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DESIGN AND ANALYSIS OF A PHOTOVOLTAIC SYSTEM FOR A HOUSEHOLD

Degree Programme in Environmental Engineering
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The purpose of this thesis was to design a photovoltaic (PV) systems for a warehouse building situated in Nakkila and investigate possible methods to increase self-consumption. The thesis includes a feasibility study and different options presented to the client.
Average daily production, of different system sizes, and average daily consumption) were compared only for the summer months and eventually the surplus power was estimated. Two suitable power output were identified, 3kW and 4kW system.
The former was designed as a simple system with a main criteria of producing minimal surplus energy, while the latter was conceived as a bigger system and coupled with recovery system for the surplus energy. The extra energy will be converted into hot water using a 1-phase switch controller connected to a coil.
The results show that both systems are a valuable investment.
A first installation will be done up to 3kWp with a 4kW inverter. In the future the PV system will be upgrade to 4kWp. The oil burner will be substitute with a 100L water tank and a solar controller switch will be used to reroute the surplus production to the tank.

CONTENTS

1 GENERAL INTRODUCTION

Solar energy is clean and is abundantly available source of energy. Solar technologies use the sun radiation to provide heat and electricity for domestic and industrial applications. With the increasing concerning about our environment, the industrialized countries have increasing their investments towards renewable energy sources. Many household owners nowadays have decided to embrace the power of then sun and invest their money on a solar system. There are two main small scale technology to harvest the sun's light, photovoltaic and solar thermal. Photovoltaic cells convert the sun light from into a flow of electrons. Thermal collectors collect heat by absorbing and trapping the radiation from the sun and transferring the heat to heat-transfer agent and storage.

The energy potential from the sun is enormous, but despite this unlimited solar energy resource, harvesting it is a challenge mainly because of the limited efficiency of the solar cells. In the range of 10-20% (Website of PV Education). As many other renewable energy sources, solar energy is intermittent in nature; meteorological conditions, seasons, day and night. To make the matter worse consumption behaviour can heavily impact on the overall efficiency. Let us think about a typical family household with two kids which has a 3kW peak power system. Let us now follow their typical day: at 7am lights on, shower and breakfast; at 8am at work and school; at 5pm back with shower lights, laundry, cooking stove, TV, computer.

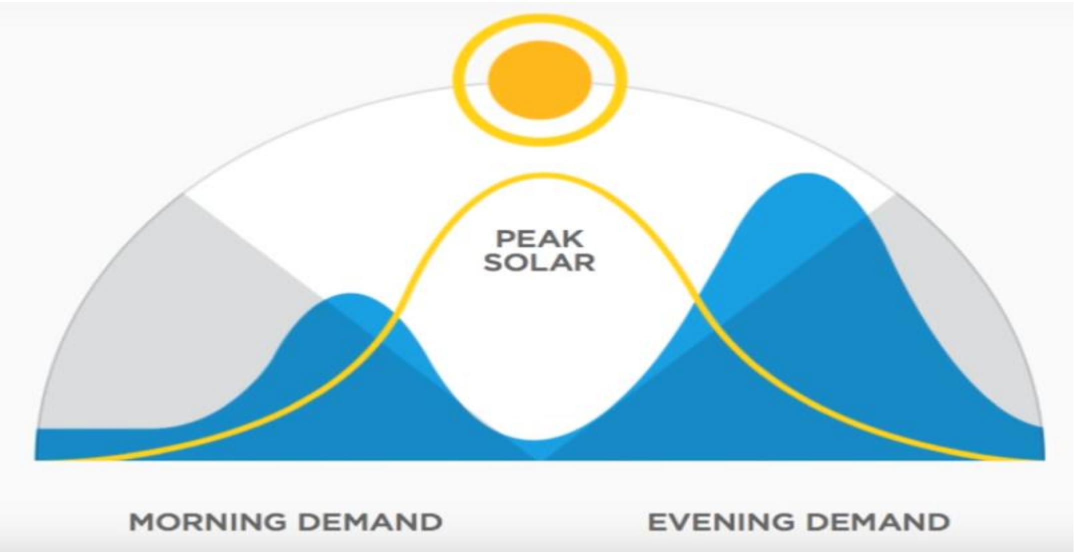

Figure 1-1. An example how home energy consumption and solar production from a photovoltaic solar system intersect during the day. (Website of Solar Choice 2016)

What happened between 8am and 5pm? Most of the appliances are off and the consumption is minimum. The PV panels production, in the while, start to rise until midday and then decline till the sunset (Figure 1-1). The results is a good part of this electricity will be exported to the grid, which for sure will not benefit the family savings.
To maximize the efficiency of a photovoltaic system and the environmental benefit derived from it, we should use all the energy produced. Feeding energy to the grid means losing precious kWh which will count on the payback time. In the calculation of the payback time, in fact, it is assumed that all the energy produced is used, even though is not yet practically achievable. Taking into account that the feed-in-tariff are lower than the purchasing price. Especially in Finland where solar PV is excluded from the current feed-in tariff system (Website of Energia Virasto 2016). Therefore the more energy is feed to the grid the less cost-effective will be our design.
Thus, the purpose of this thesis is not only to study and design a photovoltaic system for a detached house but also take into account about possible methods to increase self-consumption. This pose a good challenge to find the current state of technology in the market. Particular attention has been focus on thermal storage for heating and domestic hot water. At the moment there is no established way to design such a system and overall a perfect design does not exist, especially because this is an entirely new market segment. The entire process is purely based on the judgement and experience of the engineer.

2 PV SYSTEM SELF-CONSUMPTION IN SMALL SCALE SYSTEMS

There are smart ways to take advantage of the surplus electricity and increase our self-consumption of PV production. For example we can store the extra energy, change consumption behaviors or use smart systems to program our appliances. Those methods will be described in the following chapter.

2.1 Storing solutions

Probably one of the simplest, but not cheapest solution is to store the energy during the day time, and then use it during the evening time.

2.1.1 Battery storage

A battery storage system can be used in both off and on-grid houses (Figure 2-1). It simply charge a bank of batteries when there is an excess of production. The major components of a battery solar power system are:

- Charge controller: it controls and prevents the battery bank from overcharging by modulating the flow of electricity from the PV panels.
- Battery Bank: A group of batteries wired together. The batteries are similar to car batteries, but designed specifically to endure the type of charging and discharging they'll need to handle in a solar power system.

Battery system have an efficiency that range between 70%-90% depending on the battery chemistry, it can be quite expensive to put up a big storage, up to 700$ per kWh for a Lithium-ion (Website of Power Tech System). Also battery technology is not yet fully developed.

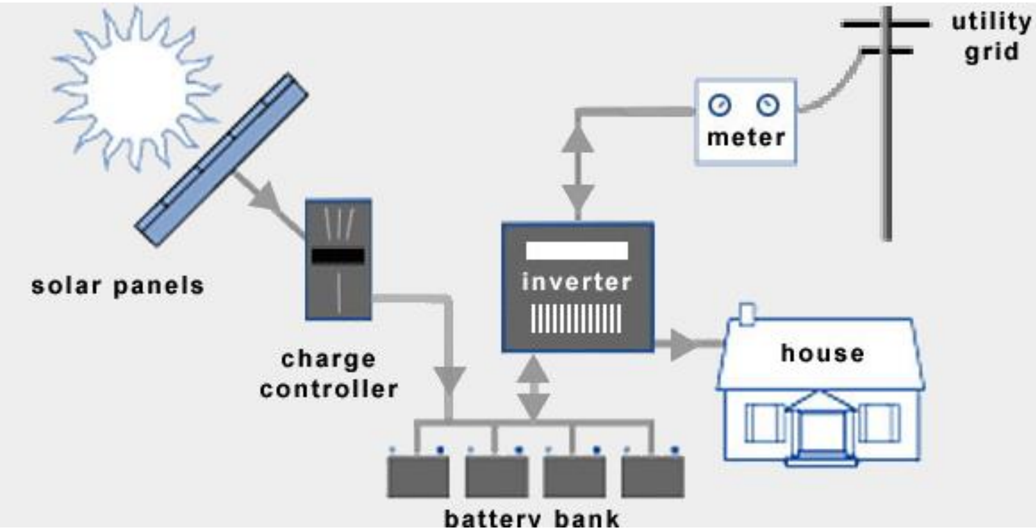

Figure 2-1. Working principle of a battery storage system in an on-grid configuration (Website of Energy Informative 2015)

Tesla Powerwall is an example of modern battery type energy storage design by Tesla. Is a compact and design wise battery system that can store up to 10 kWh. The innovation of this product stands on its compact design that can fit on a wall of a detached house. Unfortunately we need to take into account of the maximum power output of 2kW which might be not enough to power a house at peak time. (Website of Tesla). Thus batteries is still a rising technology and we hope to see big improvements in the future which for sure will benefit PV systems.

2.1.2 Thermal Storage.

Another good way to store the excess photovoltaic energy is to transform it into heat. Usually this is done in a normal water tank through an electric coil. The water can then be used for radiator, floor heating and domestic hot water. There are two main method to do that:

- Direct storage: it simply use a device (figure 2.2) attached to a DC coil and directly convert the electricity generated by the Photovoltaic panels into heat. The device has a MPP tracker and a potentiometer to regulate the flux of energy to the coil. The system use very few components and it does not need extra piping or cabling. Unfortunately solar thermal is still more efficient and is it not possible to use the electricity once converted.

Figure 2-2. Potentiometer, MPPT device with coil for direct water heating (Thermic Energy Webite 2014)

- Surplus storage: it takes advantage of the excess power generated and reroute it into a boiler. It is more complicated system, there is still the need of an inverter and also a device that can detect the exported energy and work as a potentiometer to regulate the variable flux of electricity into a coil. This kind of system will be discussed more in depth in chapter 4.3

2.1.3 CAES

Compressed air energy storage (CAES) involves compressing air and storing it. Small scale CAES can be effective energy storage solutions when used in conjunction with photovoltaic panels, where a compressor is powered by surplus energy from PV panels during the day and then released via turbines (Figure 2-3). Unfortunately small scale CAES is still at his early stages and no such a device is commercially available. A major problem with this type of system is the conversion and compression losses: from the inverter to the AC motor to charge the compressor, then to the turbine and once again to the AC generator. This whole process can yield to overall efficiency of less than 40% (Villela, Kasinathan, De Valle & Alvarez 2010, 967)

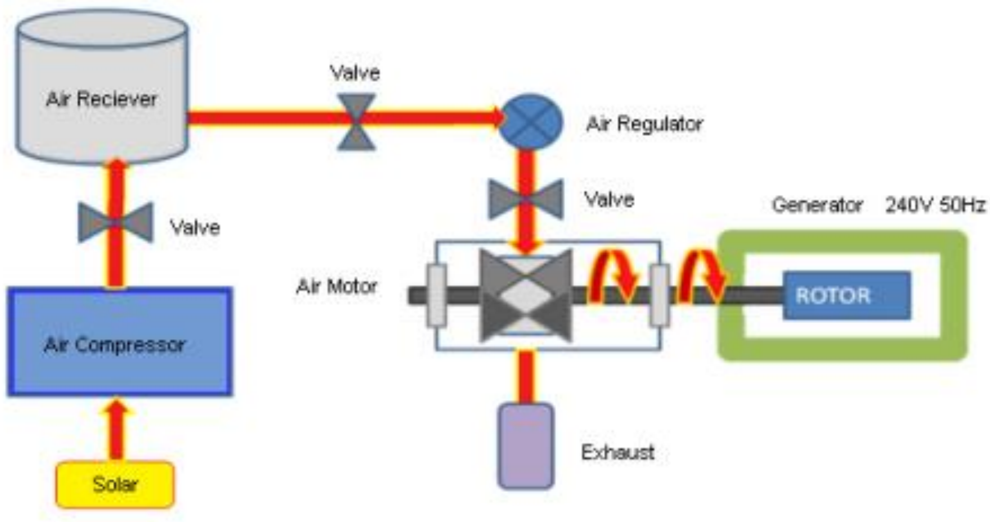

Figure 2-3 Model flow diagram (Herriman 2013, 44)

2.2 Relay in the inverter

Those who want to increase self-consumption in a more targeted manner can opt for self-energy management systems. Those systems are relay on a plug-in card. A radio transmitter is connected to the relay. It controls the remote-control socket and thus also the household appliances. The installer or system operator programs a threshold value on the inverter, 2000 watts, for example. When this value is surpassed, the relay is activated and in turn activates the load. If output falls below another defined value, say, 1800 watts, the load is deactivated (Website of PV magazine 2016).

3 INTRODUCTION TO THE CASE AND MAPPING

3.1 Introduction of the case of study

The location of the project is in the village of Nakkila, situated 15 km south-east of Pori. There are no nearby constructions and the land is all property of the client. This can give freedom on possible trees cutting to remove shadowing. The place is easily accessible by an asphalted road. Is also present a large parking where is possible to place a scaffolding structure if needed. (Figure 3-0)

Figure 3-0. Area owned by the client (Google earth 2016).

In the area owned there are two main constructions. The first one is a one floor detached house with 225 m2 surface area (Figure 3-1)

Figure 3-1. Detached house

The second construction is a fully functional mechanical shop, build in 1982, not anymore used as a business. The owner use it only for private jobs. The construction roof is going to be our target location for the panels. (Figure 3-2 and 3-3)

Figure 3-2. Mechanical shop

The roof is tilted (about 3 degrees) towards the south, with an azimuth of about 20 degrees; there is also another roof area tilted towards east this might create shadowing during morning hours during autumn and spring (Figure 3-4).

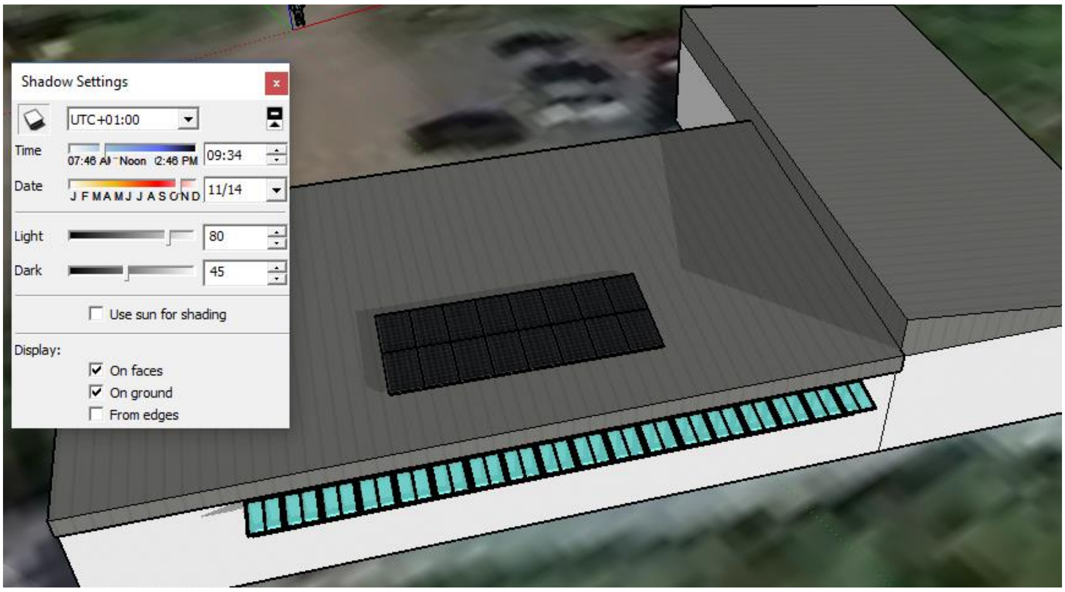

Figure 3-3. Shadowing of the east part of the roof during autumn morning

In front of the building is present a thick line of tall trees. Fortunately the trees can be cut to mitigate the possible shadowing.

Figure 3-4. Other side of the mechanical shop construction

3.1.1 Customer wishes, possibilities, problems and budget.

The customer impose a maximum budget of about 6000 euros, therefore all the design phase was taking this value in strong consideration. This arise the search of possible trustable suppliers outside Finland.

The client main wishes for this design document are:

- Use the solar energy surplus for the domestic hot water in the workshop, especially during summer (100 Litres per day). The hot water is at the moment provided by an oil burner
- Use the energy for the geothermal pump located in the house.
- Research of possible method to use smartly all the energy produced by the system. The use of batteries or other method might be an option.
- Possibility to expand the systems in the future. The customer wants to open the possibility for a future peak power upgrade without the need of replacing the inverter

3.2 Description of the case

What follows is a description of the current state of the house and the warehouse. The main electric meter is located in the mechanical shop. At the moment of the mapping all the systems installed were fully operating even though the house was going through renovation. Also the owner has not scheduled any important modification or update in the near future. The owner has a 3-phase electrical system for his home and warehouse

3.2.1 Systems

In the house the main source of heat and domestic hot water is a water to water geothermal pump. The model of the pump is Nibe F1245 a 10 kW ground-source heat pump with integrated water heater. Equipped with a 180 liters tank and if there is a greater need for heating/hot water than the compressor can provide there is a 7 kW backup heater. The heating water is accumulated in a 100 liters external tank, Nibe UKV (Figure 3-6) and distributed through radiators. The reservoir is used only as a buffer, therefore no external coil or energy source is used. The cold water comes from a well which retrieve fresh water through a 2-3 kW pump (Figure 3-5)

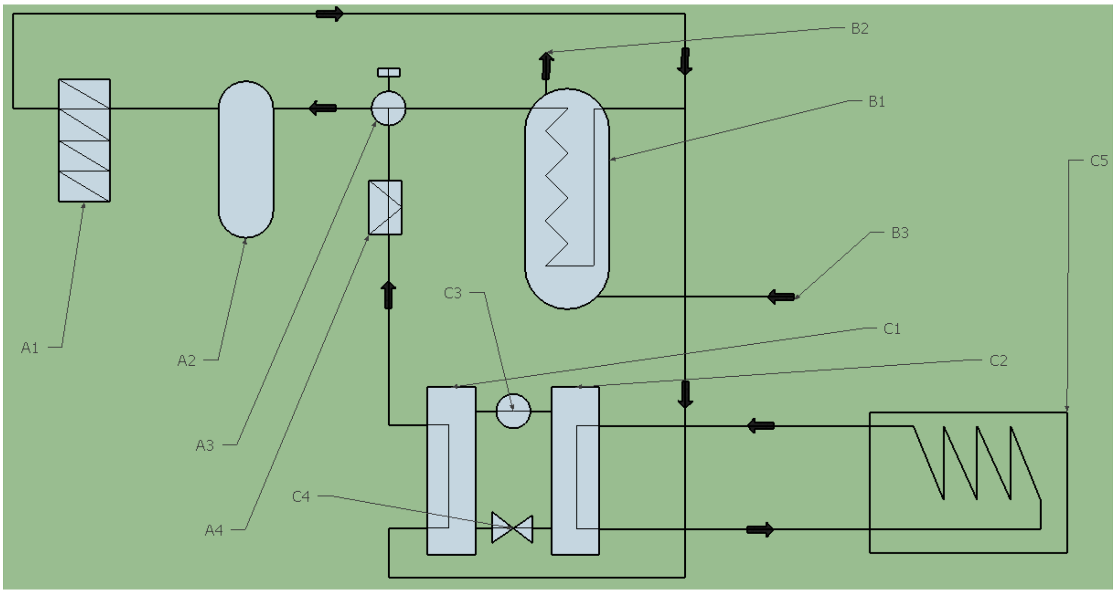

Figure 3-5. Schematic representation of the system (Sketchup). A1: radiators. A2: Nibe UKV for heating water. A3: shuttle valve radiators/hot water. A3: immersion heater. B1: hot water tank. B2: DHW output. B3: cold drinking water input. C1: condenser. C2: evaporator. C3: compressor. C4: expansion valve. C5: ground-source heat pump.

Figure 3-6. Nibe F1245, heat-pump unit. On the right side the Nibe UKV, next to the expansion vessel

The main source of heat and hot water in the warehouse is an old oil burner. Tulimax 50. The oil heater serve for both with a 200 liters tank and coil for DHW (Domestic hot water)

4 ANALYSIS AND DESIGN OPTIONS

4.1 Establish the PV system peak power output

At this point we need to identify the extent of the solar power output for our client. We want to obtain two different power output. The first for a small system with minimum power surplus. The second with enough extra energy to heat water in the workshop, especially during summer, about 100 Litres per day as specified by our client.
To do that we need to know two important information:

1. Daily energy consumption profile of the customer
2. Daily PV production profile of different peak power configuration.

For the former, from the energy provider website (Fortum Oy), was possible to extract the client consumption as a time series data as an average daily energy consumption profile for some months of the year, the data has been exported in an excel sheet and represented in the graph showed in figure 4-1. The information were recovered for the months of May and June 2015. Unfortunately was not possible to get more information for this year from the energy company. Other time period were not useful for this analysis or not available. Summer months are useful to identify unwanted exported energy, in fact PV production, during a sunny day is at its peak, while the consumption at its lowest.

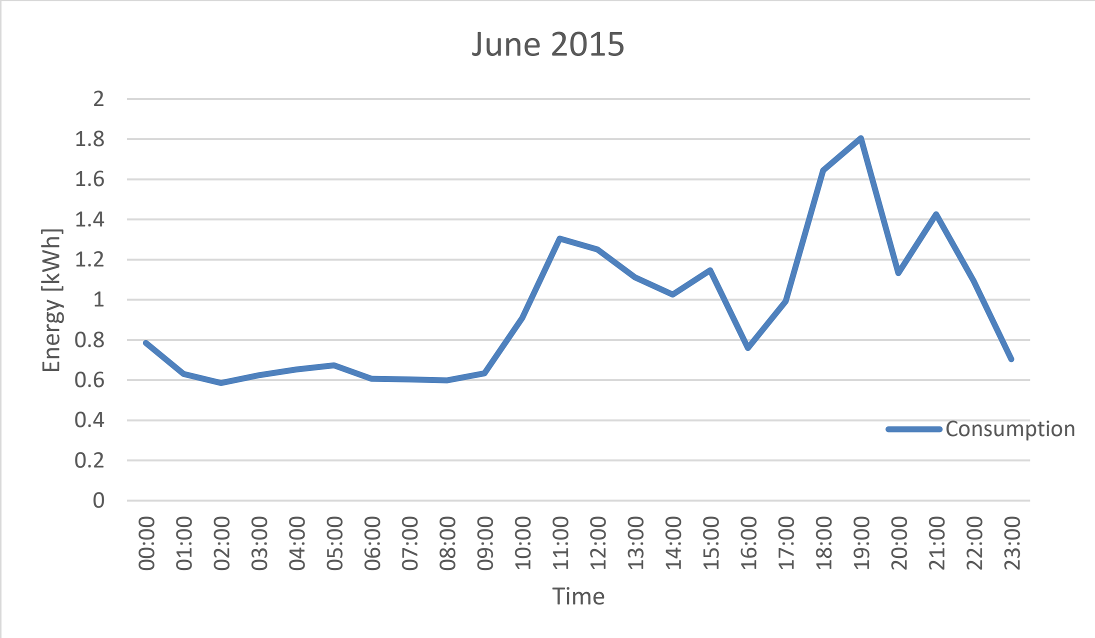

Figure 4-1. Monthly average of the daily consumption during the month of June 2015.

For the latter, SAM software (System Advisor Model 2016) has been used. SAM is a free simulation software used for renewable energy and developed by the National Renewable energy Laboratory of United States, in our case solar energy. In the input interface is it possible to select the location, type of PV, inverter and information about the design (Position, azimuth, inclination angle).

The SAM's results panel, after a simulation, displays the time series data as an average daily energy generated profile for each month of the year. May and June were exported in an excel sheet and the data represented with a graph. Different power output has been used in the simulation (2, 3, 4, 5 kWp) and the results compared with the June and May curves (chapter 4.1.1 and 4.1.2).

For the location, Helsinki was chosen, as Pori was not available, Helsinki weather is quite similar with Pori. As PV modules, 250W monocrystalline. The inverters were selected in a 1:1 ratio.

4.1.1 June power consumption-production comparison

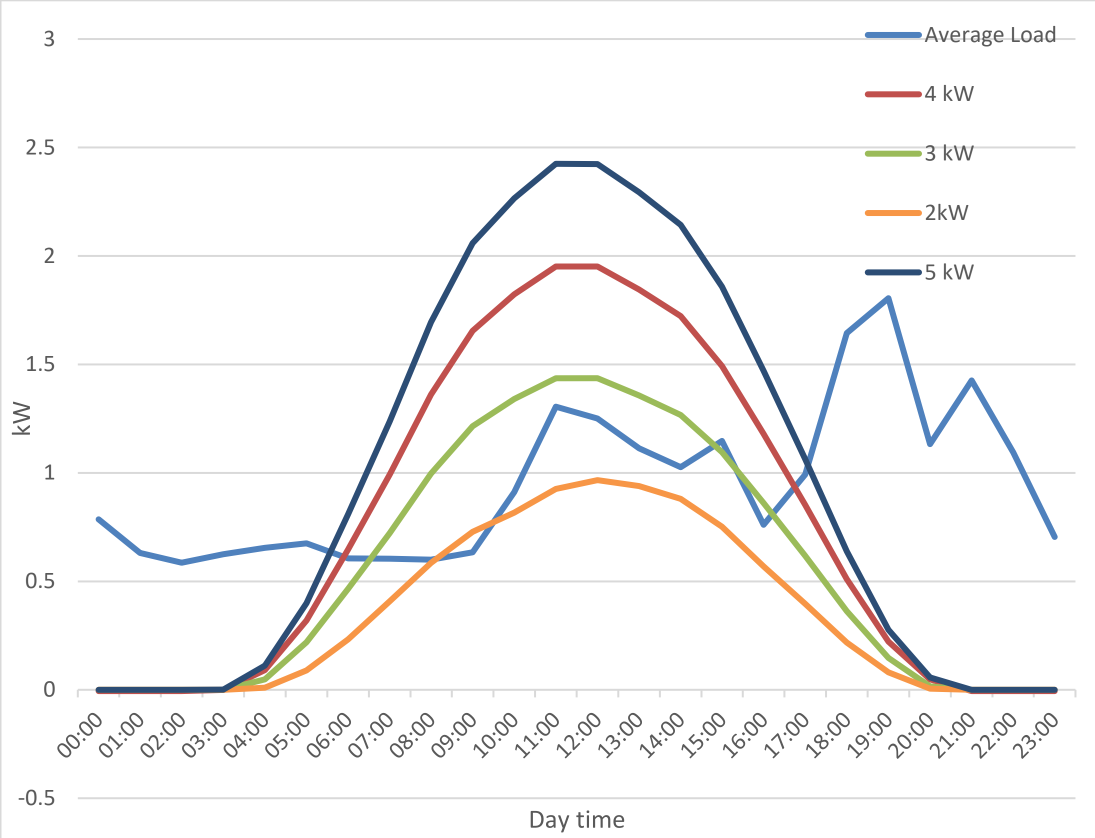

Figure 4-2. June. Comparison with consumption in June and average power output with different system size option.

The customer needs about 100 L per day of hot water in the warehouse, for simplicity we calculated the amount of energy (kWh) needed to heat that amount of water (APPENDIX A) so that we could have a rough comparison like showed in table 4-1.

kWp	Exported energy	Energy needed
3 kW	2.43 kWh	6.03 kWh
4 kW	6.67 kWh	6.03 kWh
5 kW	10.72 kWh	6.03 kWh

Table 4-1. Comparison between the amounts of energy needed to heat 100 Liters of water from 8 to 60 degrees with the exported energy. APPENDIX C for calculations.

As we can observe from figure 4-2 the 2 kW system is too small even to satisfy the minimum consumption during the day, while the 5 kW system is oversized for a 100 Liters boiler (Table 4-1)

4.1.2 May power consumption-production comparison

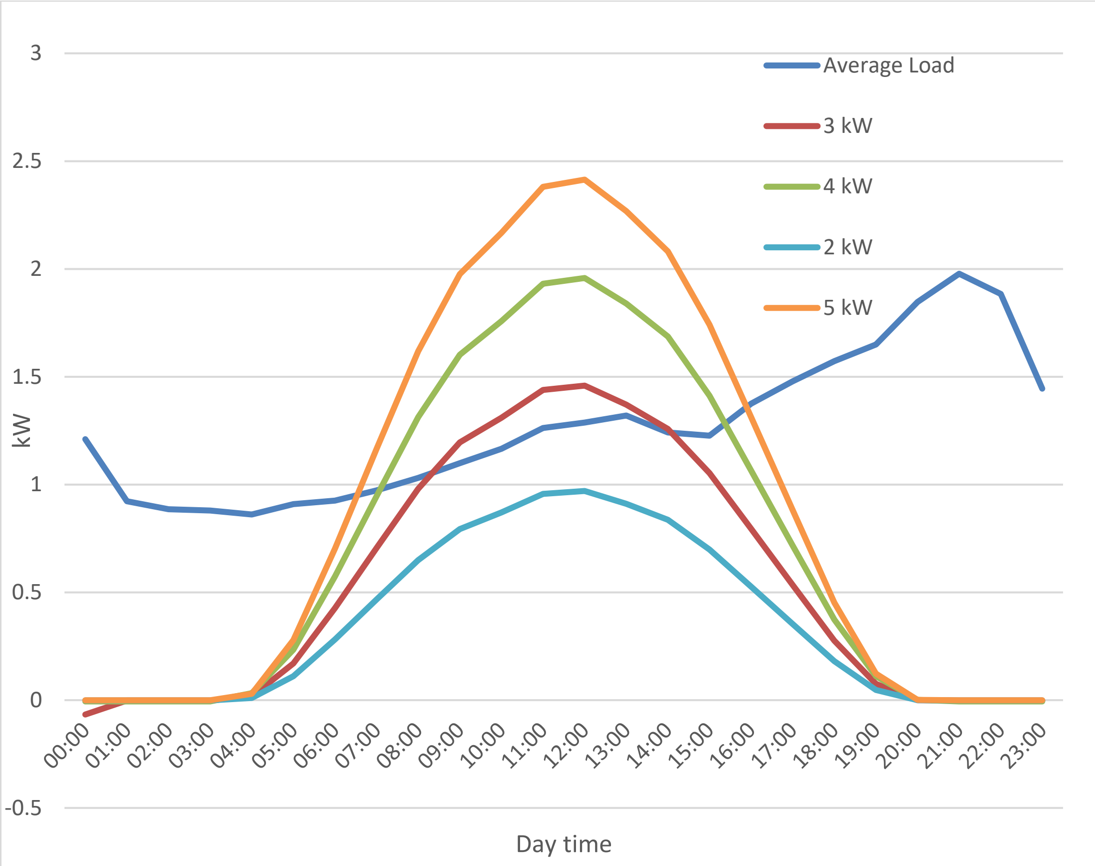

Figure 4-3. May. Comparison with consumption in May and average power output with different system size option.

The customer needs about 100L per day of hot water in the warehouse, for simplicity we calculated the amount of energy needed to heat that amount of water (APPENDIX A) so that we could have a rough comparison like showed in the table 4-2.

kWp	Exported energy	Energy needed
3 kW	0.65 kWh	6.03 kWh
4 kW	3.86 kWh	6.03 kWh
5 kW	7.21 kWh	6.03 kWh

Table 4-2. Comparison between the amounts of energy needed to heat 100 Liters of water from 8 to 60 degrees with the exported energy. APPENDIX B for calculations.

As we can see from the graph in figure 4-2 the 2 kW is definitely too small, while the 5 kW is oversized (Consider this is an average during the month) (Table 4-2).

4.2 First option. Small system with minimum power surplus

According to the results found in the chapter 4.1, we can conclude that a 3 kW system is enough and it will not produce more energy than needed during the summer. 12 250W panels will be fitted into the roof of the warehouse. The upper right corner, according to the trees mapping, seems to be less affected by the shadowing (Figure 4-4)

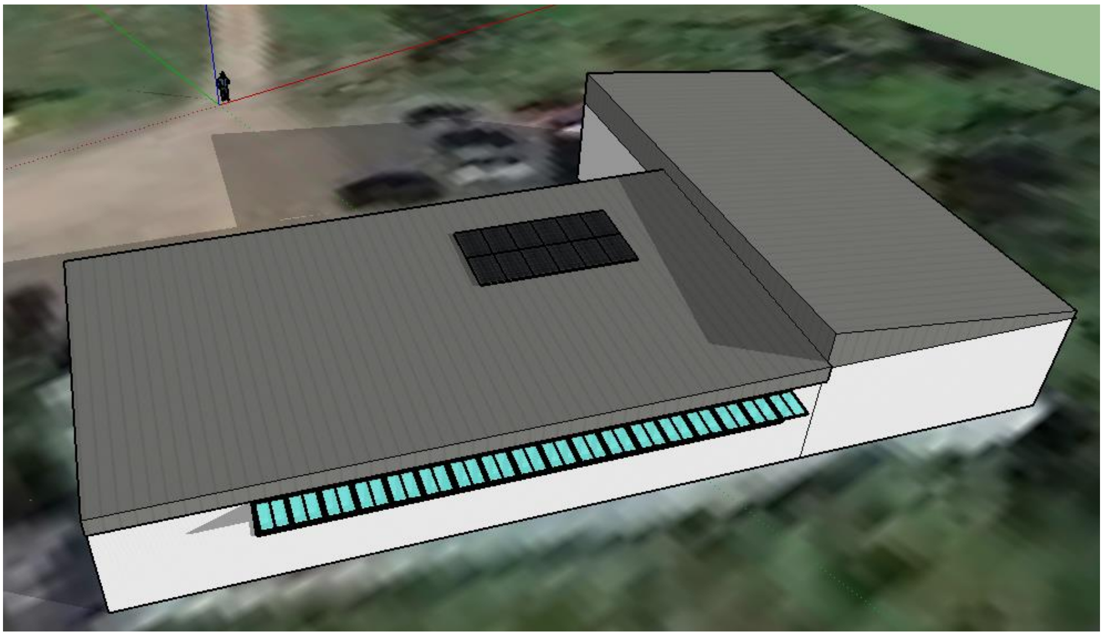

Figure 4-4. Virtual representation of the panel placement on the roof of the warehouse

The production of the system was calculated with PVGIS (Photovoltaic Geographical Information System 2012). PVGIS is a simple web-based photovoltaic energy calculator developed by the JRC (Joint Research Center) of the European commission. The estimated total production will be 2160 kWh per year like showed in figure 4-5. For the months of May, June and July we are going to have a minimum amount of unused energy. The output is directly connected to the main meter and the electricity is used normally. The inverter will be oversized to permit a future upgrade of the system up to 4 kW. Hence the customer can initially install a 3 kW peak, system with a 4 kW inverter, and in the future expand the peak power to 4 kW and using the option discussed in the chapter 4.3.

PVGIS estimates of solar electricity generation

Location: 61°21'53" North, 22°0'19" East, Elevation: 27 m a.s.l.,

Solar radiation database used: PVGIS-classic

Nominal power of the PV system: 3.0 kW (crystalline silicon)
Estimated losses due to temperature and low irradiance: 6.4% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 5.1%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 23.6%

Fixed system: inclination=3°, orientation=20°				
Month	E_d	E_m	H_d	H_m
Jan	0.48	15.0	0.26	8.14
Feb	2.15	60.2	0.95	26.6
Mar	4.98	154	2.06	63.7
Apr	9.12	274	3.83	115
May	12.20	380	5.31	165
Jun	12.60	379	5.59	168
Jul	12.10	374	5.41	168
Aug	8.63	268	3.81	118
Sep	5.24	157	2.28	68.3
Oct	2.23	69.2	0.99	30.7
Nov	0.66	19.8	0.33	10.0
Dec	0.23	7.05	0.14	4.40
Yearly average	**5.91**	**180**	**2.59**	**78.7**
Total for year		**2160**		**945**

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

Figure 4-5. Results from PVGIS (Website of PVGIS 2017)

4.2.1 Effect and considerations of an oversized inverter and future upgrade

Efficiency: as is it shown on the diagram in figure 4-6, the difference in efficiency is less than 1%. The comparison has been done using SAM (System Advisor Model

2016). A 4 kWp of PV power with a 3kW inverter (blue line) and a 3 kW system with a 3 kW inverter (red line). Therefore we can conclude that oversizing the inverter will not have a considerable effect on the power output.

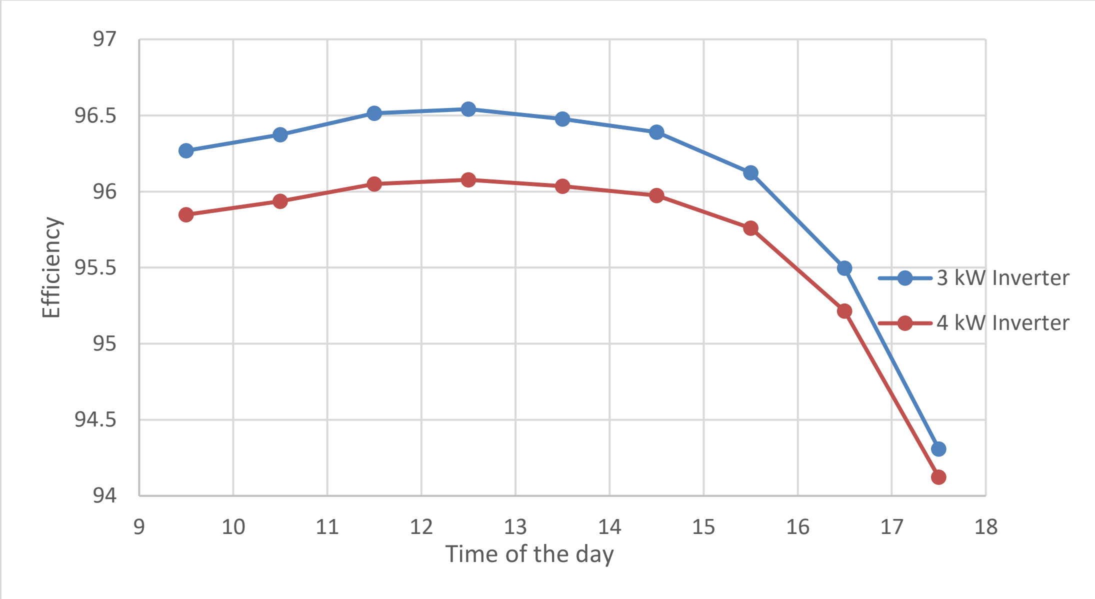

Figure 4-6. Diagram showing efficiency curves from two different inverters.

Adding panels: in a future upgrade is it suggested to buy same specification's panels as the previous ones. Different voltage and current can affect the power output.
When connected in series, if among the panels there is a panel with rated current lower than the others, it will drag down the current passing through all the remaining panels. (Website of Solar panels venue 2013).
Therefore this factor has to take in to account when considering the upgrade.
The roof has enough space to fit four additional panels. The new panel can be placed on the right next to the previous array (Figure 4-4). A rewiring should per performed to meet all voltage and current input of the inverter. More specifically the arrangement will be of 2 strings of 8 panels each.

4.3 Second option. Bigger system with storing solution.

According to the results found in the chapter 4.1, we can conclude that a 4 kW system is optimal to adopt a storing solution. The old oil burner will be bypassed and substituted by a hot water tank sized according the need of the client (About 100 Liters). An energy device manager can be used to direct the unused electricity to an immersion heater in the new hot water tank.

The consumer habit is important for maximizing the efficiency of the system. The closer the typical consumption curve, the better results is possible to obtain from it. During the day, in fact, the production of the photovoltaic is at its peak, while the load is at its minimum, due to the fact that a typical family's or individual's working schedule is from 8:00 to 16:00.

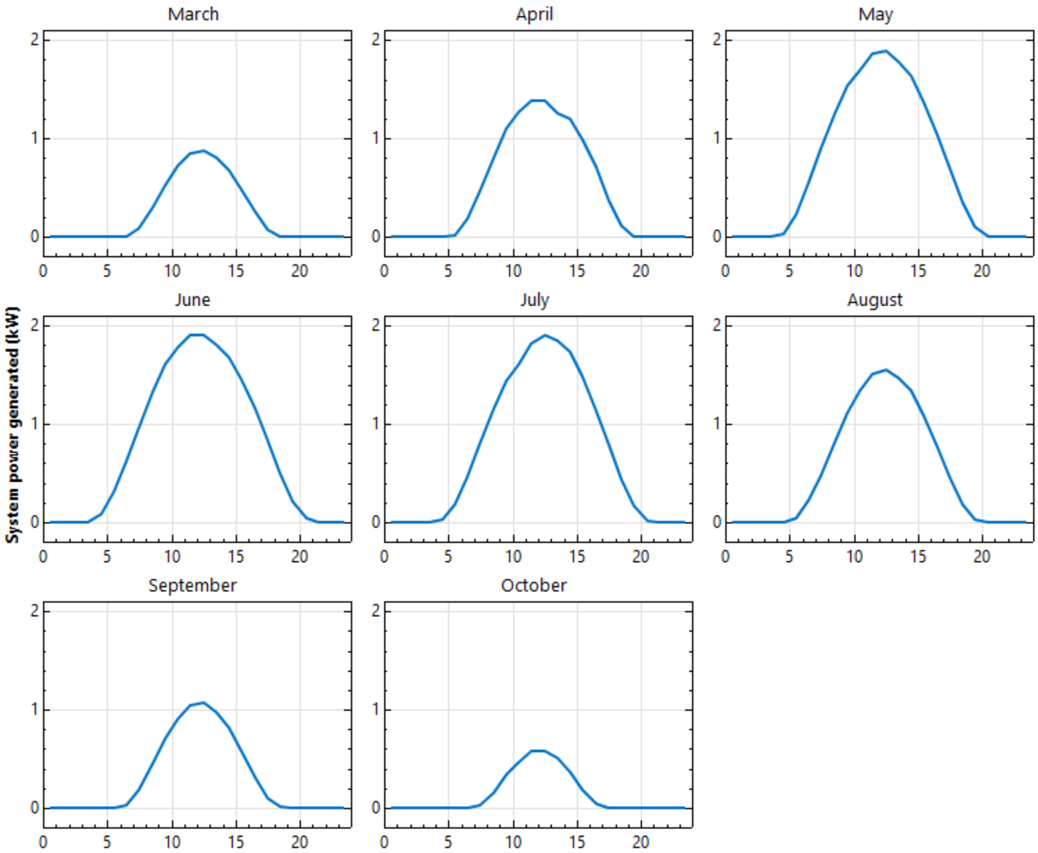

Figure 4-7. Time series data as an average daily energy generated profile for each month of the year.

From the figure 4-7 is it possible to assume that the July's energy production is similar to June, but it was not possible to compare it with the consumption profile for lack of data.

The production of the system has been calculated also with PVGIS (Figure 4-8)

PVGIS estimates of solar electricity generation

Location: 61°21'53" North, 22°0'19" East, Elevation: 27 m a.s.l.,

Solar radiation database used: PVGIS-classic

Nominal power of the PV system: 4.0 kW (crystalline silicon)
Estimated losses due to temperature and low irradiance: 6.4% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 5.1%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 23.6%

Fixed system: inclination=3°, orientation=20°				
Month	E_d	E_m	H_d	H_m
Jan	0.65	20.0	0.26	8.14
Feb	2.87	80.3	0.95	26.6
Mar	6.64	206	2.06	63.7
Apr	12.20	365	3.83	115
May	16.30	506	5.31	165
Jun	16.80	505	5.59	168
Jul	16.10	499	5.41	168
Aug	11.50	357	3.81	118
Sep	6.99	210	2.28	68.3
Oct	2.98	92.2	0.99	30.7
Nov	0.88	26.4	0.33	10.0
Dec	0.30	9.40	0.14	4.40
Yearly average	**7.88**	**240**	**2.59**	**78.7**
Total for year		**2870**		**945**

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

Figure 4-8. Results from PVGIS (Website of PVGIS 2017)

4.3.1 Design description

The idea is to detect and measure the electricity going to the grid. Usually this is done attaching a current sensor (Figure 4-10) on the active phase cable between the consumer unit and the electric meter, and reroute it to a heating element placed in a boiler (Figure 4-11). If the system is 3-phase and we have connected our solar system to only one of your supply phases with a single-phase solar inverter, we could simply use that phase (Figure 4-9).

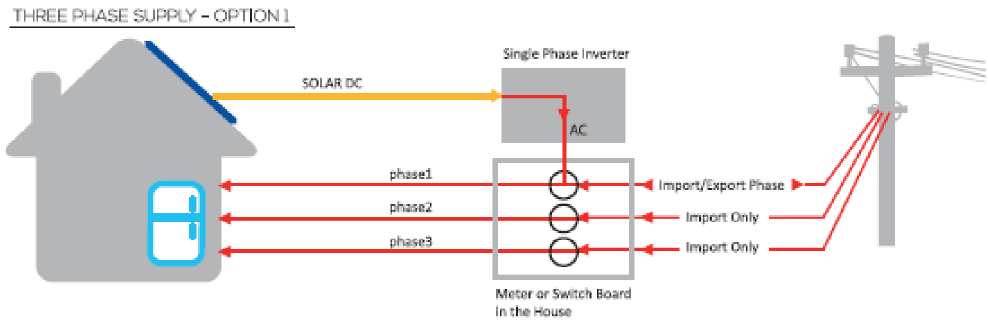

Figure 4-9. Attachment of 1-phase inverter on a 3-phase system (Website of powersmartsolar 2017)

To achieve such an operation we will need the assistance of a controller that can communicate between the house electric meter and the energy storage.

Figure 4-10. 100A SCT-013-000 Non-invasive AC Current Sensor (Website of RoboShop 2017)

For the purpose of this thesis we will take as an example the APOLLO GEM from APOLLO solar electric, but on the market there are many options available with different prices and quality (Solar iBoost, PV Manager 2.1, Fronius ohmpilot, etc.) "Apollo GEM can divert surplus generated PV or wind power which would have been exported to the grid to produce hot water, run heaters, power a battery charger or any other appliance. It has two outputs, allowing two heaters or other appliances to be connected to the system." (Website of Apollo Solar Product UK 2015).

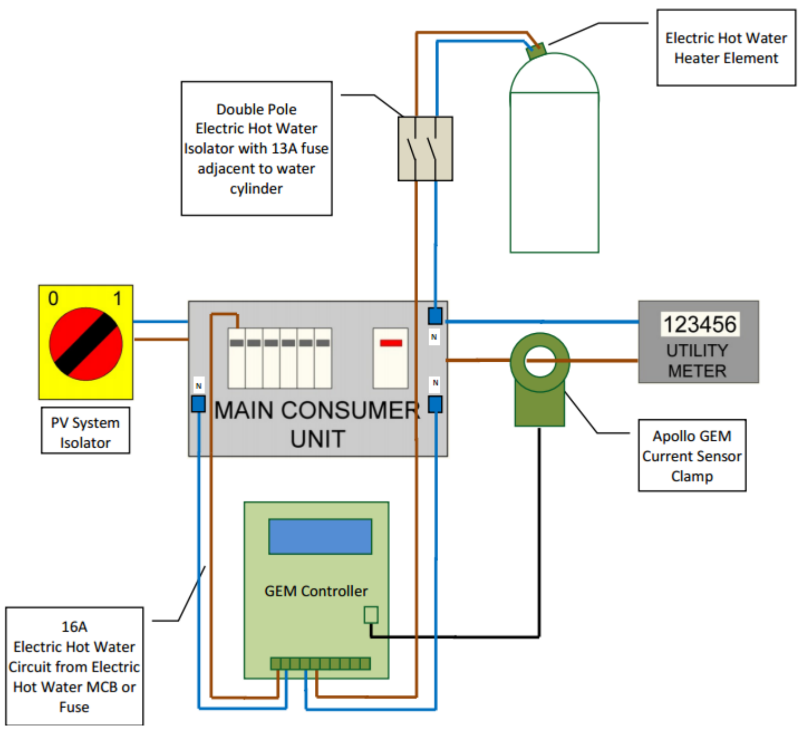

Figure 4-11. Schematic of the connection. Apollo GEM Installation (Website Apollo Solar Product UK)

“GEM system uses a variable power technology starting from 0.1KW and therefore any surplus power from 0.1KW to 3.1KW can be used”

(Website of Apollo Solar Product UK 2015)

Apollo GEM can work in two distinct modes; variable power mode and threshold power mode. For the purpose of this thesis we will describe only the variable power mode, which is what is needed.

The load must be a restive heating load typically rated at 3 kW such as a standard water heater. In this mode the current meter monitors input and export power. If power is exported the controller will start to divert power to the heater. The amount of power sent to the heater is variable from around 50W to the full load power e.g. 3KW. The actual power sent to the heater will match the excess power being generated keeping the exported power to around zero whilst ensuring that no additional power is imported to run the heater. Priority is always given to the household appliances and generated power is only sent to the heater when it is excess to other requirements. (Website of Apollo Solar Product UK)

The Apollo GEM ha also a two power output mode. Once the boiler maximum temperature is reached the energy is diverted to a second output like showed in figure 4-12. In our case can be the electric coil of the geothermal pump.

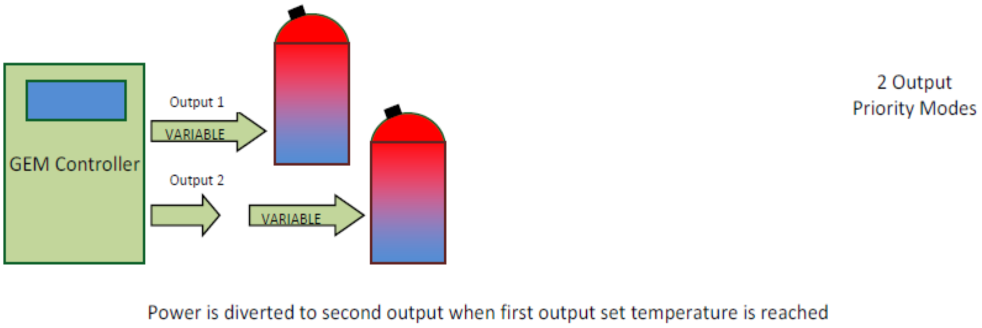

Figure 4-12. Two output mode configuration (Website Apollo Solar Product UK 2015)

4.3.2 Controller connection with 3-phase solar PV system

Energy manager controller for PV application are still a relative new market segment and for our acknowledgement a 3-phase compact solution is not yet still available on the market. The information given by many manufactures like in figure 4-13, have showed that for a 3-phase system the only way to is to use three devices for each phase.

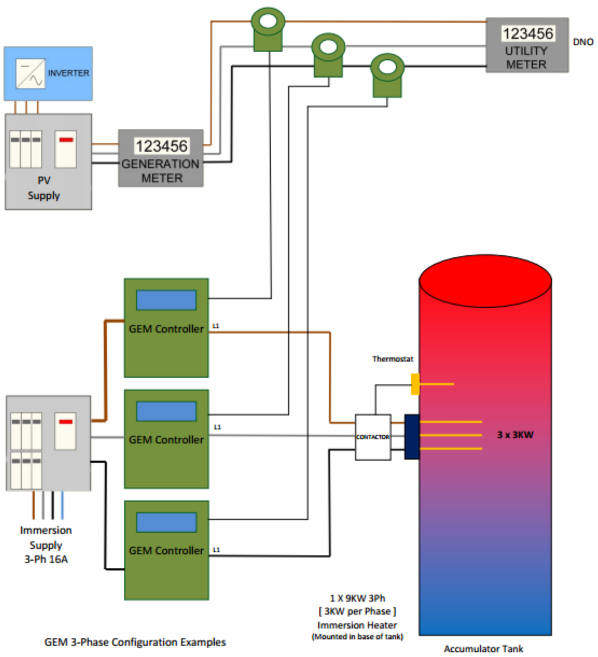

Figure 4-13. GEM 3-Phase Configuration Examples ((Website Apollo Solar Product UK 2015)

That would clearly rise the total investment cost and make the installation more challenging. Therefore the one phase installation is the most preferable option.

5 ECONOMIC ANALYSIS OF THE OPTIONS

5.1 First option

5.1.1 Investment

Component	**Number of unit**	**Price (Euro)**	**Total (Euro)**
250W Solar panels	12	132.5*(4)	1590
4 - 3.8 kW inverter	1	800*(5)	800
Mounting brackets	1	405*(5)	405
Cables	-	150*	150
Installation	-	500**	500
Total cost			**3445**

Table 5-1. List of the components and prices of a 3kWp PV system.

*Prices from Satmatic 2015

**Installation price is purely arbitrary, has been set according to previous experience, but it might vary.

*(4) Website of ENF Solar 2017

*(5) Website of Alma Solar 2017

All the prices include taxes but not shipping.

5.1.2 Payback time

The formula of the payback time is simple and give a rough estimation after how many years the investment will be repaid:

$$Payback\ Time = \frac{Investiment}{Value\ of\ the\ replaced\ energy\ annualy}$$

The value of the replaced energy is the energy price multiplied by the yearly PV production.

The calculation does not take into account:

1. Inflation rate
2. Energy price fluctuation
3. Photovoltaic panels degradation

We also have assumed that:

1. All the energy produced is used
2. No maintenance costs

Yearly PV production	2160	kWh
Total investment cost (Table 5-1)	3445	Euro
Price of the electricity	0.118	Euro/kWh
Payback time	13.5	Years

Table 5-2. Data and results for the calculation of the payback time

The table 5-2 above shows that the simple payback time is about 13.5 years with the current market price of the electricity.

A more accurate method to calculate the payback time is the return of investment.

ROI is the ratio of a profit or loss made in a fiscal year expressed in terms of an investment and shown as a percentage of increase or decrease in the value of the investment during the year in question. The basic formula for ROI is:

$$ROI = \frac{Net\ profit}{Total\ investiment * 100}$$

(Website of Study.com).

This calculation has been done with PVCalc (Website of PVcalc). PVcalc is a simple web-based ROI calculator. This method take in consideration the inflation of the energy and prices, in our case is 1.2% (Website of Statistics Finland); the maintenance costs, 0.5% of the initial investment cost; the degradation of the panels, 0.5% for Si

(Silicon) technology (Website of NREL); also in this case all the energy produced is used (Figure 5-1, 5-2).

Project Definition			
General Information		**Setup cost (all in)**	
Currency	EUR	Price (per kWp)	1148
Divisor	1	**Running cost**	
Useful life (years)	25	Lease (€/year)	0
Nominal power (kWp)	3	Insurance prem. (%)	0
Annual Yield *per kWp* (kWh/kWp)	720	Maintenance (%)	0.5
Degradation (%/year)	0.5	Inflation rate (%/year)	1.2
Feed in tariffs		**Financing**	
Years	0	Own funds (%)	100
Price (per kWh)	0	Loan type	Redeemable
Index linked	☐	Redemption Sched.	Uniform
Own consumption		Years	0
FIT subsidy (€/kWh)	0	Interest rate (%)	0
Own consumption (kWh/year)	2160	Disagio (%)	0
Electricity price projection		Investment Yield (%)	0
		Tax	
Price now (per kWh)	0.118	Tax rate	0
Energy Price Inflation (%/year)	1.2		help

Figure 5-1. Input value on PVCalc (Website of PVCalc 2017)

Project Summary:	
Nominal power (kWp)	3
Purchase value (EUR)	3444
Own Funds (EUR)	3444
Loan amount (EUR)	0
Present value of net income[1] (EUR)	6416
Levelised energy cost (€/kWh)	0.078
Loan type	Redeemable
Amortisation time (y)	13.1
Dividend (EUR)	NA
Dividend (%)	NA
IRR before tax (%)	5.3
Eff. tax rate (%)	0.0
IRR (%)	5.3

Figure 5-2. Results values from PVCalc (Website of PVcalc 2017)

5.2 Second option

5.2.1 New boiler feasibility

Let us first analyze whether a new electric boiler will be worth the investment without considering the power produced by the photovoltaic system.

Oil burner running costs:

Efficiency	70	%	(Website of HT Enerco Oy 2015)*
Price of fuel	90.1	c/L	(Website of Petroleum and Biofuels Associations Finland 2017)
Heat of combustion	36	MJ/L	(Website of Teboil 2016)
Total cost for 100L of water	0.77	Euro	APPENDIX D for calculation
Price for kWh	13	c/kWh	

Table 5-3. Oil burner running costs

*Considering the status of the boiler, electricity used and piping losses.

Electric boiler running costs:

Efficiency	95	%	(Website of Energy Gov 2015)
Price of electricity	3.79	c/kWh	Transfer fee (Lammaisten energia Oy)
	4.49	c/kWh	Energy price (Fortum Oy)
	3.6	c/kWh	Taxes (Lammaisten energia Oy)
Total cost for 100L of water	0.75	Euro	APPENDIX D for calculation
Price for kWh	11.8	c/kWh	

Table 5-4. Electric boiler running costs

Considering the savings outcome from the PV energy re-routed to the boiler, the status of the oil burner, the maintenance costs and the increasing oil price in table 5-3, we can conclude that an electric boiler is worth the investment as showed in the table 5-4. Unfortunately for lack of data we could not properly estimate those savings. To do that we would need the daily hourly consumption for the month of July and August.

5.2.2 Investment cost

Component	**Number of unit**	**Price (Euro)**	**Total (Euro)**
250W Solar panels	16	132.5*(4)	2120
3.8 - 4 kW inverter	1	800*(5)	800
Mounting brackets	-	405*(5)	405
Cables	-	150*	150
Installation (PV)	-	500	500
Energy manager (Apollo GEM)	1	300**	300
Boiler	1	519**	519
Pipes	-	100	100
Total cost			**4894**

Table 5-5. List of the components and prices of a 4kWp PV system.

*Satmatic 2015

**Website of Apollo Solar Product UK 2015

***Website of Mr. Central Heating 2017

*(4) Website of ENF Solar 2017

*(5) Website of Alma Solar 2017

All the prices include taxes but not the shipping costs

The total investment price is in within our client the budget.

5.2.3 Payback time

The formula of the payback time is simple and give a rough estimation after how many years the investment will be repaid:

$$Payback\ Time = \frac{Investiment}{Value\ of\ the\ replaced\ energy\ annualy}$$

The value of the replaced energy is the energy price multiplied by the yearly PV production.

The calculation does not take into account:

4. Inflation rate
5. Energy price fluctuation
6. Photovoltaic panels degradation

We also have assumed that:

3. All the energy produced is used

No maintenance costs

Yearly PV production	2870	kWh
Total investment cost	4894	Euro
Price of the electricity	0.118	Euro/kWh
Payback time	14.4	Years

Table 5-6. Data and results for the calculation of the payback time

The table 5-6 shows that the simple payback time is about 14 years with the current market price of the electricity.

A more accurate method to calculate the payback time is the return of investment. ROI is the ratio of a profit or loss made in a fiscal year expressed in terms of an investment and shown as a percentage of increase or decrease in the value of the investment during the year in question. The basic formula for ROI is:

$$ROI = \frac{Net\ profit}{Total\ investiment * 100}$$

(Website of Study.com).

This calculation has been done with PVCalc (Website of PVcalc). PVcalc is a simple web-based ROI calculator. This method take in consideration the inflation of the energy and prices, in our case is 1.2% (Website of Statistics Finland); the maintenance costs, 0.5% of the initial investment cost; the degradation of the panels, 0.5% for Si (Silicon) technology (Website of NREL); also in this case all the energy produced is used (Figure 5-3, 5-4).

Project Definition			
General Information		**Setup cost (all in)**	
Currency	EUR	Price (per kWp)	979
Divisor	1	**Running cost**	
Useful life (years)	25	Lease (€/year)	0
Nominal power (kWp)	3	Insurance prem. (%)	0
Annual Yield *per kWp* (kWh/kWp)	718	Maintenance (%)	0.5
Degradation (%/year)	0.5	Inflation rate (%/year)	1.2
Feed in tariffs		**Financing**	
Years	0	Own funds (%)	100
Price (per kWh)	0	Loan type	Redeemable
Index linked		Redemption Sched.	Uniform
Own consumption		Years	0
FIT subsidy (€/kWh)	0	Interest rate (%)	0
Own consumption (kWh/year)	2870	Disagio (%)	0
		Investment Yield (%)	0
Electricity price projection		**Tax**	
Price now (per kWh)	0.118	Tax rate	0
Energy Price Inflation (%/year)	1.2		help

Figure 5-3. Input value in PVCalc (Website of PVCalc 2017)

Project Summary:	
Nominal power (kWp)	3
Purchase value (EUR)	2937
Own Funds (EUR)	2937
Loan amount (EUR)	0
Present value of net income' (EUR)	6470
Levelised energy cost (€/kWh)	0.066
Loan type	Redeemable
Amortisation time (y)	11.2
Dividend (EUR)	NA
Dividend (%)	NA
IRR before tax (%)	7.1
Eff. tax rate (%)	0.0
IRR (%)	7.1

Figure 5-4. Results values in PVCalc (Website of PVCalc 2017)

6 CONCLUSION

Below we are going to sum up our proposed solution for the client main requests:

- Use the solar energy surplus for the domestic hot water in the workshop: the oil burner will be substituted with a 100L water tank with a 3kW electric coil.
- Research of possible method to use smartly all the energy produced by the system: solar controller switch will be installed to re-route the surplus energy produced by the PV system.
- Possibility to expand the systems in the future: the whole investment will be done in two parts:

  a) A first installation up to 3kWp in total with a 4kWp inverter.

  b) A second installation to add 1kW more to the pre-existing PV system.

As showed by the feasibility study the whole system is within the budget.

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APPENDIX A

Amount of heat needed to heat up a volume of 100 litres of water from 8 to 60°C

$Q = c*m*(T_2-T_1)$. Calculated with Excel

T1	8	°C
T2	60	°C
Water volume	100	Litres = Kg
Specific heat of water	4180	J/(kg, °C)
Heat added (Q)	21736000	J
Heat added (Q)	6.03782608	kWh

APPENDIX B

Amount of energy wasted by the system in the month of May 2015 with a 4kW system. Calculated with Excel

Time	Load (kWh)	Production (kWh)	Production - Load (kwh)
0.5	1.210934258	0	0
1.5	0.921892161	0	0
2.5	0.885381581	0	0
3.5	0.879296484	0	0
4.5	0.861041194	0.0322336	0
5.5	0.909721968	0.234298	0
6.5	0.92493471	0.574622	0
7.5	0.973615484	0.946756	0
8.5	1.031423903	1.31302	0.281596097
9.5	1.098359968	1.60237	0.504010032
10.5	1.165296032	1.75748	0.592183968
11.5	1.262657581	1.9311	0.668442419
12.5	1.286997968	1.95788	0.670882032
13.5	1.320466	1.83882	0.518354
14.5	1.241359742	1.68718	0.445820258
15.5	1.226147	1.41172	0.185573
16.5	1.375231871	1.06462	0
17.5	1.478678516	0.716997	0
18.5	1.572997516	0.373571	0
19.5	1.649061226	0.110475	0
20.5	1.846826871	0.00177638	0
21.5	1.977656452	0	0
22.5	1.883337452	0	0
23.5	1.445210484	0	0
			3.866861806

APPENDIX C

Amount of energy wasted by the system in the month of June 2015 with a 4kW system. Calculated with Excel.

Time	Load (kWh)	Production (kWh)	Difference (kWh)
0.5	0.785604533	0	0
1.5	0.631208267	0	0
2.5	0.5857976	0	0
3.5	0.624396667	0	0
4.5	0.6539136	0.0907915	0
5.5	0.6743484	0.319551	0
6.5	0.6062324	0.647567	0.0413346
7.5	0.603961867	0.992497	0.388535133
8.5	0.5994208	1.36057	0.7611492
9.5	0.6334788	1.65455	1.0210712
10.5	0.910483867	1.82236	0.911876133
11.5	1.305556667	1.95131	0.645753333
12.5	1.251063867	1.95096	0.699896133
13.5	1.112561333	1.84461	0.732048667
14.5	1.026281067	1.72259	0.696308933
15.5	1.146619333	1.49286	0.346240667
16.5	0.760628667	1.17917	0.418541333
17.5	0.992223067	0.851775	0
18.5	1.643866133	0.510495	0
19.5	1.805074	0.222382	0
20.5	1.132996133	0.0480924	0
21.5	1.425894933	0	0
22.5	1.094397067	0	0
23.5	0.703865333	0	0
			6.662755333

APPENDIX D

Running costs of oil burner, all the calculation are done using the value in the appendix A and they take in consideration the energy needed to heat 100 litres of water:

Heat of combustion	36	MJ/L
Burner efficiency	70	%
Cost of oil	90.1	c/L
Energy needed at efficiency	31.051	MJ
Litres of fuel	0.862	L
Total cost of oil	0.776662	Euro

Running costs of electric boiler:

Cost of electricity	11.88	c/kWh
Energy needed at efficiency	6.3556064	kWh
Total cost of electricity	0.75	Euro