming energy from the grid in AC loads are already valid.

It is only necessary to install the PV system at the buildings.

So, this chapter is going to be focused on the supervisory system design. A detailed zoom of it can be seen in the picture Fig. 5.22. below:

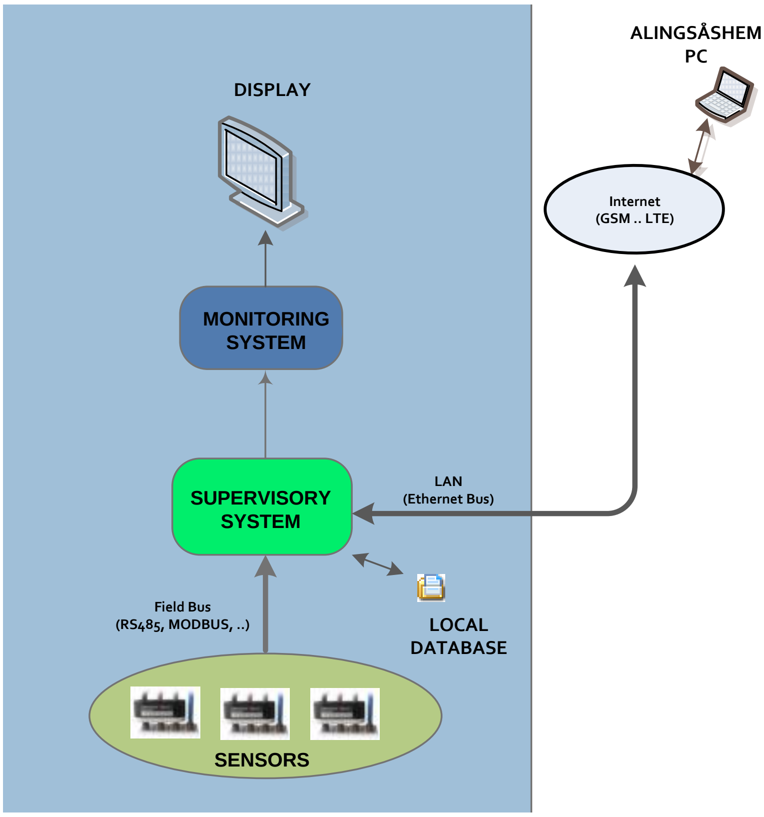

Fig. 5.22. Supervisory system design zoom view

The final objective proposed for Brogården site is to show in a display located at a visible place the main production parameters, such as the instantaneous power (in W) and the AC total energy produced (in kWh) since operation starting point.

The aim is to keep informed to the building tenants and visitors to Brogården site, in order to reach a high pedagogical value.

At the same time, this basic information has to be automatically communicated to **Alingsåshem.**

Additionally, it is suggested that the supervisory system can compile the real time data calculations in a database for ulterior analysis of the system evolution.

It is also interesting that a PC can connect locally or remotely with the supervisory system to get the data stored in the database, for example.

So, for getting the requirements above, an eligible supervisory and monitoring system design is proposed in the figure 5.23. below:

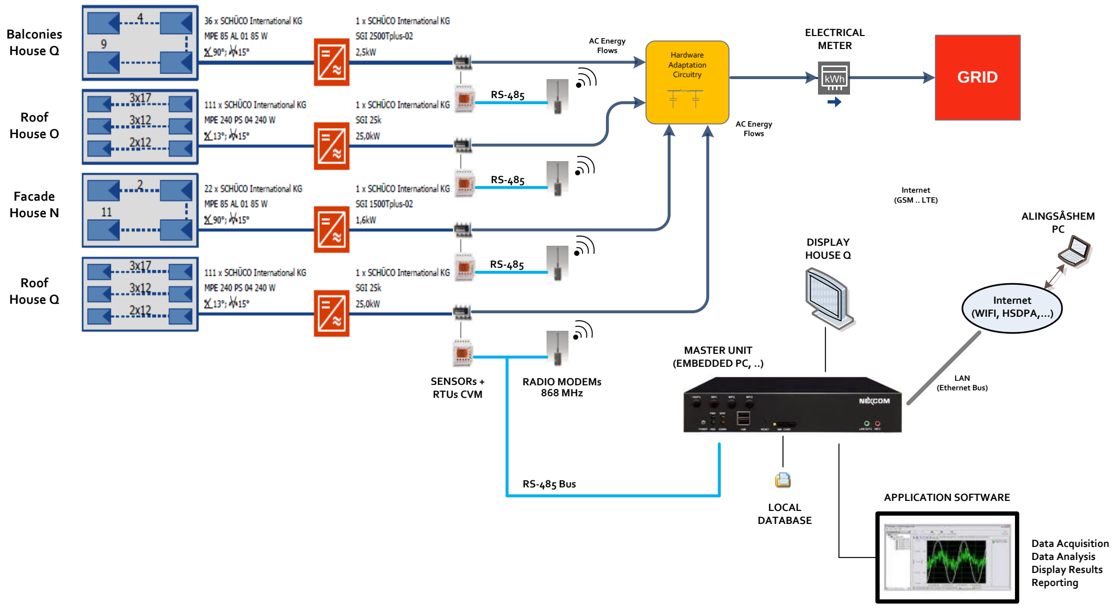

Fig. 5.23. Example of Supervisory system design applied to Brogården site

It can be verified that the schematic integrates two main separate networks, one for the energy flow (in wide dark blue) and another one for communicating between RTUs and Master units (in wide cyan) through RS485 bus.

Moreover, there can be other connections to the Master Unit for displaying results by the monitor (for example, with VGA/HDMI output), for connecting with remote equipments through a LAN network (Ethernet bus, WiFi, GPRS, 3G, ..).

The proposed device for working as a Master Unit is an embedded PC, also it is named as industrial PC. It works exactly as a desktop PC but it only contains the necessary peripherals to carry out its tasks. So, it is an optimized concept from the performance and security point of view.

This PC contains an internal hard disk to log all data acquired from the system. It is able to execute any kind of common application in Windows operating system. For example, it is possible to program and run an application software for acquiring data from sensors connected to the RTUs units, analysing these data in real time and calculating the needed parameters (power and energy mentioned above) and displaying to the corresponding monitor installed in a very visible place at the building.

In reference to the communication network between the Master Unit and the sensors, it can be noted that two PV arrays are located at House Q, one at House N and another one at House O. So to facilitate the connections layout, it can be advisable to place the Master Unit and the visualization display inside the House Q for optimizing the cable layout.

Totally, there are four inverters. So, they are needed four sensors to measure the energy flowing to the inverter output. The sensors are directly connected to each RTU units, and these ones are connected to the Master Unit through a RS485 bus. The RS485 bus connection inside the House Q can be directly cabled or wireless interfaced to the Master Unit, but in Houses O and N is suggested to integrate a wireless gateway to facilitate the installation of the system. The wireless connection is made by radio modems working at 868 MHz frequency, it´s a free frequency band with power enough to reach the needed distances at Brogården .

RS485 bus admits up to 256 devices at the same bus, so this isn´t going to be a problem. And its bandwidth is high enough for transmitting the needed parameters in real time. At the same time, the RS485 physic layer is a differential bus (it works with positive and negative voltages in reference to ground signal), what means is a very secure field bus against external perturbances (electromagnetic noise).

In reference to the power network, the nowadays inverters are ready for connecting and feeding into the grid, so the four output cables from the inverters can probably be simply joined inside the Hardware Adaptation Circuitry box (HAC box). The only one output from this box connects to the output electrical meter to measure the outgoing electricity, and then it is feed into the grid.

The HAC box can better be located close to the meter and grid connection.

Devices description

The main devices contained in the proposed supervisory system design are the RTU units (including their corresponding sensors) and the Master Unit.

The device selected to work as a RTU unit is the same for the all inverter outputs. The device is CVM-Mini from Circutor manufacturer. The picture Fig. 5.24. below shows a photograph of the device. It is prepared for carrying out measures in AC lines. It integrates an small display to help the configuration of the device and let the user to visualize the measured parameters in real time.

Fig. 5.24. CVM – Mini RTU Unit model

The Table 5.12. below compiles all parameters that it is able to measure and send to the Master Unit in real time through the RS485 bus.

As it can be checked the CVM is able to measure a wide range of different parameters from AC lines.

PARAMETER	UNIT	L1	L2	L3	III
Phase-neutral voltage	*V f-n*	•	•	•	
Phase-phase voltage	*V f-f*	•	•	•	
Current	*A*	•	•	•	••
Frequency	*Hz*	•			
Active power	*kW*	•	•	•	•
Reactive power L	*kvarL*	•	•	•	•
Reactive power C	*kvarC*	•	•	•	•
Apparent power	*kVA*	•	•	•	•
Power factor	*PF*	•	•	•	•
Cos φ	*Cos φ*				•
Maximum demand	*Pd*	•	•	•	•
Neutral current	I_N			•	
Voltage THD	*% THD - V*	•	•	•	
Current THD	*% THD - A*	•	•	•	
kWh (consumption and generation)	*W·h*				•
kvarh.L (consumption and generation)	*W·h*				•
kvarh.C (consumption and generation)	*W·h*				•
kVAh (consumption and generation)	*W·h*				•
Harmonic content (V and A) *	*%*	•	•	•	15^{th}
Temperature	*ºC*		•		

Table. 5.12. Measured parameters by CVM - Mini

For Brogården application it would probably be only necessary the two parameters yellow flag marked (Active power in kW and Active energy in kWh).

The Master Unit work is made by an embedded PC, which can be seen in the picture Fig. 5.25. below.

Fig. 5.25. Master Unit - Embedded PC NEXCOM

In Figure 5.26. below are compiled the main characteristics and specifications of this device.

Specifications

Main Chipset
- ICH-8M

CPU
- Intel® Atom™ D410 Single Core 1.6GHz

Memory
- DDR2 667/800 SDRAM one 200-pin SO-DIMM up to 2GB

Expansion
- Mini-PCIe socket (PCIe + USB) x 1 (for WLAN module)
- Mini-PCIe socket (USB) x 1 (for 3.5G module)
- 1 x Bluetooth module (optional)
- 1 x GPS module
- PCI-104 x 1

I/O Interface-Front
- 5 x LED's for power stand-by (on power button), power status, HDD, WLAN/ HSDPA and GPIO
- Power button
- 2 x USB port
- 1 x SIM card socket
- System reset button
- 1 x Mic-in, 1 x Line-out
- 4 x mounting hole SMA-type for WLAN/HSDPA/BT

I/O Interface-Rear
- Mounting hole reserved: For RF coax to SMA bulkhead x 1 (for GPS) reference, signal connect to function board
- 8V~60V wide range DC power input, power ignition signal control
- Dual VGA output (clone mode)
- 5V/1A, 12V/1A DC power output, can be controlled by S/W
- 1 x Mic-in, 1 x Line-out
- 2 x RS232 (COM1/2/), 1 x RS485 (COM3)
- 2 x USB 2.0
- 1 x LVDS (DB26 female connector for LVDS with backlight, control power (+12V) and USB 2.0 x 1)
- 10/100/1000 Fast Ethernet, RJ45 with LED connector x 1
- 1 x GPIO (4 input & 4 output)

Expandable Storage
- SATA 2.5" HDD Bay x 1

Power Management
- Selectable boot-up & shut-down voltage for low power protection
- HW design ready for 8-level delay time on/off at user's self configuration
- Power on/off ignition, software detectable
- Support S3/S4 suspend mode

Fig. 5.26. Specifications for embedded PC NEXCOM

As it can be checked it integrates all needed peripherals to communicate both to local or remote devices in several ways.

Application softwares description

Furthermore the hardware interfaces seen before, the Master Unit has to execute a software application to acquire data from sensors, analyze them in real time and display them to the monitor.

This application can be acquired from a commercial solution (see chapter 5.1.2.3.) or can be programmed by oneself.

Figures below show an example about what specific tasks this application should make.

Before acquiring data from sensors, the application must set the specific RTU unit configuration. In the example, there are three different RTUs to choose (CVM unit is selected for Brogården site).

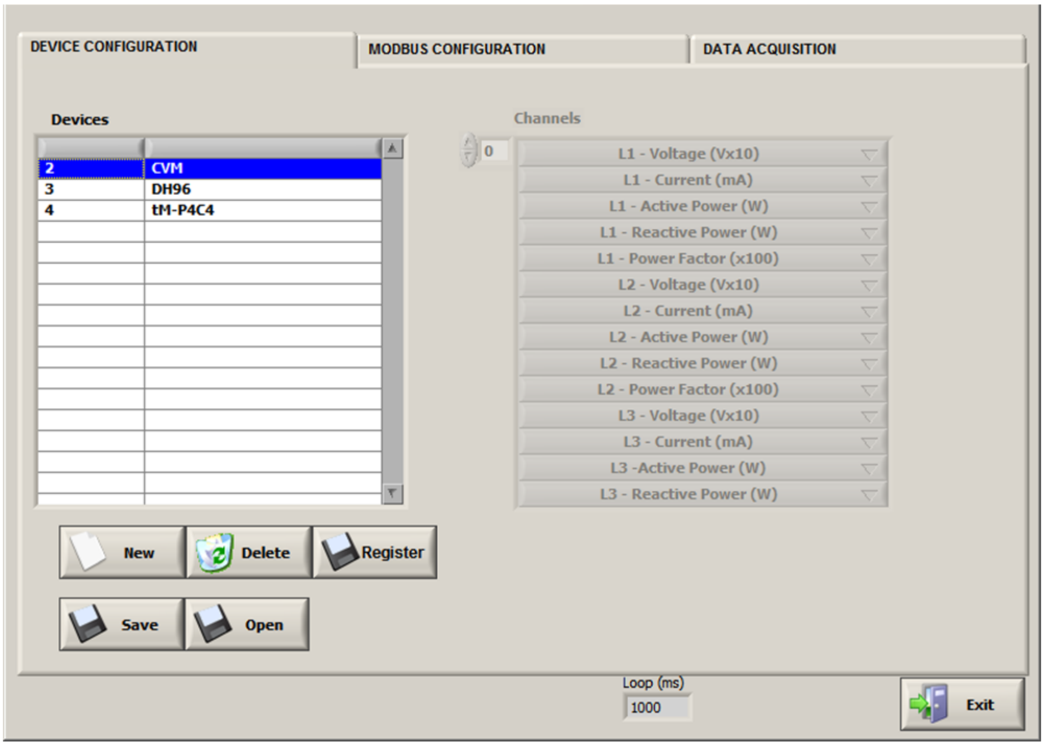

Fig. 5.27. RTU devices configuration

On the right box, they appear all the parameters read by the RTU selected. After setting the RTU unit, it must be set the configuration of the field bus protocol. The field bus used is MODBUS over the RS485 physic layer. The parameters to set are displayed in Figure 5.28. below.

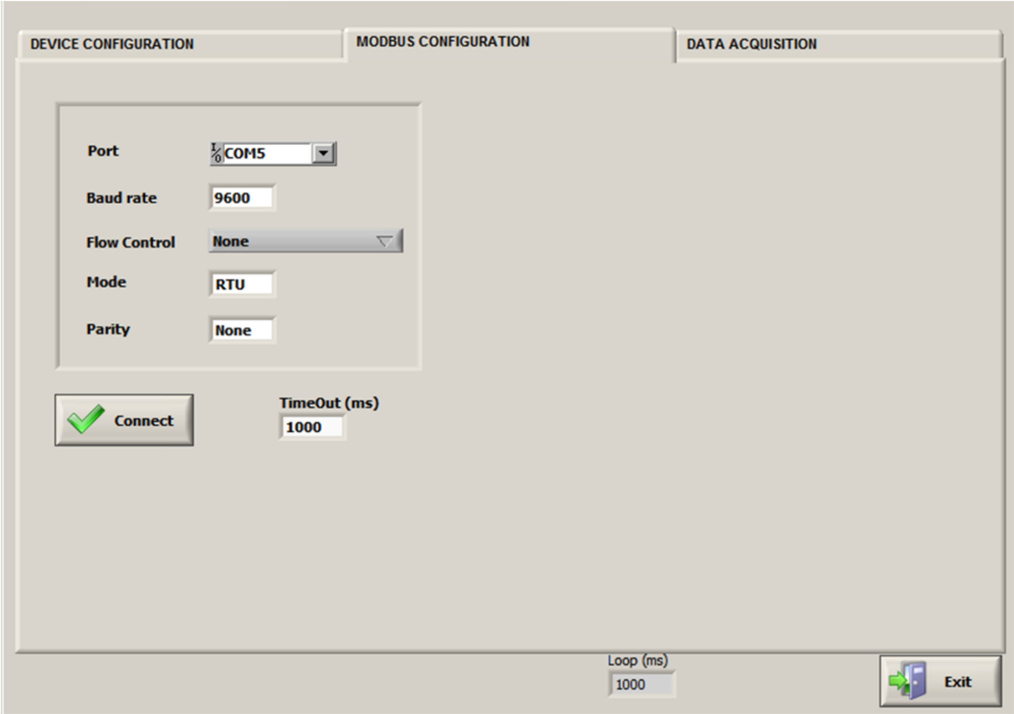

Fig. 5.28. Field bus parameters configuration (in this case MODBUS)

This configuration is based on setting the common values for the COM port in the PC, the baud rate and parity to communicate, the type of flow control used, and the communication mode (as RTU or Master unit).

After that, the connection can be established, and data can be acquired by pressing the “Acquisition” button in next tab (as it can be seen in Figure 5.29. below).

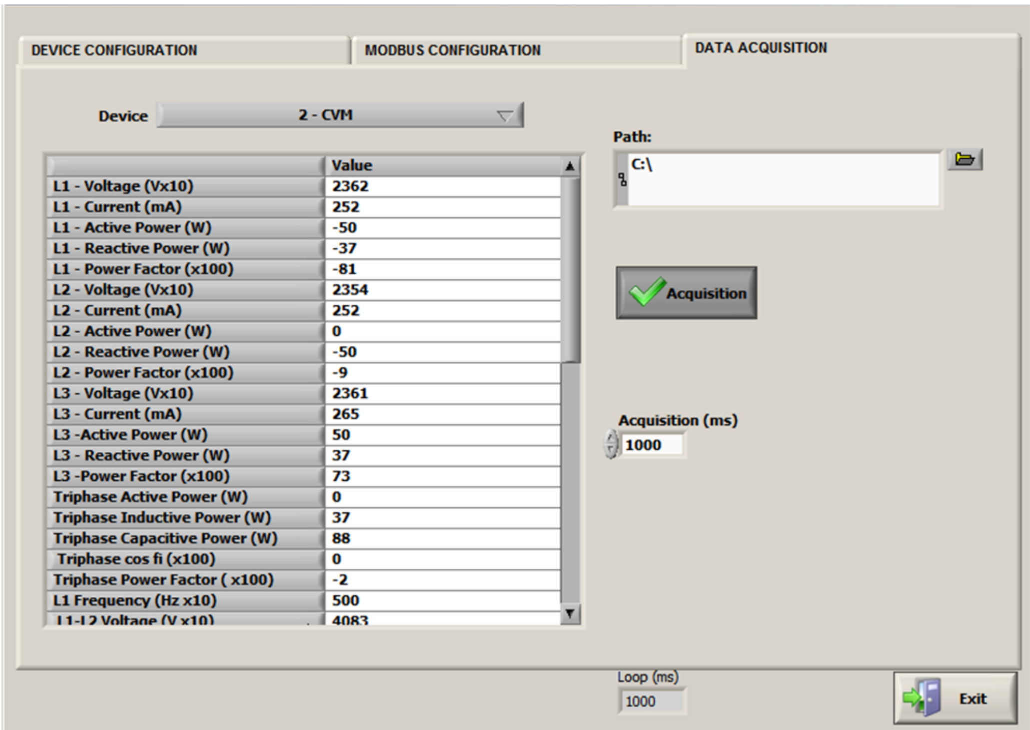

Fig. 5.29. Example of parameters acquired from RTU - CVM model

The acquired data can be logged in the hard disk memory for future revision, or can be analyzed in real time for calculating the total power and energy values for displaying on a visible monitor.

The Figure 5.30. below shows an example of application that searchs for an specific log report, selects the wanted parameter to visualize and displays it in a configurable graph. This monitoring application is DIAdem from National Instruments manufacturer.

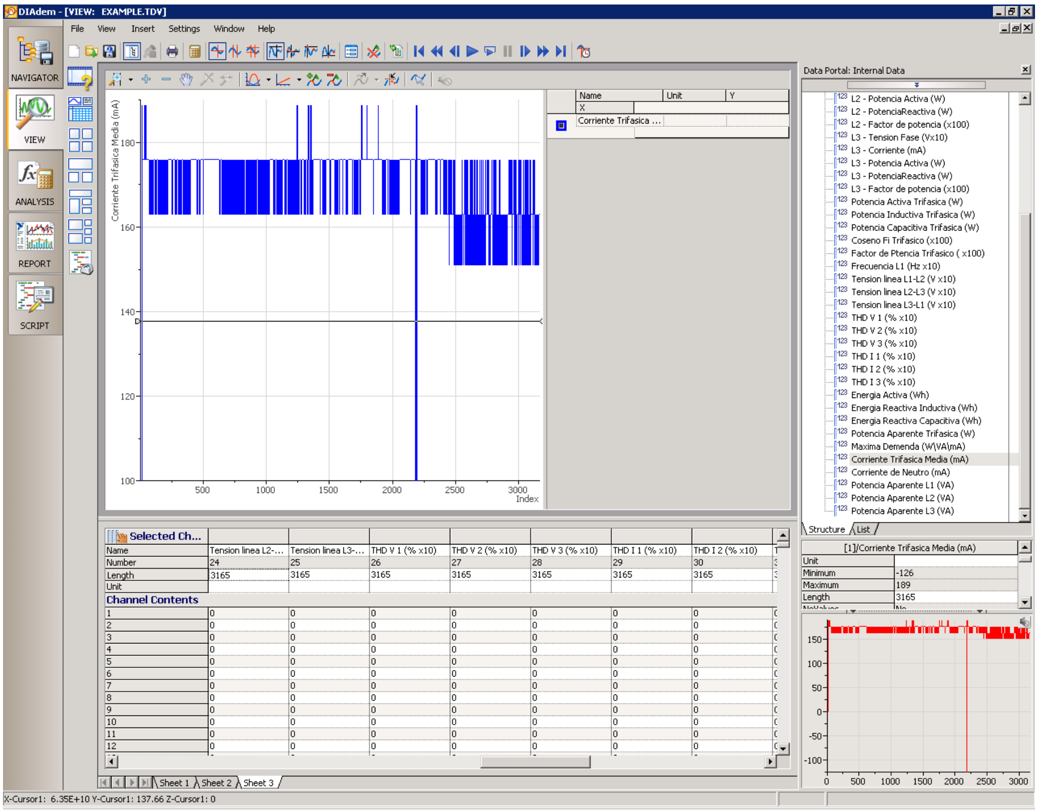

Fig. 5.30. Example of commercial monitoring application (© 2012 DIAdem software from National Instruments)

The definitive idea would be to integrate all the functionalities (setting, acquiring, analyzing, monitorizing, logging, warning and remote communicating) in only one software application.

The investment costs due to the main equipments of the Supervisory system design should be added to the calculations made in chapter 4.6.4. LCC.

4 x CVM Mini	=	920 €
4 x RSLink Radio Modem 868 MHz	=	540 €
4 x Sensor	=	100 €
1 x Embedded PC NEXCOM	=	834 €
TOTAL COST	=	**2,394 €**

These costs are prices excluding taxes, they are referenced to June 2011. Installation cost, software cost and other costs due to any auxilliary devices are not included.

Chapter 6 Conclusions

This chapter compiles the main report findings related to Alingsas-Brogården site.

Load identification

- ✓ The load has been calculated considering the group of four Houses NOPQ as only one load for the energy balance calculations.
- ✓ The load types present in this report are residential electricity (electricity for fans and pumps, stairwell lighting, elevators) and also the electricity for laundry rooms.
- ✓ The expected demand for the four Houses NOPQ is estimated to be **8,500 kWh in June** and **108 MWh/y.**
- ✓ Annual and daily profiles have been used to perform the calculations on the simulation software.

Swedish electrical supply company review

- ✓ Both Swedish national situation as local situation at Brogården have been analyzed. Furthermore, the massive market uptake has also been included.
- ✓ PV solar energy could be considered as the only realistic option for local electricity production (inside your own building).
- ✓ According to the law, the only remuneration that a electricity micro producer is entitled is from the grid owner who compensates the producer for having reduced his distribution losses.
- ✓ There are three basic options for supporting small scale PV power production:
    - ➢ Green certificates
    - ➢ Feed in tariffs
    - ➢ Net metering
- ✓ Nowadays, neither feed in tariffs nor net metering are thus regulated in Swedish law. Nevertheless, several electricity companies have taken own initiatives and the offer is widely extense.
- ✓ It is a common understanding within the solar energy business that net metering on a monthly basis would be the preferable option in the future.
- ✓ In Brogården, the involved agents are Alingsåshem as the PV installation proprietor, Alingsås Energi Nät as the grid owner and Telge Energi as the power producer.
- ✓ In reference to massive market uptake, power flow studies showed that voltage rise in the grids is not a limiting factor for integration of distributed solar PV generation

- ✓ Related to the installation safety, several studies were carried out and the main conclusion in terms of firemen's safety is that there is no fundamental difference between a PV installation and many other electrical installations. Thus the most significant risk lies in the fact that a fireman does not know that there's a power source on the roof which is easily overcome by appropriate marking of buildings with PV attached.

PV installation in Brogården

- ✓ For dimensioning, several parameters have been taken into account: Energy efficiency, economical cost, pedagogical values and aesthetics, among others.
- ✓ A PV installation has been designed including three different applications:
  - ➢ Building Integrated PV (BIPV) in balconies of House Q
  - ➢ Building Integrated PV (BIPV) in facade of House N
  - ➢ Building Applied PV (BAPV) on the roofs of Houses O, Q
- ✓ All the selected surfaces are oriented towards the South face for improving the energy performance.
- ✓ Due to it is reasonable to believe that the political obstacles for net debit in Sweden will be solved in near future, this kind of bussiness model has been selected.
- ✓ For dimensioning the installation the suggestion is to find an energy balance on a monthly basis (June is the optimal month to do this: 8,500 kWh).
- ✓ The different roof, facade and balcony areas have been estimated from drawings found in the construction documents.
- ✓ Detailed designs have been made about each surface, taking into account the specific measures and adding the aesthetics finishing touches as well.
- ✓ The installation sizing is composed by:
  - ➢ **36 PV** panels integrated on balconies surface (House Q)
  - ➢ **22 PV** panels integrated on facade surface (House N)
  - ➢ **111 PV** panels integrated on roof surface (House Q)
  - ➢ **111 PV** panels integrated on roof surface (House O)
- ✓ The total installed power is **58.2 kWp**, and the estimated energy production is around **55 MWh/y**.
- ✓ A detailed LCC study has been included. The investment cost rises to **1,140,000 SEK**. The conclusion drawn from this analysis is that under given

conditions (see chapter 4.6.4. for more detail) the present value of the saving potential of the installation is approx. **1,200,000 SEK**.

- ✓ The sensitivity of different parameters have been included. So for example, the decrease of the system cost of 10% leads to an increase of 9.5% of the net profit (present value). On the other hand, if the lifespan of the installation is increased from 30 to 45 years, the calculated net profit will double, but if 25 years is used instead, the expected net profit will be approx. 30% less than if 30 years is used. Also, a change in electricity tariff increase rate has been analyzed, in this case if the 7,5% rate is used (instead of nominal 5%), the net profit will double, but if the 3% rate is used then the net profite will decrease to the half.

GERES design

- ✓ A global approach to the GERES design has been included, both its internal architecture as the supervisory and control systems. The GERES design described could be applied to any other BEEM_UP project.
- ✓ In reference to the supervisory and control systems, a general overview has been described. Furthermore, a brief compilation of current manufacturers and distributors of different SCADA commercial solutions in the market has been included.
- ✓ The specific GERES design applied to Brogården has been analyzed and described in depth.
- ✓ The local energy sources are simplified to only PV installation.
- ✓ The bussiness model selected is net debit, in which the surplus electricity locally produced can be sold to the grid. So the energy storage system is not necessary in this topology.
- ✓ The complete PV system, including power hardware restrictions (inverters, strings layout, shading effect and other restrictions), has been designed.
- ✓ The resulting energy balance is:
  - ➢ Total power installed = **58.2 kWp**
  - ➢ Total PV area = **444 m^2**
  - ➢ Energy Produced by PV Array (DC) = **49,651 kWh/y**
  - ➢ Energy Produced by PV Array (AC) = **47,372 kWh/y**
  - ➢ Surplus Energy to Grid = **15,664 kWh/y**
  - ➢ Solar Fraction = **43.7%**
  - ➢ System Efficiency = **11.2%**

- ✓ The generated DC energy taking into account the complete system (with power hardware considerations) is around **10%** lower than the one obtained in chapter 4 (without power hardware considerations).
- ✓ The control system and the energy route selection hardware are not necessary because of there are two independent circuitries. One for the input energy from the grid towards the load, and another for the output energy from the PV panels to the grid.
- ✓ The supervisory system should consist of a number of sensors to measure the energy in the inverters output in real time for showing the instantaneous power produced and the accumulated generated energy by the installation to the tenants and visitors at Brogården site. In addition, the system should warn to Alingsahem about the state of the installation for maintenance tasks.
- ✓ A practical solution for these purposes has been designed and suggested.
- ✓ 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
    - ➢ 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

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.

Remark!

The overall objective of this report is to provide a protocol for integration of electricity generation systems in Brogården. This means that the information compiled in this report refers to the specific project at Brogården site, but given with a generic character to enable to any other future projects to apply this protocol.

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- GENERAL ELECTRIC, official web site: http://www.ge.com/
- INDUSOFT, official web site: http://www.indusoft.com/
- CIRCUTOR, official web site: http://www.circutor.com/inicial.aspx

Software Tools

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- METEONORM Version 6.1. Official web site: http://meteonorm.com/
- PV*SOL Expert Pro Version 5.5. Valentin Software Inc., official web site (English version): http://www.valentin.de/en