Pierre Lafosse

Departement of Mechanical and Marine Technology

End of Master Project

SOLARLAB Project

Under the supervision of Professor Richard J Grand

External examiner:

Jean-Pierre FRADIN

Allal BOUZID

Western Norway University of Applied Sciences

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Introduction

As part of my final year of study at ICAM, I have to write a thesis on a project. This end of study project can be performed with compagnies in France on the premises of the ICAM in Toulouse or in a partner university from abroad.

My end of study project took place in Norway in the city of Bergen in the Western Norway University of Applied Sciences (HVL). My missions were oriented around the development of a solar laboratory - called SolarLab or passive house - equipped with photovoltaic panels.

The SolarLab belongs to the Department of Mechanical & Marine Engineering, of the Western Norway University of Applied Science. The project is led by Professor Richard J. Grant. Throughout the project he was my supervisor. I spent 5 months working on this project, from August to December 2022.

I chose this project because I was sensitive to learn more about renewable energy. It was a logical choice. This project was also taking place in a bilanguage country where people speak almost fluently English. Moreover, these news knowledges could give me an idea of my future career path.

The purpose of this report is to give an account of what I have achieved during my semester. It is written in chronological order, firstly a presentation of the solar lab with a description of the exiting installation and system. We will talk about the problems encountered and their resolution, then about the solar irradiation calculations on software analysis.

Context

Since 2020, ICAM students worked each semester on this project, one after the other. Their job was to connect all the electrical components of the passive house and make sure they worked properly. Their job was to connect all the electrical components of the passive house and make sure they worked properly.

The project was launched in 2019 with the installation of a passive house on the outside area of the University. Then, twelve solar panels were mounted on it to provide electricity and make the house auto sufficient. This work was carried out by the Department of Mechanical & Marine Engineering of the University. The aim was to create a solar lab for students, to perform practical projects and lessons.

The work of ICAM students is to develop, optimize and improve the installation to make it accessible to students.

I arrived at HVL for the first semester of the academic year 2022/2023, taking over from Alexandra Pulcina, an ICAM student like me, who was present last semester. Before us, three ICAM students had also succeeded to each other.

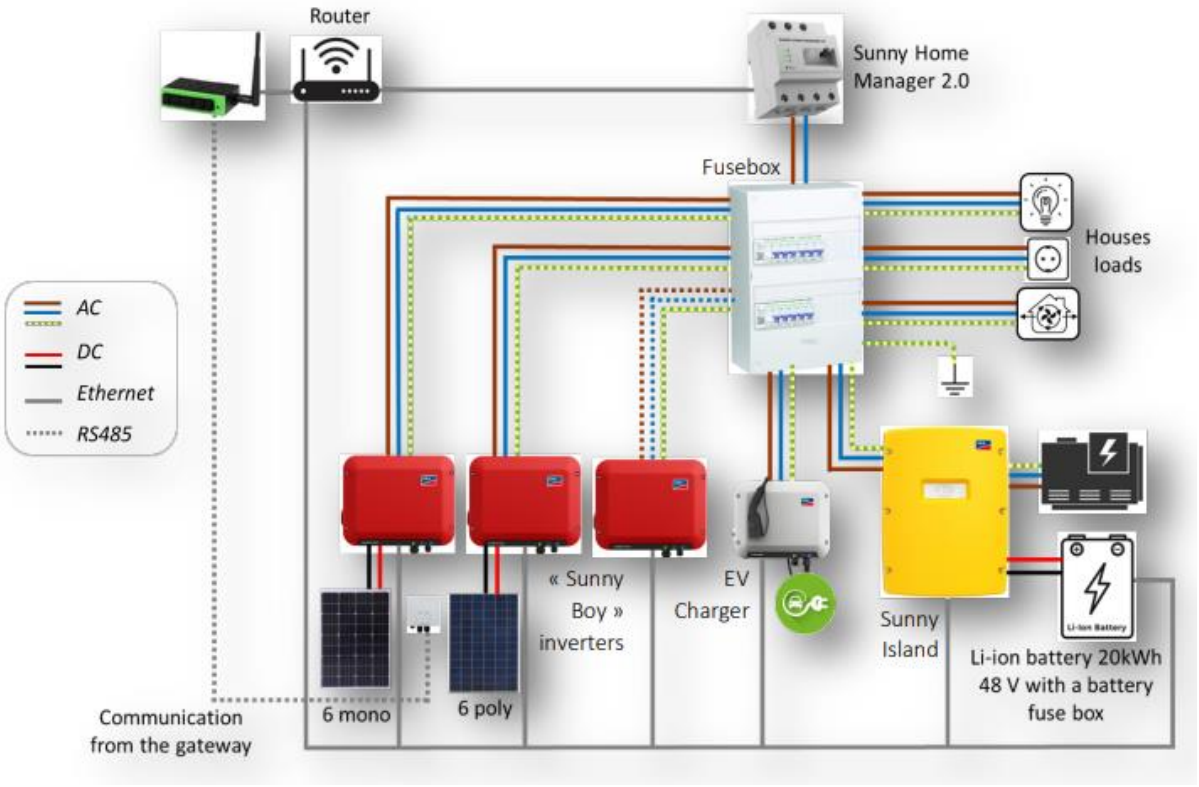
1.1 Solar Lab

The solar laboratory aims to be a passive house. A passive house is a building standard that is truly energy efficient, affordable, and ecological at the same time. Passive House is not a brand name, but a construction concept that can be applied by anyone and that has stood the test of practice. This type of design is growing rapidly because it makes it possible to limit its environmental impact, to be self-sufficient in energy or to provide energy in places isolated from any electrical network. For this purpose, the SolarLab is equipped with an off-grid system electrically connected to photovoltaic panels placed on the roof of the laboratory.

Bergen is considered the rainiest city in Europe so at first glance it may seem illogical to choose to use solar energy. However, in parallel to the project, I took a solar technology course, and a professor told us that the idea is far from being far-fetched. For example, in the summer in the town of Narvik above the Arctic Circle, where the weather conditions are the same, the energy production of a tracker panel is equal to the same panel in Tuscany in Italy. Although the period from October to February is rainy and does not allow the production of sufficient energy, necessary for the proper functioning of the SolarLab, the period from March to September is very sunny. In addition, we found that climate change, due to the global warming, has resulted in more sunny days in Bergen in recent years. It should be noted that during the winter period we must find solutions for the SolarLab to be self-sufficient.

The SolarLab is composed of twelve crystalline solar panels mounted in south exposition. The top part is composed of six monocrystalline photovoltaics panels and the bottom part six polycrystalline panels (Appendix 1). In order to have a general idea of the power production, here is a simple calculation: each crystalline panel is supposed to produce 285W and each thin technology panel can produce about 120W. So, the total energy harvested can be 12*285 + 14*120 = 412 kW in standard test condition. They are connecting in series to create four different strings: one string is composed of three panel. Three inverters link the photovoltaics solar production to the battery loads. They convert solar panels DC into AC power. The solar energy storage system is composed of 8 Li-ion 2.5 kWh battery modules allowing it to store up to 20kWh of solar energy production.

Below is the electrical diagram of the SolarLab when I arrived and all the components:



1 : Electrical diagram of the SolarLab

Previously the last electrical connection to the grid was the Sunny Island box made by Alexandra. The Sunny Island is a battery-powered inverter. Its manufacturer reference is 6.0H from the brand called SMA Flexible Storage System.It manages the balance between the energy produced by the solar panels and the energy consumed in the passive house. It has a battery and generator management system, and a load controller. In the event of excess energy, for example strong solar radiation and low consumption, the Sunny Island draws energy from the AC grid, thereby charging the battery. Conversely, in the event of an energy shortage, no or very little solar radiation and high consumption, the Sunny Island supplies the alternating current grid from the batteries to the Sunny Home Manager 2.0 which manages the energy flows of the installation.

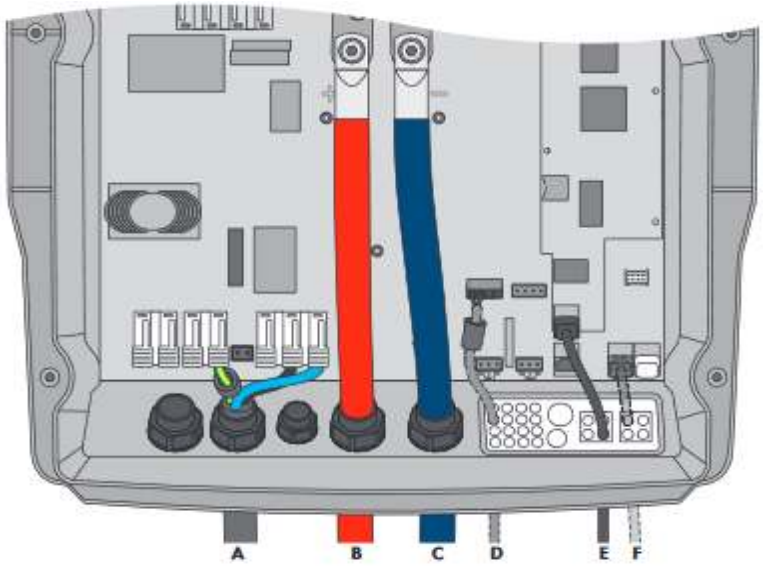
Finally, the Sunny Island monitors energy flows, identifies potential savings, and enables efficient use of solar energy. It is he who controls all the devices to maximize the production of energy and its use.

1.2 Sunny Island commissioning

As previously explained, the sunny island is the brain of the SolarLab electricity network, however we faced a problem when switching it on. Alexandra and an electrician tried several configurations together but all remained unsuccessful. My first job was to understand and solve this problem.

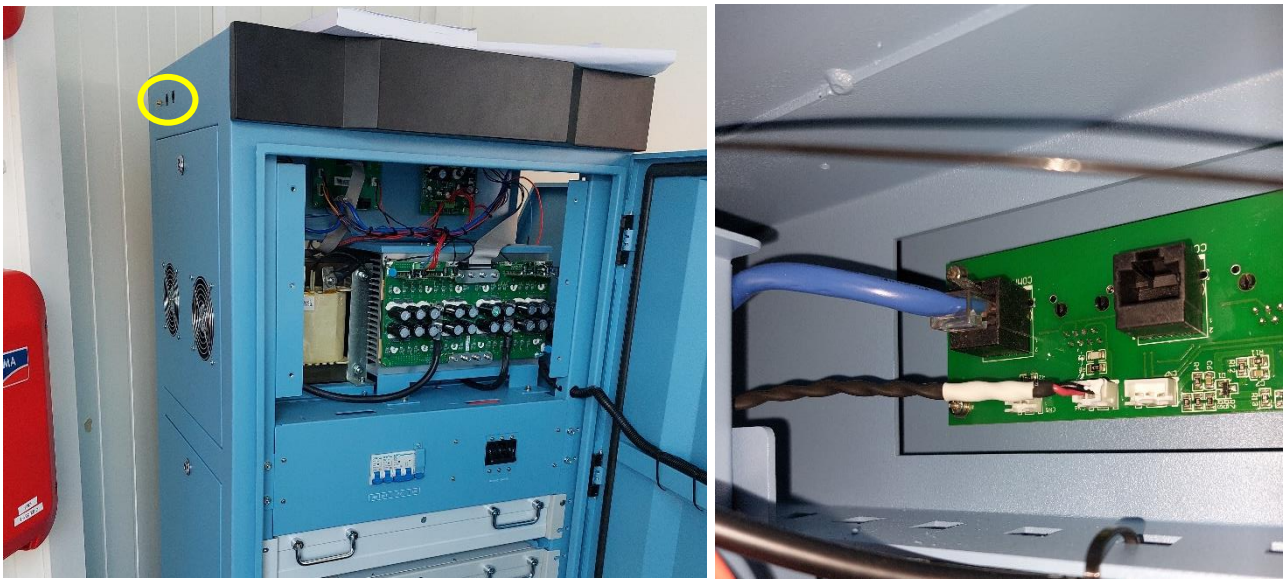
The main problem was that the Sunny Island could not retrieve the data from the PowerOak battery. This data is not retrievable and usable, due to a cable issue that will later be explained. This data is important because it allows us to know the percentage of electricity in each battery, the charging speed, etc.

The Sunny Island is connected to the lithium-Ion batteries with a single cable who is a data Ethernet cable. This Ethernet cable allows us to connect to the network, retrieve the data and display it on a computer screen. Then, on this computer, we can change some parameters via an application.



3 : Connection to Sunny Island

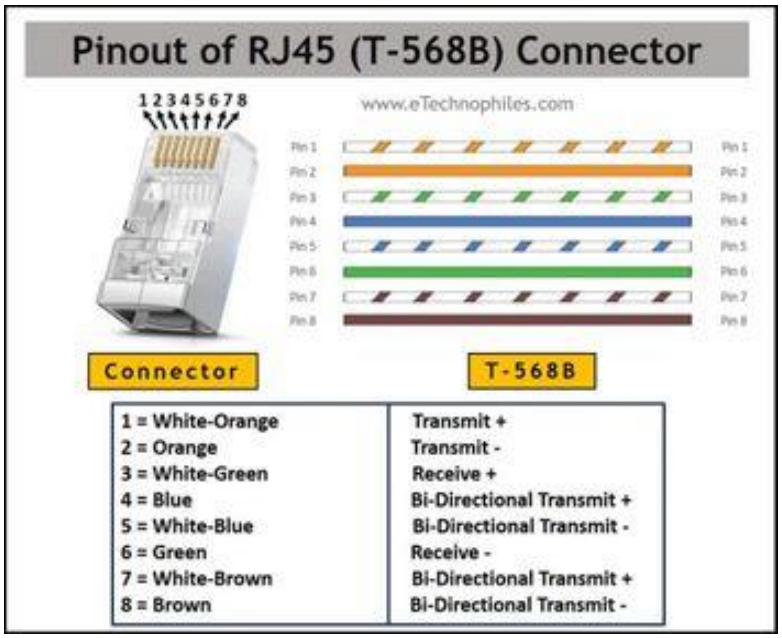
The communication cable to the lithium-ion battery is number F.



4 : Connection to Batterie PowerOak

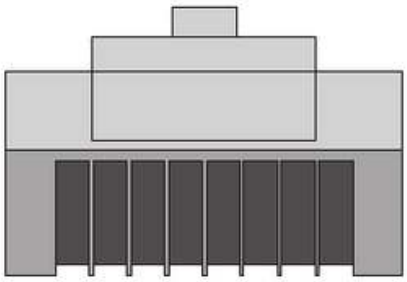
The input is on the right side of the battery.

First of all, together with Harald, an electrical technician from the school, we tried to strip this Ethernet cable on an electrical board and use an ammeter to check whether the battery was exchanging information. The data cable is an RJ45 T-568B connector.



5 : RJ45 Pinout T-568B

We were only focussed on checking three plugs of the RJ45 cable, number 1, 5 and 6.



No.	Item	No.	Item	No.	Item	No.	Item
1	RS485 B	2	RS485 A	3	NC	4	NC
5	GND	6	GND	7	NC	8	NC

6 : RJ45 Plug assignment

For more information see the link number 1 in the webography.

We noticed that no signal was coming out of the battery. Therefore, we checked the date of the Ethernet cable and the Sunny Island terminal. The check concluded to no significant problem.

After calling in two electrical teachers, we could not fix the problem. It occurred to me that investigating whether the SMA brand was compatible with the lithium-ion batteries. By inspecting the technical reports of the Sunny Island, a list of batteries approved for compatibility was provided. Unfortunately, the PowerOak battery wasn't reported in this list. Therefore, we contacted the manufacturers who never replied to us. Based on this analysis we had to come to the conclusion that the battery wasn't compatible.

The Sunny Island and PowerOak battery, did not exchange the same language and that communication was impossible. We had to buy new solar energy storage system. For this the school management chose asked me to conduct a market analysis of which batteries would be most suitable for the project and other future academic projects.

III - New batteries

My next task was to justify the choice of purchasing a new battery by presenting calculations and justification criteria to the head school. For this purpose, I have analysed the lithium-ion batteries of manufacturers who are compatible with the Sunny Island 6.0H. In appendix 2, you can find this list.

3.1 Purchase argument

The SolarLab is already equipped with a PowerOak battery with capacity of 20 kWh, but communication between the two elements (Battery and Sunny Island) is impossible because they don't use the same language technology.

The batteries we find must be compatible with the Sunny Island 6.0H model.

After conducting researches it seems that lithium-ion solar batteries are the best energy storage option. Lithium-ion solar batteries are deep cycle batteries, so they have DoDs of around 95%. Many lead acid batteries only have a DoD of 50%. This means you can use more of the energy that's stored in a lithium-ion battery without having to charge it as often.

Lithium-ion solar batteries do not require as much maintenance as flooded lead-acid batteries do.

The energy density of a battery is how much power the battery can hold relative to the physical size of the battery. Efficiency refers to the amount of usable energy you get out of your battery compared to how much energy it took to store it. Lithium-ion batteries have efficiencies between 90 and 95%.

Most lithium-ion solar batteries have a minimum warrantied lifespan of around 10 years, or a cycle life of 10,000 cycles - whichever comes first. Lead acid batteries, on the other hand, only have warrantied lifespans of around 10 years.

Lithium ions batteries are scalable and can be used as battery pack – many batteries connected in parallel – to serve high power applications or devices such as solar panel applications.

Lithium-Ion batteries can now be found across industries, from aviation, and telecommunications to IT and the car industry. With all the advantages stated above one can say that Li-ion batteries can be a good choice for the solar panel installation of the passive house. Moreover, this technology is part of the list of approved batteries by SMA himself.

3.2 Selection criteria

In order to sort out all the information, I applied some selection criteria to make the right choices.

The first selection criteria was geographical. The close to Norway it is the better the ranking. Secondly, that quality matches the price range the school allows. Thirdly, that the seller provides customer service and purchase guarantee. Fourth, customer feedback is positive for uses that are relatable to our project. Finally, the battery needs to be of appropriate size. I had to provebattery size that corresponds to the use required by the passive house with calculation. Battery energy storage capacity depends on the length of time you want the batteries to supply your home and your energy consumption. For that, we assume that the passive house consumes 5 kWh (per day) because of this electrical equipment like heat pump and light bulbs. Generally speaking an off grid system energy storage is often sized to account for 2 full days of autonomy. Lead-acid deep-cycle batteries have a recommended depth of discharge of 50%. This means that double the calculated ampere hour will have to be installed. With these parameters, we can use the following formula:

$$Battery\ Ah\ required\ [AH] = \left(\frac{Energy\ consumption\ [Wh]\ .\ Full\ days\ of\ autonomy\ [day]}{Battery\ Bank\ voltage\ [V]}\right).\ Depth\ of\ Discharge$$

Energy consumption [Wh]	5000
Full days of autonomy [day]	2
Depth of Discharge [%]	50
Battery bank voltage	48
Battery Ah required [Ah]	416,7
Battery size required [kWh]	**20**

$$Battery\ Ah\ required = \left(\frac{5000\ .\ 2}{48}\right).\ 2 = \ 416{,}7\ [Ah]$$

$$Battery\ size\ required\ = \frac{U}{V} = \frac{416.7}{48} = 20\ 000\ [Wh]$$

Finally, the minimal batterie size required for the passive house will be 20 kWh.

3.3 BYD manufacturer

It appears that BYD company validates all these criteria. Furthermore, of all the SMA applications presented on the forums or videos, this brand is a reference.

BYD Lithium batteries are among the most versatile on the market. They are, a recommended option for industrial uses and intermediate installations as they have expandable capacities. Although for the use of self-consumption it is the most used. The BYD lithium batteries allow the installations to be expandable in a simple way. All produced batteries are 10 years guarantee. In addition, these batteries include a BMS system, that is one of the most important points!

Battery Management System (BMS) includes monitoring the battery, providing battery protection, estimating the battery's operational state, continually optimizing battery performance, and reporting operational status to external devices.



7 : Battery Management System from REC company

3.4 BYD Battery-Box Premium LVS

One Battery-Box Premium LVS is a lithium battery pack for use with an external invert as SMA Sunny Boy inverter of the passive house. This battery is therefore fully compatible with the Sunny Island and recommended by customers. A Battery-Box Premium LVS contains between 1 to 6 battery modules LVS stacked in parallel and can reach 4 to 24 kWh of usable capacity.

3.5 Pricing analysis

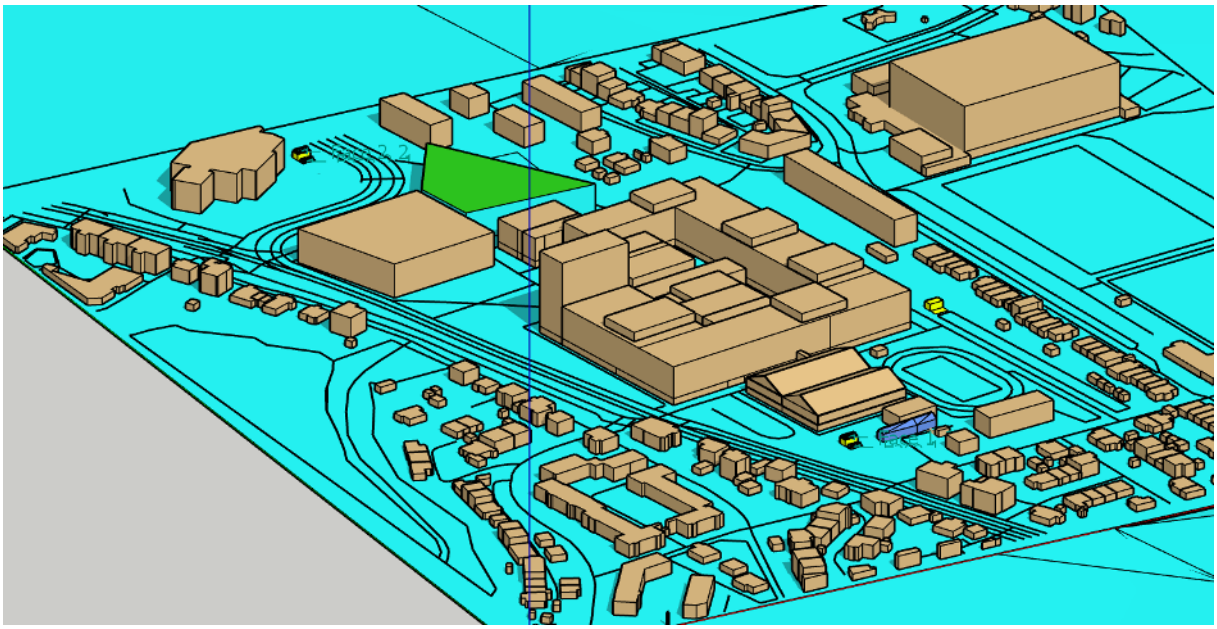
To argue this purchase with the school management and the budget, I made comparisons of several websites to buy at the lowest. As expected, Norwegian sites are the most expensive. The full presentation with prices is attached as appendix number 3.

The main work I did this semester was on the computer. Indeed, the school lent me a personal computer to work on the software. Professor Richard was interested in having software available for students to calculate solar irradiation on surfaces, especially on the SolarLab.

4.1 Sketchup

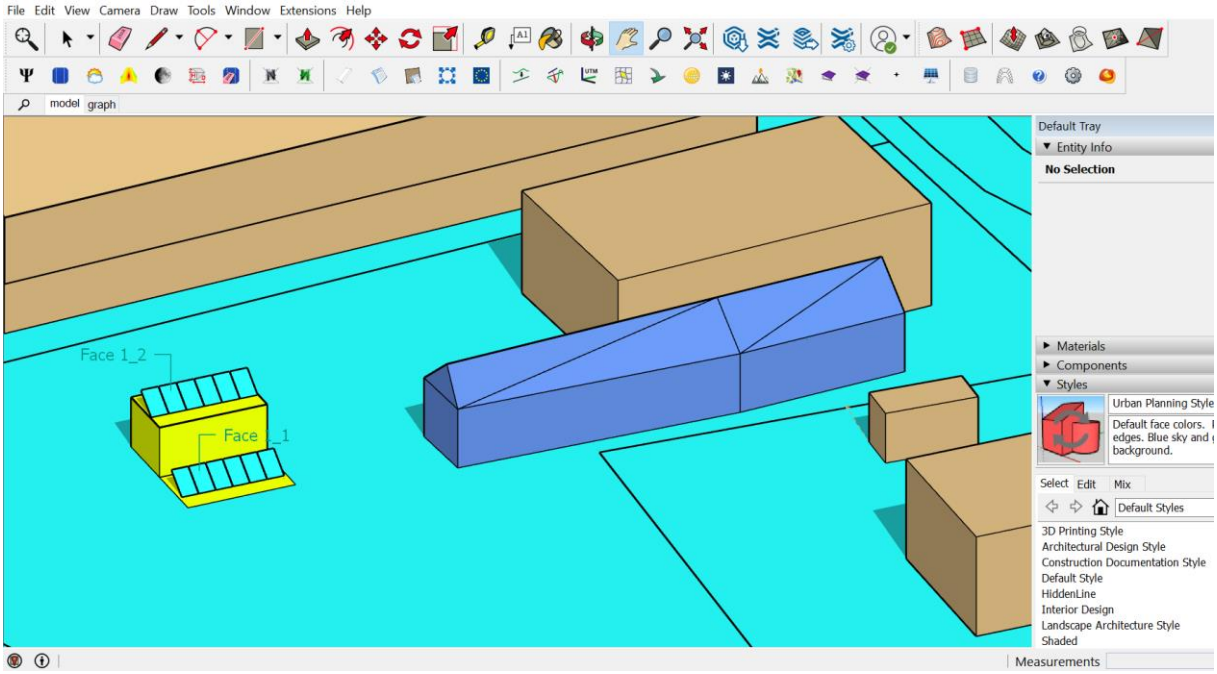
Sketchup is a 3D modelling Computer-Aided Design program for broad range of drawing and design applications. I have used this software to draw the campus of the school. This was my first time using this design software so I had to learn from myself by watching video tutorials.

My first job was to model the school campus to place the SolarLab on the map. For this I used a software that retrieves data from a defined area on google maps and models the buildings in that area. CADMAPPER. Instant CAD files for any location on earth. Architects and urban planners use Cadmapper to save hours of routine drawing. It transforms data from public sources such as OpenStreetMap, NASA, and USGS into neatly organized CAD files. So CADMapper generates the 3D models of the campus on a surface area of 1 km². This zone consists of the school and the main buildings surrounding it.



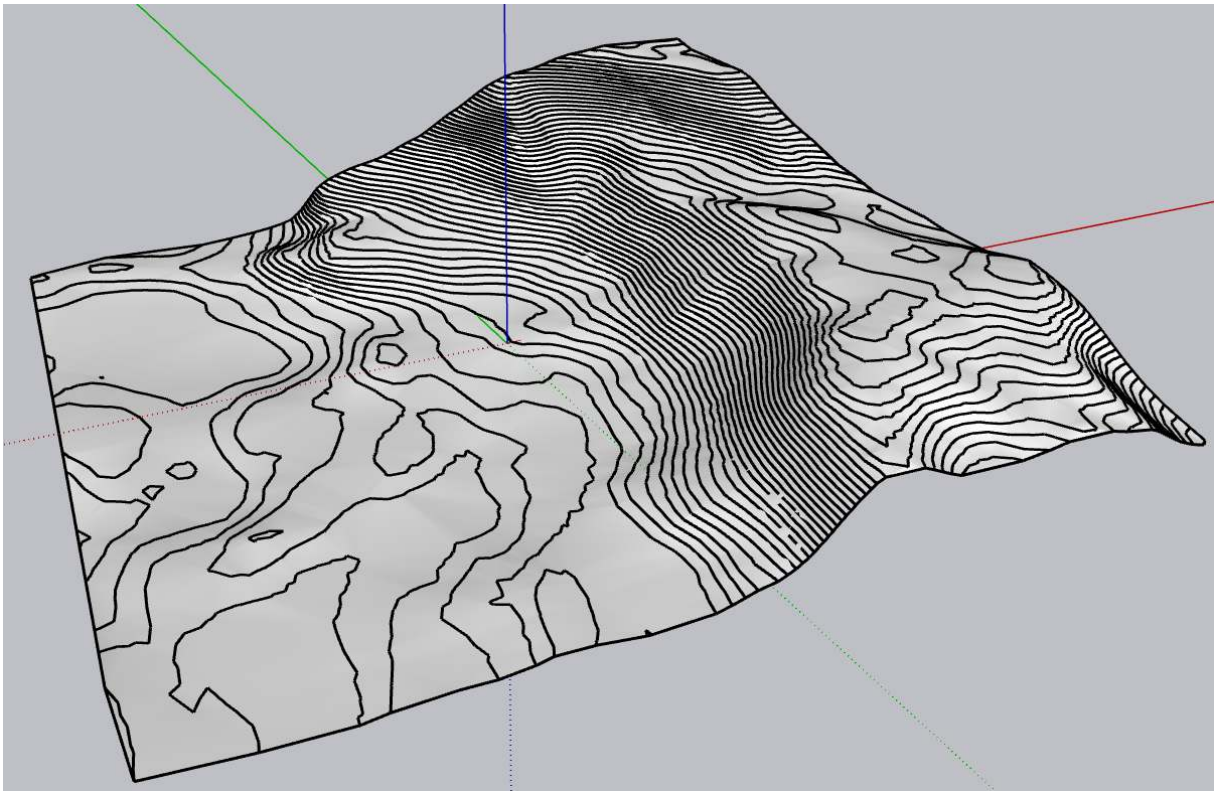
8 : Campus model on Sketchup

I had to redesign a few buildings, including the location of the new climate house to the east of the SolarLab after gained access to architect's drawings. (Appendix number 4)



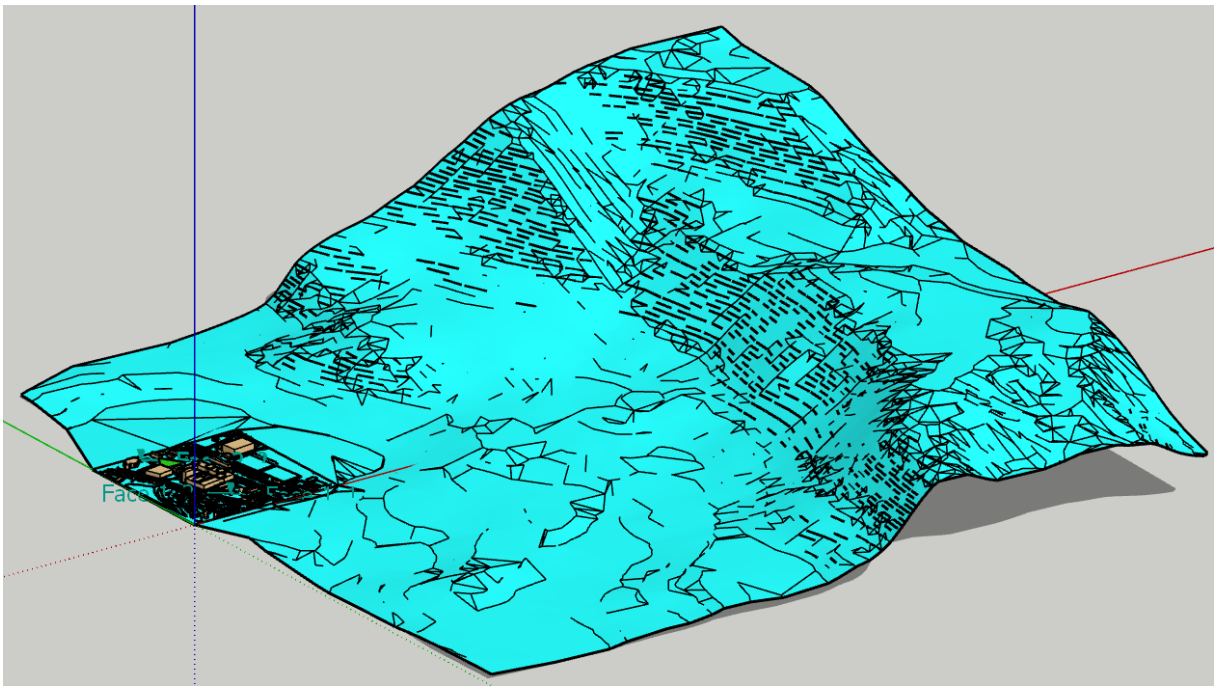
9 : SolarLab and Climate house

Afterward, in order to have an accurate model since it will be used to analyse the solar irradiations, I drew the neighbouring landscape. The school campus is bordered to the east by Bergen's largest mountain called Ulriken, which is over 600 metres high.

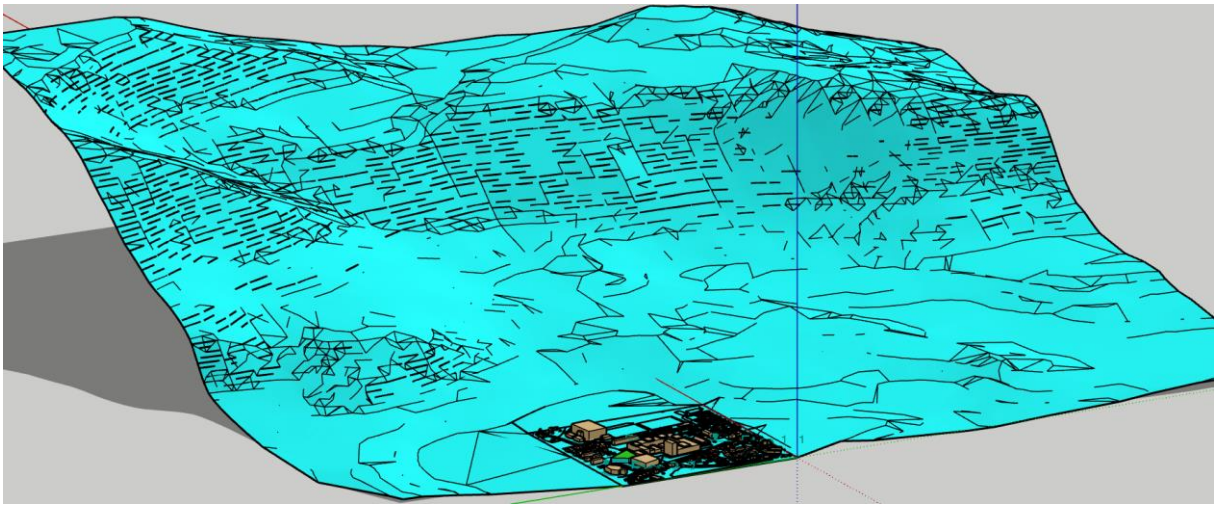


10 : Ulriken map model on Sketchup

The site of the university is particularly flat, so I have not drawn any changes in ground level. I then fussed over the two previous models to obtain the study model.



11 : Final map model see from Sud Ouest



12 : Final map model see from North Ouest

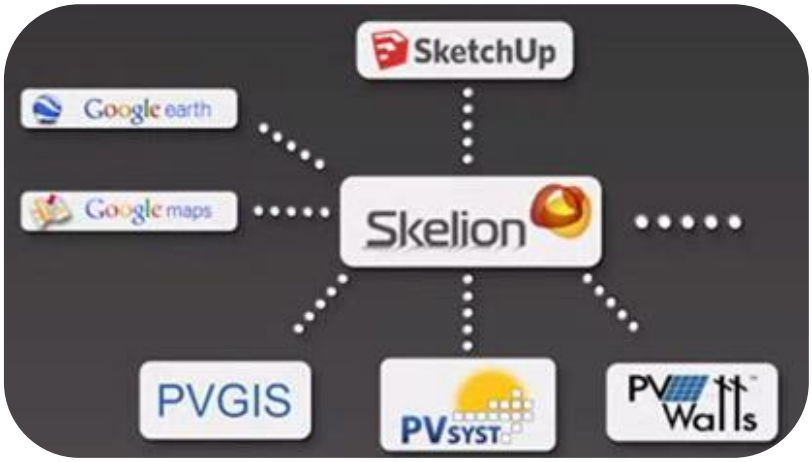
Once the complete model was finished, my teacher wanted me to find a plugin compatible with sketchup for a simulation of solar photovoltaic systems In order to find out the theoretical electricity production that the SolarLab could provide considering the weather data from Bergen.

The second reason is that the school management wants to change the location of the SolarLab on the school's campus. They want to place it in the southern area of the campus which is the least shaded. This is nonsense and our aim is to demonstrate this through analytical results.

5.1 Skelion

We chose the Skelion software after looking at all the plugins on the market. In the appendix 5 you will find the PowerPoint that compares the different plugins and justifies this choice.

Skelion, is a Sketchup's plugin to insert solar photovoltaics and thermal components in a surface. Skelion plugin gives Sketchup the possibility to insert solar panels and make renewable solar energy studies. Skelion allows to insert 3D models of the solar installation, use the PV Modules data base, or add own mode, load the current location from Google Earth.



13 : Skelion software

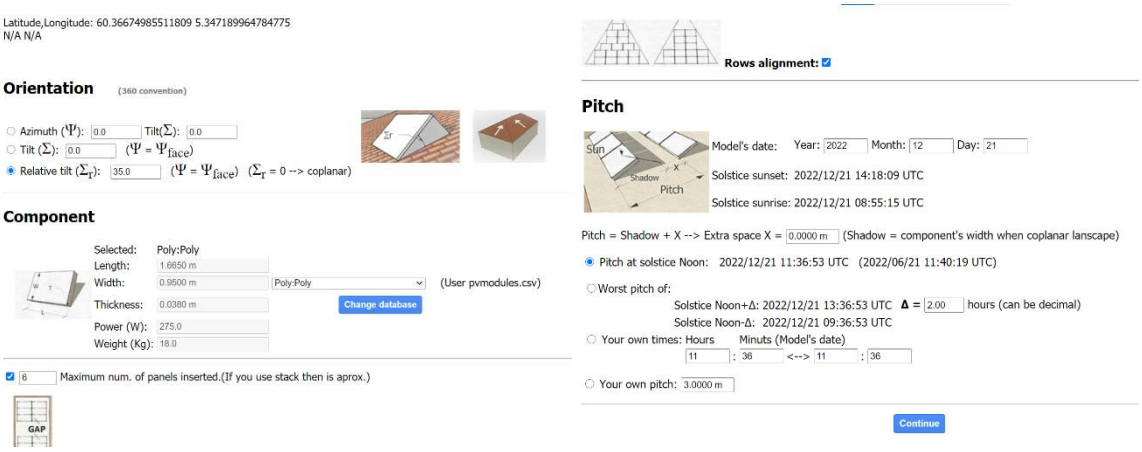
5.2 SolarLaB configuration

At first I had to geo-located the model.To do this I entered the latitude and longitude coordinates in Sketchup which are: latitude 60.366750N and longitude 5.347190E.

Then I had to chose a source to import meteorological data. I selected a meteo station close to the campus. The distance between the meteo station and the Sketchup model is approximately 10 km. I used Satel-light results from a European Project

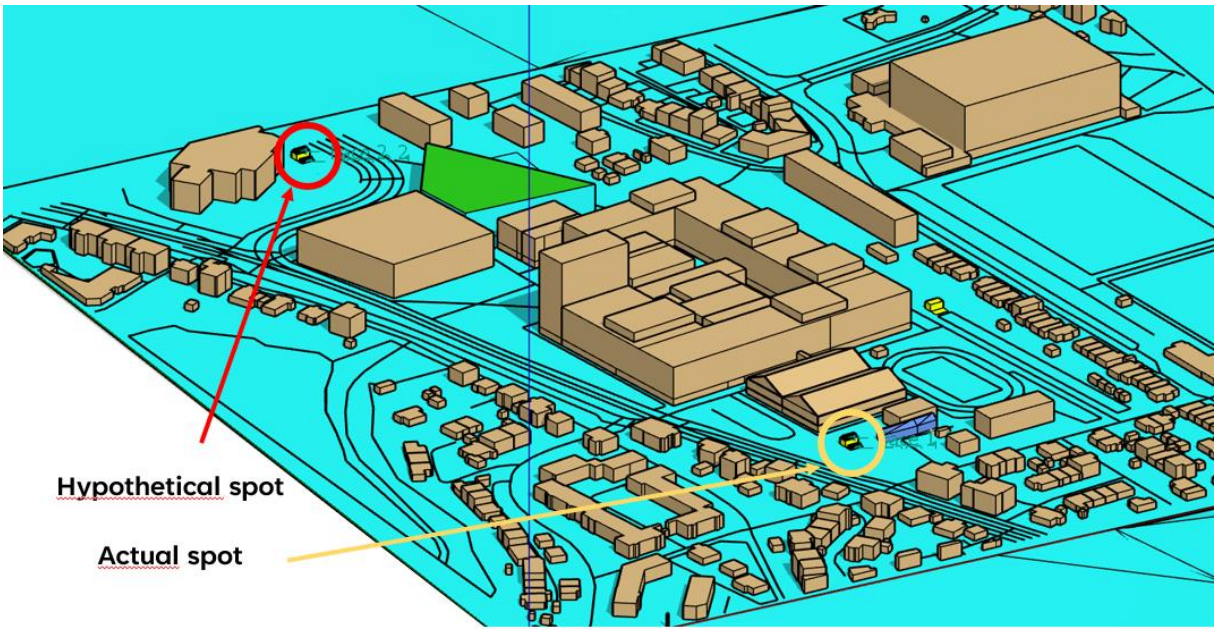
Team, which has used data from the METEOSAT Geostationary satellites, and provides detailed Irradiance (and also Illuminance - useful for natural lighting studies) time series in half-hourly values for 5 complete years (1996 to 2020) and for any pixel of about 5x7 km² in Europe. This data is used to calculate shading losses.

The next step is the configuration of the solar panel database. Twelve crystalline solar panels are mounted in the south exposition of the solar laboratory. The top part is composed of six monocrystalline photovoltaics panels, whilst the bottom part is composed of six polycrystalline panels. The technical data sheet for these panels can be found in the appendix number 1. The solar panels face south at 35 degrees.



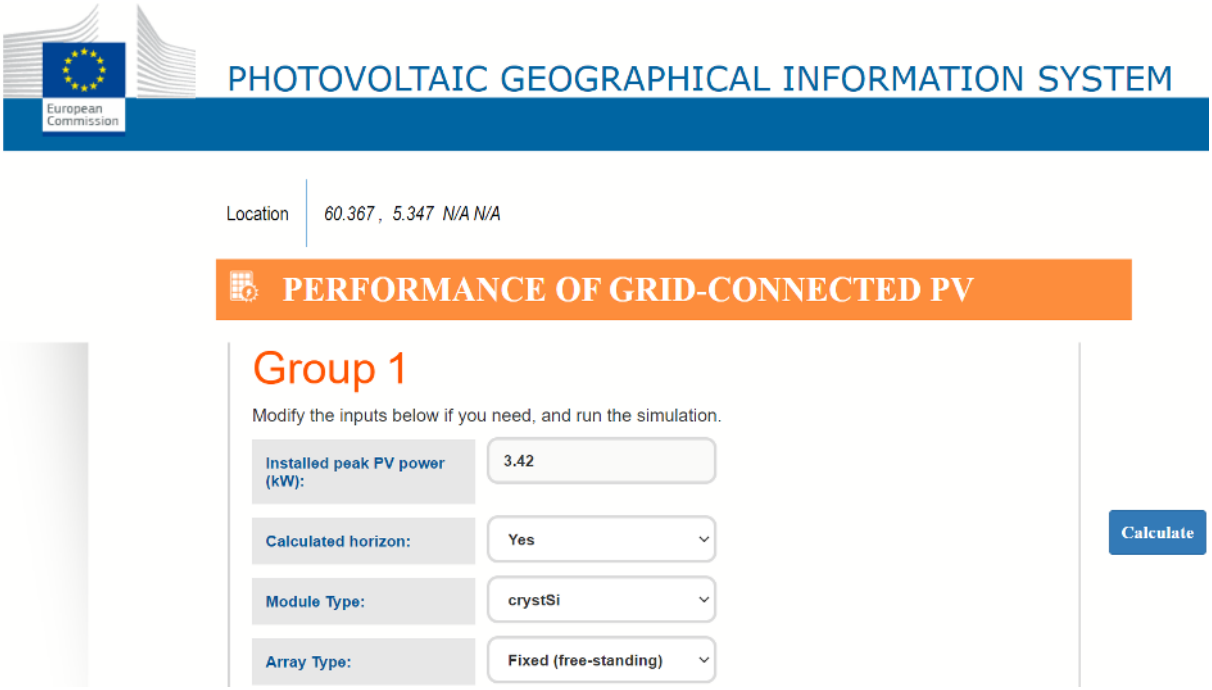
14 : Solar panel configuration interface

As mentioned earlier, the management wishes to change the location of the SolarLab. So I created another SolarLab model on my Sketchup drawing located in the southern part, next to the tramway and the O-BYGG building.



15 : Localisation of two SolarLab model on Sketchup

The Skelion software has a calculator called JRC PVGIS Europe. This application calculates the monthly and yearly potential electricity generation E [kWh] of a photovoltaic system with previous defined modules tilt and orientation. It also calculates the monthly shadow losses on solar panel faces.

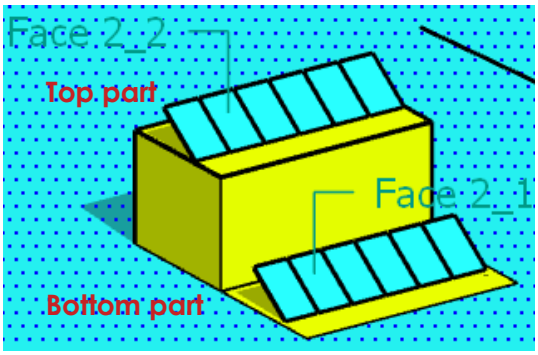


16 : PVGIS Europe calculator interface

5.3 Report and comparison

On Monday 28 November I made a presentation to Mr Nils-Ottar Antonsen and Boris Balakin, two professors of the department of Mechanical and Marine Engineering. During this presentation supervised by my professor Richard, I explained the significant differences between the two spots studied.

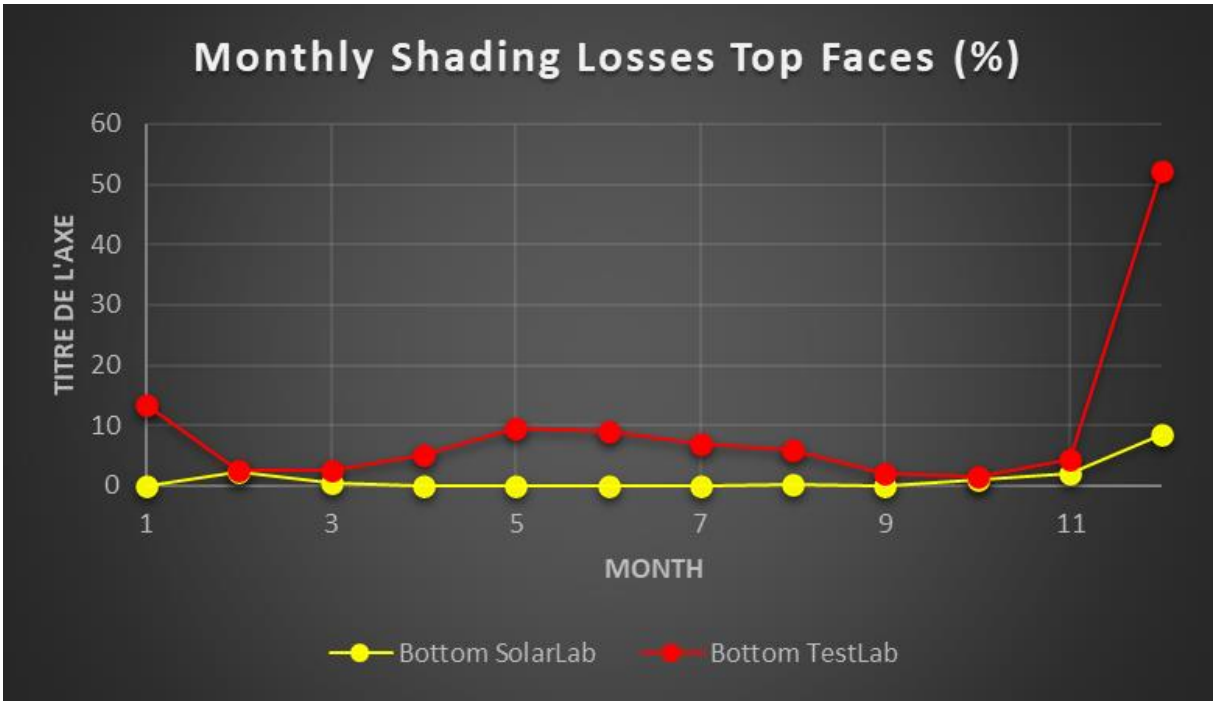
For this study, I compared the two solar faces of the SolarLab, which is the top part and the bottom part.



17 : Faces of the SolarLab

5.3.1 Bottom faces report

Here are the results of the simulation for the bottom faces of each SolarLab's. The entire report in details from PVGIS analysis is in appendix number 6 and 7.



Monthly Shading Losses Top Faces (%)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual SolarLab	0	2.24	0.5	0.03	0	0	0	0.12	0.01	1.09	2.12	8.57
Hyp SolarLab	13.35	2.52	2.44	3.63	6.75	5.61	4.96	4.06	1.71	1.57	4.4	52.1

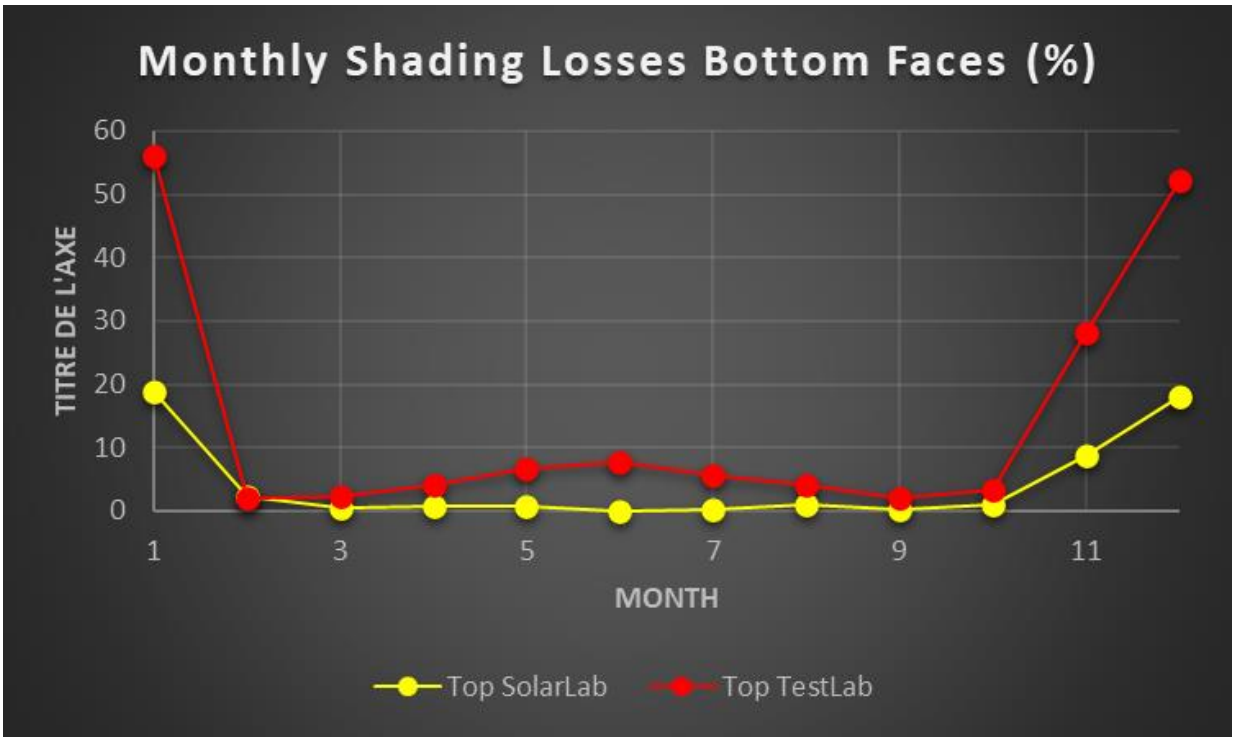
Top Face	Average (%)
Actual SolarLab	**1,22**
Hyp SolarLab	**8.59**

In the report from PVGIS analysis many parameters are calculated but only the monthly shading losses are interesting for this study.

We can notice on first look the solar panels on the top face of the actual location of the SolarLab are almost shadow only in December. The other months have a rather low shadow rate. On the other hand, we can note that the analysis of the second location of the SolarLab is very shaded, all year round. The average shading (8.59 %) is higher than the highest value of the critical month of the current location (8.57 %).

5.3.2 Top faces report

Here are the results of the simulation for the top faces of each SolarLab's. The detailed report from PVGIS analysis is in appendix number 6 and 7.



Monthly Shading Losses Bottom Faces (%)												
Face	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Actual SolarLab	18.81	2.24	0.51	0.76	0.85	0	0.13	0.9	0.23	1.11	8.68	18.2
Hyp SolarLab	56.08	2.04	2.28	4.14	6.75	7.8	5.76	4.06	2.01	3.26	28.17	52.1

Bottom Face	**Average (%)**
Actual SolarLab	**4,37**
Hyp SolarLab	**14,54**

With this simulation it seems obvious that spot number 2 near the north of the campus is the worst location for the SolarLab. Indeed, it is noticeable that the percentage of shaded areas are almost multiplied by about 10 through the year.

The conclusion of this meeting after showed the analysis results and debating was therefore to suspend the change in location of the SolarLab project.

5.4 Case study

Richard invited me to follow his lecture about solar energy along the semester; these lectures have been interesting and helpful for the project. Also, it was a great source of knowledge and culture about this emerging technology. Simona Petroncini is one of the professors who animated this class through the semester. She works in different solar energy companies like Solbære AS – Sustainable Photovoltaic, Over Easy Solar AS and Greenstat Energy AS. She started her own business in this sector some years ago.

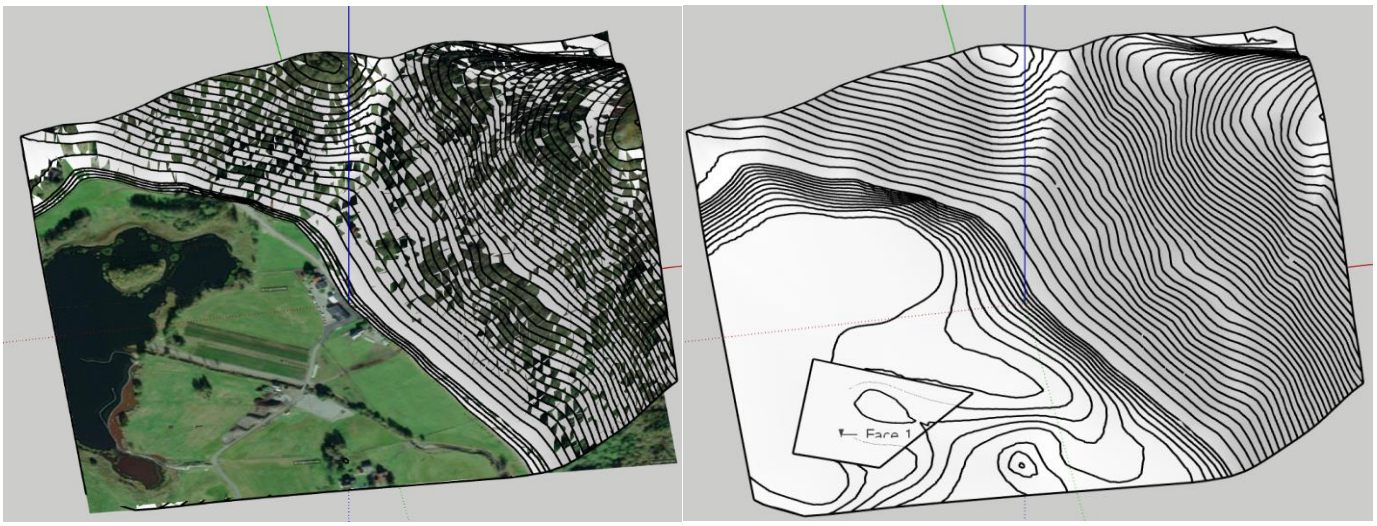
I mentioned the software that I was using to her, and she asked me to have a look on an area near to Bergen with the software and make an evaluation in terms of solar irradiation and shadows. The address of the area is Unnelandsvegen 319, 5268 Haukeland. The goal of this evaluation is to know if Simona would be interested in buying the same software Skelion for her work.



18 : Picture from the study area.

The area is the one in red on the picture.

For this study I have modelled the field and the mountain around.



19 : Area of case study

I did three different benchmarks. On the first benchmark I tried to put the maximum of solar panels on the field. I made the assumption that their dimension was 1*1 m, this is not realistic measurements, but the aim of this first analysis was to see the critical month of shadow.

On the second report, I changed the solar panel characteristics with more realistic standard size and power value. One panel measures 1m in length and 2 m in width with a power of 385 Wp.

On the third report I put 2 stacks of solar panel per row. The reports of these three cases are attached in appendix number 8, 9 and 10.

6.1 Installation of the pyranometer

Richard wanted to install a pyranometer because this type of device measures the global solar radiation (direct, diffuse and reflected). These are the radiation captured by the solar panels. The pyranometer purchased is a model Kipp & Zonen SMP11 Pyranometer (class A) (Appendix 11)

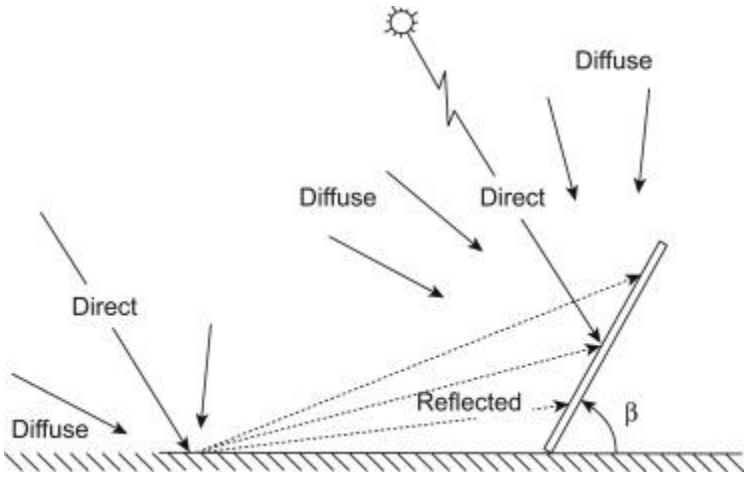


Figure 20 : Different radiation type captured by the solar panel and the pyranometer

My task was to find the perfect stop on the campus in term of solar irradiation and hide the pyranometer from the shadow. I used the software Shadow Analysis on my Sketchup Model to find the perfect spot. And as I thought, the area on the man building of the campus, who is also the taller one, is the perfect area. At the meeting on Monday 28 November, I also gave a presentation on the location of the pyranometer and requested access to the roof, which is 7 floors high. This presentation is in appendix number 12.

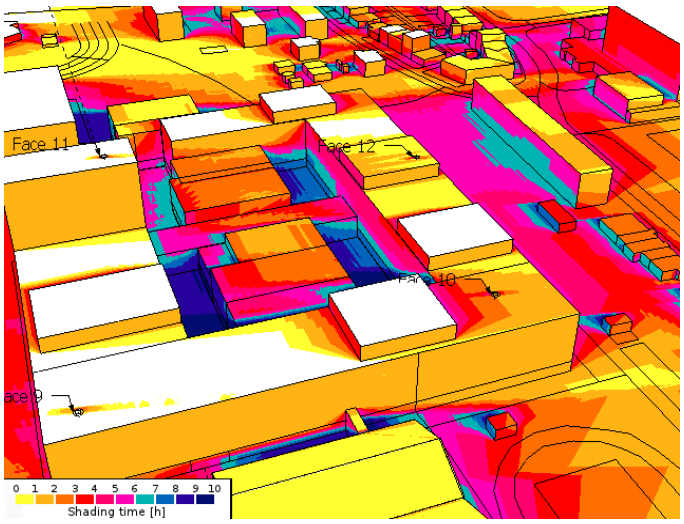
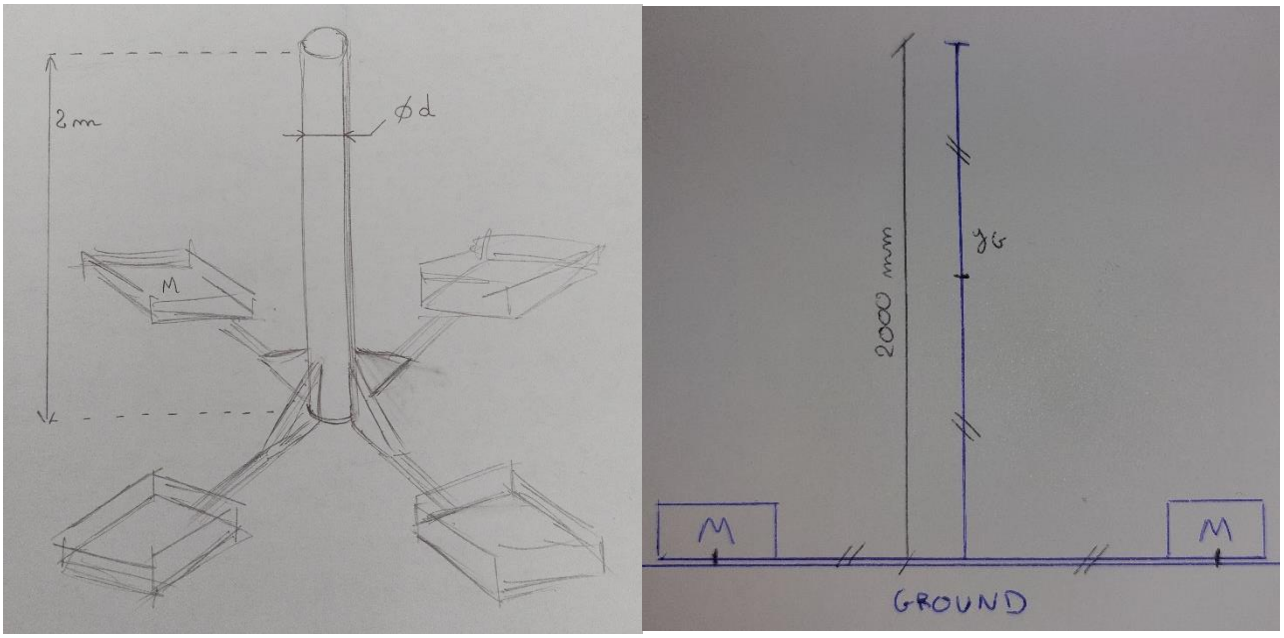


Figure 21 : Shadow Analysis on the campus model

A technician sent us photographs of the rooftop of the main building. We saw two potential spots. The first one can be on the top of electrical building, the pyranometer will stand directly on the roof on a concrete base, and the second fix the pyranometer on the top of a pole with a ballasted base. It was finally decided with Richard that the pyranometer stand would be fixed to a pole at a height of two metres.



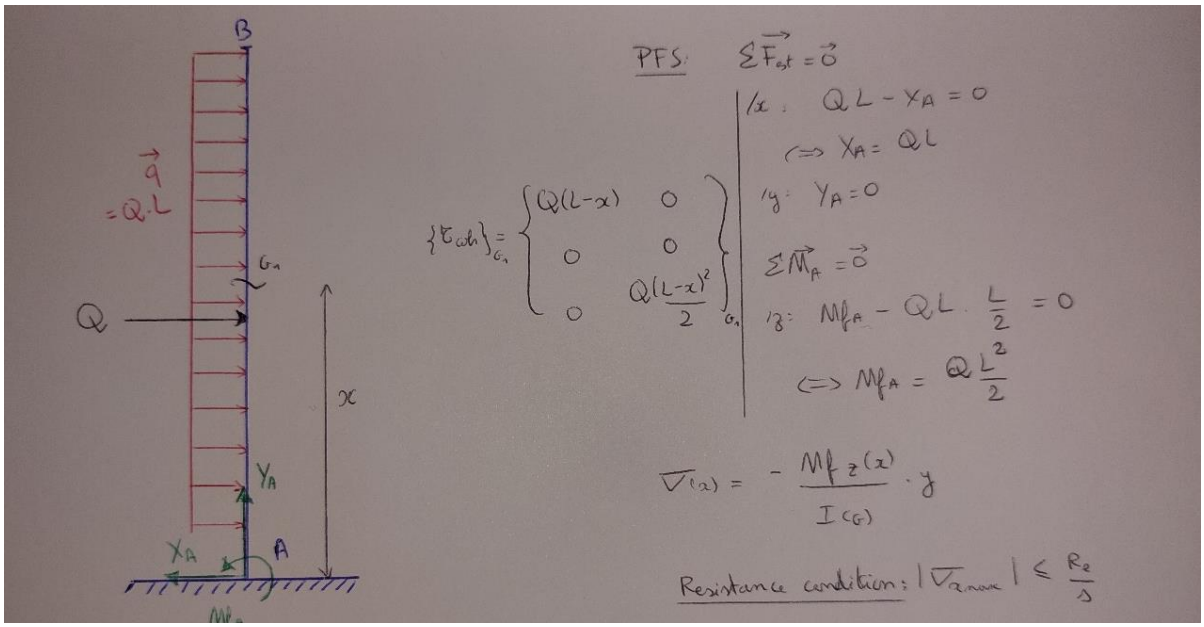
22 : Schematic draws of the ballasted base

We have identified a flat on the roof, we could use it to run an ethernet cable to get the data. The pyranometer will be plugged directly into an electrical outlet.



23 : Rooftop pictures

With my knowledge of material strength, I calculated the minimum cross section of the pole to withstand the wind. The strongest wind recorded in Bergen is 29.6 m/s.



$$q = \frac{1}{2} . Cx . P . v^2 . S$$

$$q : Wind\ force\ [N].$$

$$Cx : Air\ penetration\ coefficient = 1$$

$$P: Wind\ density\ [kg/m3] = 1{,}292$$

$$v : Wind\ speed\ [m/s] = 29{,}6$$

$$S : Surface\ [m^2]$$

$$Xa = q.(L - x)$$

$$Mfa = 0{,}5 . q . L^2$$

d Ø [m]	d Ø [mm]	S [m²]	q [N]	Mfa [N.m]	Io [mm4]	σ max [Mpa]
0,03	30	0,19	106,69	213376,73	19168,13	3,34E+02
0,035	35	0,22	124,47	248939,52	30880,33	2,82E+02
0,04	40	0,25	142,25	284502,31	46596,03	2,44E+02
0,05	50	0,31	177,81	355627,89	92392,93	1,92E+02
0,06	60	0,38	213,38	426753,46	161268,83	1,59E+02
0,07	70	0,44	248,94	497879,04	257933,73	1,35E+02

$$Résistance\ condition : \ \sigma\ max < \frac{Re}{s}$$

$$Re\ steel\ [Mpa] = 250$$

$$security\ coefficient = 1$$

d Ø [mm]	Resistance condition	M [kg]
30	No	*
35	No	*
40	Yes	15
50	Yes	18
60	Yes	22
70	Yes	25

The minimum diameter of the pole should be at least 40 mm for a wind of 30 m/s. We also should ballast the system with 15 kg for each side. The next student's job is to fix this pyranometer on the rooftop, build the support, install the device and start collecting data.

VII – Difficulties

At the beginning, it took time to understand the functioning of all devices together. However, I soon realised that there was a problem with the batteries, and we quickly decided that we needed to change them.

Sometimes I was not able to significatively go forward in my work due to technical problems or maybe because the real expectations had not been defined clearly on the SolarLab. All has been clarified along the project with meetings and talks. And we noticed that the director of studies was not in favour of this project, unlike the teachers who saw a real interest in it.

The main difficulties were financial constraints. These were major problems as the cost were high and did not depend on us but on the study management. That's why I didn't do much work on developing the SolarLab system, but mainly on software analysis. My work was to justify with proof future purchases of components (batteries, pyranometer) to release funds to continue the experiments in the SolarLab.

Due to the lack of row material in the market and high worldwide demand, price for solar equipment is changing fast and getting higher. In general ordering takes a lot of time to come in Norway and it is very expansive. At the beginning of the project, I expected to design electricity car charger, this new purchase was not a priority.

I was a very autonomous and could organize my work as I wanted to. I had to adapt and organise myself according to everyone's time, because they are most of the time busy with courses, or other student projects. Working alone was sometimes pleasant but a bit boring. I liked the moments of meeting and exchange with the teachers or the technicians like Harald. It was sometimes difficult to get things done quickly, but I think it's part of the Scandinavian culture to take your time.

Conclusion

This project was very formative and interesting. I was able to complete all of the tasks that were asked of me during the semester. I feel that this project has rosen my degree of autonomy and confidence, on making choices, assuming my error.

I discover the word of research. Working in another language than my native tong was a challenge, I am sure that this experience abroad has opened my mind to new ways of working. It was interesting to work with people who don't have the same mindset as me and see world and problems on another side.

I came to Norway because I was interested in the subject of photovoltaics, and I wanted to know more about low-carbon solutions. I learned a lot from the courses on the solar system subject and technology. Richard is also a very sensitive teacher and taught me a lot about the realities of renewable energy in Europe and the world. Using the PVGIS software and the Sketchup modelling system allowed me to advance my application for an internship in Paris for the next semester. I was accepted as an assistant photovoltaic engineer in the Norwegian company Statkraft Renouvelable.

The atmosphere in the Department of Mechanical and Marine Engineering was very nice, and I thank all the people who have crossed my path, teachers, students and technicians. Beyond his technical support, I sincerely thank Richard for having accompanied me during this project. Thanks also to Western Norway University of Applied Sciences who opened the doors of his school.

Webography

SolarLab components manuals:

Sunny Island manual: https://www.manualslib.com/manual/874232/Sma-Sunny-Island-8-0h.html?page=49#manual

PowerOak batteries brochure: https://poweroakamerica.com/index.php/products/5000w-solar-backup-generators-es5048/

CAD stuff

Shadow Analysis: https://deltacodes.eu/en/ShadowAnalysisSkp/download

Open Street Map: https://www.openstreetmap.org/#map=6/46.449/2.210

Skelion tutorial videos: http://skelion.com/en/training.htm?v1.0.1

https://www.youtube.com/watch?v=rCAQ1W5UA-U&t=473s

Batteries information websites

https://www.solarreviews.com/blog/are-lithium-ion-the-best-solar-batteries-for-energy-storage

https://bydbatterybox.com/

https://www.europe-solarstore.com/byd-battery-box-premium-lvl-15-4.html

https://www.camgox.com/byd-battery-box-premium-lvs-16.0-en.html

https://www.cleanenergyreviews.info/blog/home-solar-battery-cost-guide

Knowledge documents on solar technology

https://www.suncalc.org/#/60.3322,5.3389,6/2022.11.30/12:31/1/3

https://www.solarempower.com/blog/how-to-calculate-solar-panel-battery-and-inverter-size/

https://www.les-energies-renouvelables.eu/conseils/photovoltaique/les-chiffres-essentiels-du-photovoltaique/

https://www.solarreviews.com/blog/peak-sun-hours-explained

https://globalsolaratlas.info/map?c=41.376809,-39.375,3

Appendices

Appendix n°1 : PV datasheet (Astronergy 285 and REC Solar 275)

Appendix n°2 : List of batteries compatibles with Sunny Island 6.OH

Appendix n°3 : Pricing analysis for batteries

Appendix n°4 : Climate house map

Appendix n°5 : Solar softwares comparaison

Appendix n°6 : PVGIS report for the two location of the SolarLab on the campus

Appendix n°7 : PVWATTS report for the two location of the SolarLab on the campus

Appendix n°8 : First case study on Unnelandsvegen field

Appendix n°9 : Second case study on Unnelandsvegen field

Appendix n°10 : Third case study on Unnelandsvegen field

Appendix n°11: Instruction sheet pyranometer SMP11

Appendix n°12: Monthly Shadow analysis on the campus

Appendix n°1 : PV datasheet (Astronergy 285 and REC Solar 275)



VIOLIN™

Crystalline PV Module
ASM6610M Series

- With innovative 4-busbar mono cell
- Reduced series resistance
- Increased cell efficiency
- More power output

275 | 280 | 285 | 290

EN

ELECTRICAL SPECIFICATIONS [1]				
STC [2] rated output (P_{max})	275 Wp	280 Wp	285 Wp	290 Wp
Standard sorted output		-0/+3%		
Warranted power output STC ($P_{nominal}$)	275Wp	280 Wp	285 Wp	290Wp
Rated voltage (V_{mpp}) at STC	31.45 V	31.55 V	31.65 V	31.75 V
Rated current (I_{mpp}) at STC	8.86 A	8.98 A	9.09 A	9.21 A
Open circuit voltage (V_{oc}) at STC	38.05 V	38.15 V	38.25 V	38.35 V
Short circuit current (I_{sc}) at STC	9.40 A	9.50 A	9.60 A	9.70 A
Module efficiency	16.81%	17.12%	17.42%	17.73%
Rated output (P_{mpp}) at NOCT [3]	205.6 Wp	208.9 Wp	212.2 Wp	215.6 Wp
Rated voltage (V_{mpp}) at NOCT	28.93 V	29.02 V	29.11 V	29.20 V
Rated current (I_{mpp}) at NOCT	7.11 A	7.20 A	7.29 A	7.38 A
Open circuit voltage (V_{oc}) at NOCT	35.17 V	35.26 V	35.35 V	35.44 V
Short circuit current (I_{sc}) at NOCT	7.60 A	7.68 A	7.76 A	7.84 A

Temperature coefficient (P_{mpp})	-0.442%/K	Maximum system voltage	1000 Vdc
Temperature coefficient (I_{sc})	+0.042%/K	Number of diodes	3
Temperature coefficient (V_{oc})	-0.329%/K	Reverse current loadability (IR)	20 A
Normal operating cell temperature (NOCT)	46°C ±2°C	Maximum series fuse rating	15 A

[1] Measuring uncertainty Pmpp: +/-3 %; Tolerance for Voc, Isc, Vmpp and Impp: +/-10 %
[2] Standard test conditions that are defined as follows:
1,000 W/m² irradiation at a spectral density of AM 1.5 and a cell temperature of 25°C.
[3] Nominal operating temperature of the cell at 800 W/m² irradiation, 20°C ambient temperature, wind speed of 1 m/s
[4] Manufactured in an ISO9001/14001/OHSAS18001 certified facility

CERT CERT Made in Germany

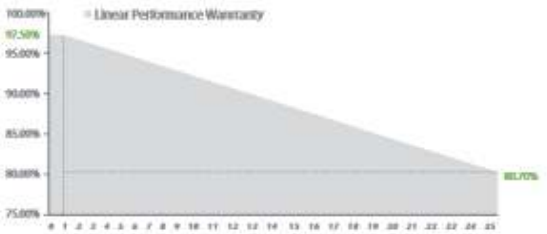
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ASTRONERGY

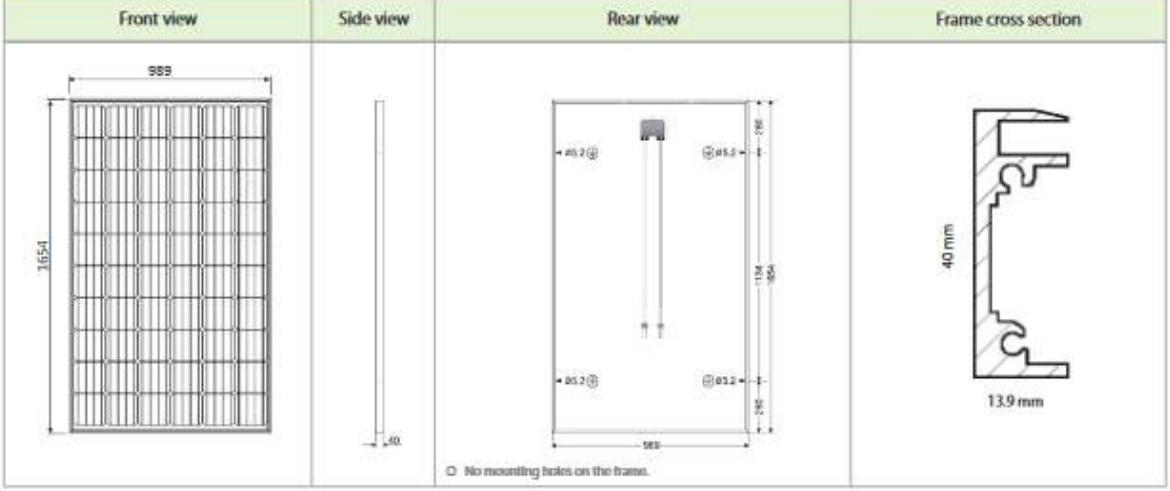
RELATED PARAMETERS	
Cell type	Monocrystalline cell, 4-busbar technology
Number of cells / cell arrangement	60 / 6 x 10
Cells dimension	157 x 157 mm²

MECHANICAL SPECIFICATIONS	
Outer dimensions (L x W x H) [5]	1654 x 989 x 40 mm
Frame technology	Aluminum, silver anodized
Module composition	Glass / EVA / Backsheet (white)
Weight (module only)	18.2 kg
Front glass thickness	3.2 mm
Junction box IP rating	IP 67
Cable length	1000 mm
Cable diameter	4 mm²
Maximum load capacity [6]	6000 Pa
Fire class (IEC 61730)	C
Connector type	MC4 pluggable

QUALIFICATION AND LINEAR WARRANTIES	
Product standard	IEC 61215 Ed. 2, IEC 61730
Extended product warranty [7]	12 years
Performance warranty [7]	Linear performance warranty
Year 1	>97.5% of warranted output power
Year 25	>80.7 % of warranted output power



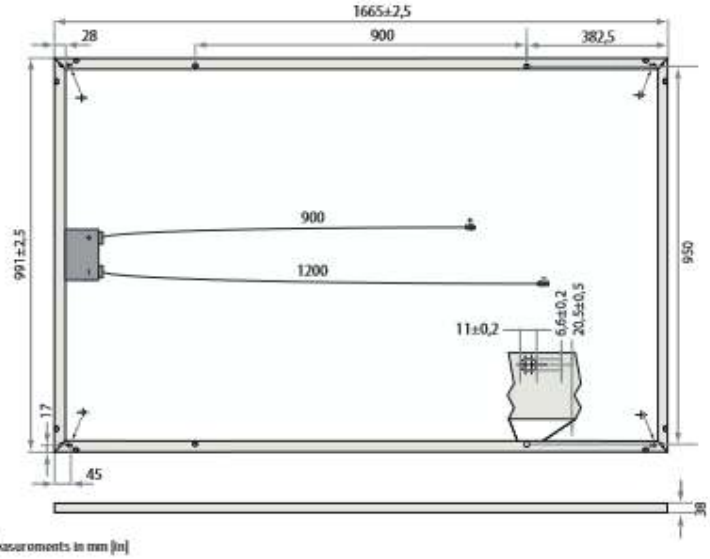
MODULE DIMENSION DETAILS



[5] Dimensional tolerance: +/- 2 mm
[6] In accordance with IEC 61215 Ed. 2
[7] According to the current warranty conditions of Astronergy Solarmodule GmbH

© Astronergy Solarmodule GmbH
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All rights reserved.

REC PEAK ENERGY SERIES



Measurements in mm [in]

16.7% EFFICIENCY

10 YEAR PRODUCT WARRANTY

25 YEAR LINEAR POWER OUTPUT WARRANTY

GENERAL DATA

Cell type:	60 multicrystalline cells 3 strings of 20 cells in series
Glass:	3.2 mm solar glass with anti-reflection surface treatment
Backsheet:	Highly resistant polyester
Frame:	Anodized aluminum (silver / black)
Junction box:	3 bypass diodes, IP67 rated in accordance with IEC 62790
Cable:	4 mm² solar cable, 0.9 m + 1.2 m in accordance with EN 50618
Connectors:	Staubli MC4 PV-KBT4/PV-KST4 (4 mm²) Tonglin TL-Cable01S-FR (4 mm²) in accordance with IEC 62852, IP68 only when connected
Origin:	Made in Singapore

ELECTRICAL DATA @ STC

Product Code*: RECxxxPE						
Nominal Power - P_{MPP} (Wp)	250	255	260	265	270	275
Watt Class Sorting - (W)	-0/+5	-0/+5	-0/+5	-0/+5	-0/+5	-0/+5
Nominal Power Voltage - V_{MPP} (V)	30.2	30.5	30.7	30.9	31.2	31.5
Nominal Power Current - I_{MPP} (A)	8.30	8.42	8.50	8.58	8.66	8.74
Open Circuit Voltage - V_{OC} (V)	37.4	37.6	37.8	38.1	38.4	38.7
Short Circuit Current - I_{SC} (A)	8.86	8.95	9.01	9.08	9.18	9.25
Panel Efficiency (%)	15.2	15.5	15.8	16.1	16.4	16.7

Values at standard test conditions (STC: air mass AM 1.5, irradiance 1000 W/m², temperature 25°C), based on a production spread with a tolerance of V_{OC} & I_{SC} ±3% within one watt class. At low irradiance of 200 W/m² at least 95.5% of the STC module efficiency will be achieved. *Where xxx indicates the nominal power class (P_{MPP}) at STC indicated above, and can be followed by the suffix BLK for black framed modules.

MAXIMUM RATINGS

Operational temperature:	-40 ... +85°C
Maximum system voltage:	1000 V
Design load (+): snow Maximum test load (+):	367 kg/m² (3600 Pa)* 550 kg/m² (5400 Pa)
Design load (-): wind Maximum test load (-):	163 kg/m² (1600 Pa)* 244 kg/m² (2400 Pa)
Max series fuse rating:	25 A
Max reverse current:	25 A

*Safety factor 1.5

ELECTRICAL DATA @ NMOT

Product Code*: RECxxxPE						
Nominal Power - P_{MPP} (Wp)	183	187	190	193	196	202
Nominal Power Voltage - V_{MPP} (V)	27.8	28.0	28.2	28.4	28.6	28.8
Nominal Power Current - I_{MPP} (A)	6.58	6.68	6.74	6.80	6.86	7.02
Open Circuit Voltage - V_{OC} (V)	34.7	34.8	35.0	35.3	35.7	36.0
Short Circuit Current - I_{SC} (A)	7.11	7.18	7.23	7.29	7.35	7.40

Nominal module operating temperature (NMOT: air mass AM 1.5, irradiance 800 W/m², temperature 20°C, windspeed 1 m/s). *Where xxx indicates the nominal power class (P_{MPP}) at STC indicated above, and can be followed by the suffix BLK for black framed modules.

TEMPERATURE RATINGS*

Nominal Module Operating Temperature:	45.7°C (±2°C)
Temperature coefficient of P_{MPP}:	-0.40 %/°C
Temperature coefficient of V_{OC}:	-0.27 %/°C
Temperature coefficient of I_{SC}:	0.024 %/°C

*The temperature coefficients stated are linear values

CERTIFICATIONS

IEC 61215, IEC 61730 & UL 1703, MCS 005, IEC 62804 (PID)
IEC 62716 (Ammonia Resistance), IEC 60068-2-68 (Blowing Sand)
IEC 61701 (Salt Mist level 6), UNI 8457/9174 (Class A), ISO 11925-2 (Class E)
ISO 9001: 2015, ISO 14001: 2004, OHSAS 18001: 2007

take-e-way WEEE-compliant recycling scheme

WARRANTY

10 year product warranty
25 year linear power output warranty
(max. degression in performance of 0.7% p.a.)
See warranty conditions for further details.

MECHANICAL DATA

Dimensions:	1665 x 991 x 38 mm
Area:	1.65 m²
Weight:	18 kg

Specifications subject to change without notice.
Ref: NE-05-07-07 Rev-F 08.17

Founded in Norway in 1996, REC is a leading vertically integrated solar energy company. Through integrated manufacturing from silicon to wafers, cells, high-quality panels and extending to solar solutions, REC provides the world with a reliable source of clean energy. REC's renowned product quality is supported by the lowest warranty claims rate in the industry. REC is a Bluestar Elkem company with headquarters in Norway and operational headquarters in Singapore. REC employs more than 2,000 people worldwide, producing 1.4 GW of solar panels annually.

REC
www.recgroup.com

Appendix n°2 : List of batteries compatibles with Sunny Island 6.OH

The lithium-ion batteries of the following manufacturers are approved for the SMA Flexible Storage System with the Sunny Island 3.0M / 4.4M / 6.0H / 8.0H:

			Self-consumption systems			Battery backup systems			Off-grid systems		
Manufacturer	Type	as of firmware	1~	3~	Comment	1~	3~	Comment	1~	3~	Comment
ADS-TEC	StoraXe® Home & Small Business SRS0009	-	✓	-	-	✓	-	-	-	-	-
Akasol	neeoQube	-	✓	-	-	-	-	-	-	-	-
	neeoRack	-	✓	✓	-	✓	✓	Only for Sunny Island 3.0M and 4.4M	✓	✓	Only for Sunny Island 3.0M and 4.4M
Axitec	AXITEC AXIstorage Li7S	2.04	✓	✓	-	✓	✓	-	✓	✓	Emergency power generator
	AXITEC AXIstorage Li9S	2.06	✓	✓	-	✓	✓	-	✓	✓	Emergency power generator
	AXITEC AXIstorage Li10S	2.06	✓	✓	-	✓	✓	-	✓	✓	Emergency power generator
BMZ	BMZ ESS 3.0	2.04	✓	✓	-	✓	✓	-	✓	✓	-
	BMZ ESS 7.0	2.04	✓	✓	-	✓	✓	-	✓	✓	Emergency power generator
	BMZ ESS 9.0	2.06	✓	✓	-	✓	✓	-	✓	✓	Emergency power generator
	BMZ ESS X	2.06	✓	✓	-	✓	✓	-	✓	✓	Emergency power generator
BYD	B-BOX	2.7	✓	✓	-	✓	✓	-	✓	✓	-
	Battery-Box LV	1.0	✓	✓	-	✓	✓	3~ only for Sunny Island 4.4M	-	-	-
	Battery-Box Premium LVL 15.4	BMU: 1.8 BMS: B-1.3	✓	✓	-	✓	✓	-	✓	✓	-
	Battery-Box Premium LVS 4.0-24.0	BMU: 1.18 BMS: 1.8	✓	✓	-	✓	✓	-	✓	✓	-
Cegasa	eBick PRO 280	3.2.0	✓	✓	-	✓	✓	-	✓	✓	-
GS HUB	HomeHub (MU8G1 + BU25G1);	MU > 8.5 BU > 3.13	✓	✓	3~ only for Sunny Island 4.4M***	✓	-	-	✓	-	-
GNB	Sonnenschein lithium	2.06	✓	✓	-	✓	✓	-	✓	✓	Emergency power generator
Hoppecke	sun|powerpack premium	1.1.0 r11767	✓	✓	-	✓	✓	-	✓	✓	-
IBC	SolStore X.X Li	2.06	✓	✓	-	✓	✓	-	✓	✓	Emergency power generator
Leclanché	Apollion Cube	2.06	✓	✓	-	✓	✓	-	✓	✓	Emergency power generator
LG Energy Solution	RESU 5.0	-	✓	-	-	-	-	-	-	-	-
	RESU 6.4	-	✓	-	Recommended for Sunny Island 3.0M and 4.4M	✓	-	Only for Sunny Island 3.0M and 4.4M	-	-	-
	RESU 3.3	-	✓	-	Only for Sunny Island 3.0M and 4.4M	-	-	-	-	-	-
	RESU 6.5	-	✓	-	-	✓	-	Only for Sunny Island 3.0M	-	-	-
	RESU 10	-	✓	-	-	✓	-	Only for Sunny Island 3.0M and 4.4M	-	-	-
	RESU 12*	2.0.0.0	✓	-	-	✓	-	Only for Sunny Island 4.4M and 6.0H	-	-	-
	RESU 13*	1.7.0.3	✓	-	-	✓	-	Only for Sunny Island 4.4M and 6.0H	-	-	-
	RESU Plus Extension Kit (accessory for parallel connection of 2 RESU batteries)**	-	✓	-	-	✓	-	Only for Sunny Island 3.0M and 4.4M	-	-	-
Mercedes-Benz Energy GmbH	Mercedes-Benz Energiespeicher Home	29.30 - 5.X	✓	-	Recommended for Sunny Island 3.0M and 4.4M	✓	-	Only for Sunny Island 3.0M and 4.4M	-	-	-
	Mercedes-Benz Energy Storage Home (2.0)	10.xx	✓	-	-	-	-	-	-	-	-
Murata	Murata PLC-BMU Solution with IJ1101M	-	-	-	-	-	-	-	✓	✓	-
Pylontech	US2000 US2000C	2.9 2.1	✓	✓	-	✓	✓	-	✓	✓	When used in a off-grid system, the battery protection mode level 3 must not be set below 4 % on the inverter.
	US3000 US3000C	2.9 2.1	✓	✓	-	✓	✓	-	✓	✓	
	US5000	1.0	✓	✓	-	✓	✓	-	✓	✓	
	US5000B	1.0	✓	✓	-	✓	✓	-	✓	✓	
	UP5000	2.1	✓	✓	-	✓	✓	-	✓	✓	
Sony	Controller IJ1004C Module fORTELION IJ1001M	-	✓	✓	-	✓	✓	-	✓	✓	-
SSL Energie GmbH	eSafe©	1.0.35	✓	✓	-	✓	✓	-	✓	✓	-
Tesvolt	Tesvolt Lithium-Ion storage Li10	3.17	✓	✓	-	✓	✓	-	✓	✓	-
	Tesvolt Lithium-Ion storage Li 20 and higher	1.11	✓	✓	-	✓	✓	-	✓	✓	-
	TS-Series	1.06	✓	✓	-	✓	✓	-	✓	✓	-

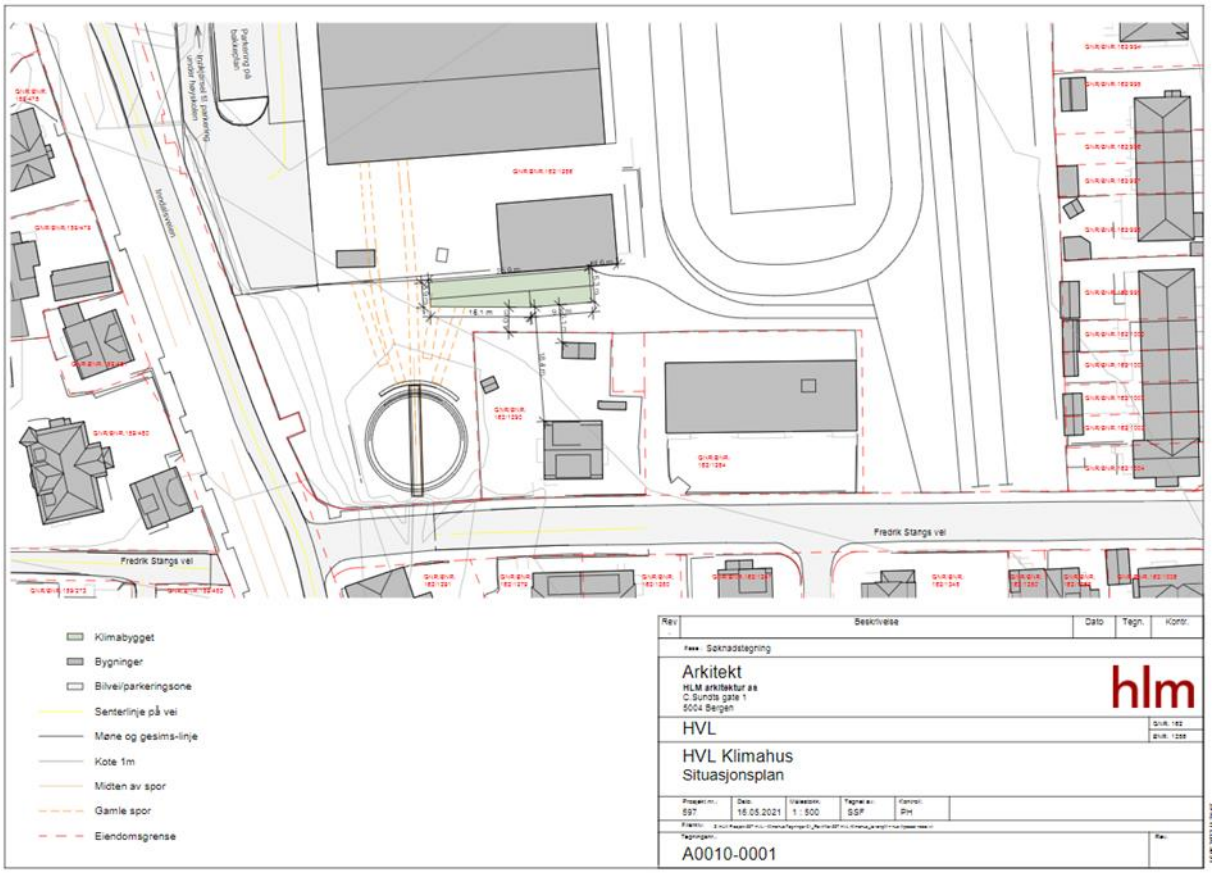
Appendix n°3 : Pricing analysis for batteries

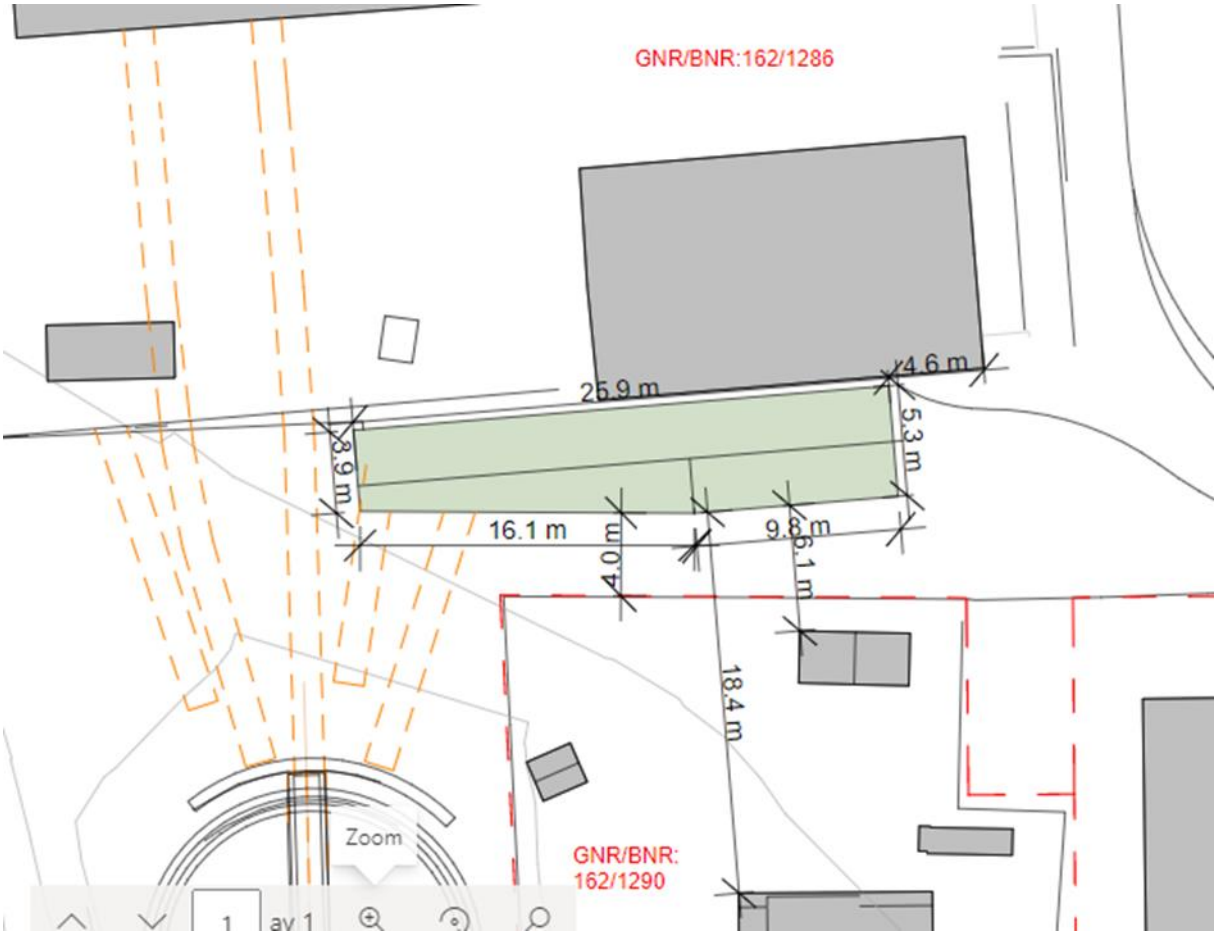
BYD Battery Box Premium LVS 4.0				
Quantity	1			
Price	2 375,84 €			
BYD Battery-Box Premium LVS Extension module 4 kWh				
Quantity	1	2	3	4
Power	8 kW	12 kW	16 kW	20 kW
Price	1 691,58 €	3 383,16 €	5 074,74 €	6 766,32 €
UPS Expedited	100,85 €	142,79 €	153,94 €	188,89 €
Taxes VAT	705,92 €	999,50 €	1 293,08 €	1 586,66 €
Total cost (BYD Battery Box Premium + Extension)	**4 168,27 €**	**5 901,79 €**	**7 604,52 €**	**9 331,05 €**
Money save	-	**0,00 €**	**62,91 €**	**111,84 €**

BATTERIE SIZE CALCULATION

BYD Battery-Box Premium LVS				
Power	8 kW	12 kW	16 kW	24 kW
Subtotal	4 434,65 €	6 352,50 €	8 252,20 €	10 309,20 €
UPS Expedited	109,95 €	131,25 €	170,50 €	213 €
Taxes VAT	769,65 €	1 102,50 €	1 432,20 €	1 789,20 €
Total cost	**4 544,60 €**	**6 483,75 €**	**8 422,70 €**	**10 522,20 €**

Appendix n°4 : climate house map





Appendix n°5 : Solar Softwares comparaison

Høgskulen på Vestlandet

Comparison of software packages for the design and simulation of solar photovoltaic systems

- HomerPro
- RETScreen
- Pvsyst
- Archelios
- Skelion Pro

The purpose of this software comparison is to find the software that best meets the project's expectations.

The aim of the solar laboratory project is to determine the ideal location on the HVL campus according to the brightness of the sun.

The comparison of the software is based on their general functionality and on the price of the licences.

1

Høgskulen på Vestlandet

HomerPro

The HOMER Pro® microgrid software by HOMER Energy is the global standard for optimizing microgrid design in all sectors, from village power and island utilities to grid-connected campuses and military bases.

HOMER Pro
STANDALONE MICROGRIDS

General aspects	Default
Simulate multiple energy sources : solar, geothermal, fuel cells, ect.	Basics functions
	Not specifically designed for solar PV. Does not generate IV curve data or perform shading analysis. Does not have any shading analysis or reporting functions.
Price $125,00 per month	Not intuitive to use and too many parameters to add manually.
	No possibility of 3D simulation

2

Høgskulen på Vestlandet

RETScreen

Developed by National Resources Canada, it is an Excel-based clean energy project analysis software tool that helps decision-makers quickly and inexpensively determine the technical and financial viability of potential renewable energy, energy efficiency

General aspects	Default
Calculate the photovoltaic energy production according to the location, analyse the costs and determine the feasibility of the project. Fairly easy to use as it is an ordinary Excel spreadsheet,	Restricted weather data Does not have any shading analysis or reporting functions. There is no possibility to add other data sources, custom solar module or inverter data. No possibility of 3D simulation Free software

3

Høgskulen på Vestlandet

PVSyst

This software is considered a standard for the design and simulation of photovoltaic systems worldwide.

General aspects	Default
Rapid production estimation at the project planning stage, detailed design, sizing, hourly estimation and reporting are its main features. Practical design tool for PV system design and estimation. Import from external CAD tools (Sketchup, Helios 3D, AutoCAD, etc).	Does not provide any visual evidence of shading, Free version is for simulate installations up to 30 kW $1351 per year for illimited version

4

Archelios

This PV software permits to evaluate solar radiation of a site, to design a photovoltaic system and calculate the energy produced and the profitability.

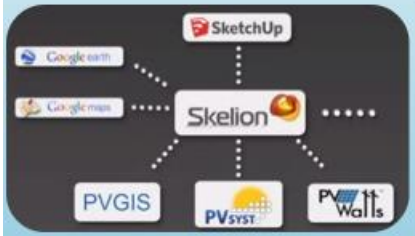
archelios PRO

General aspects	Default
Feasibility and profitability studies, simulations, production calculations, complete electrical sizing, the application is intended for all types of projects.	Archelios is for projects up to 50kWp Archelios Pro is for projects of any size. No shadow analysis Base Price : 690 EUR for Archelios 990 EUR for Archelios PRO for one year

5

Skelion Pro

Skelion, is a Sketchup's plugin to insert solar photovoltaics and thermal components in a surface.
Skelion plugin gives Sketchup the possibility to insert solar panels and make renewable solar energy studies. Skelion allows to insert 3D models of the solar installation, use the PV Modules data base or add own mode, yoad the current location from Google Earth



General aspects	
Minimal shading criteria, Solar obstructions can be projected over the roof with two different criterias (distance - height or solstice shadow) to determine the area that accomplish the criteria. Calculate shading losses using hourly meteorological data, Skelion calculates the percentage of solar energy available for each panel taking into account near shadings.	Import 3D Sketchup mesh and insert solar component on the building. Generate a PV energy report with PV calculator. For one year : 1 license : $200 USD 2 license : $350 USD 3 license : $400 USD

6

Appendixn° 6 : PVGIS report 2 SolarLab location



Performance of Grid-connected PV

PVGIS estimates of solar electricity generation

Latitude,Longitude: 60.36674985511809 5.347189964784775
N/A N/A

Faces analysis

Faces global results							
Solar panels	**N°P.**	**P. power (Wp)**	**P.weight (kg)**	**Power (kWp)**	**Energy (kWh)**	**Yield (kWh/kWp)**	**Shading L. (%)**
Poly:Poly	12	275.00	18.00	3.30	2477.53	750.77	3.42
Violon crystalline PV Module:Mono	12	285.00	18.20	3.42	2589.25	757.09	2.61

Results for solar modules in each face												
Face	**Model**	**N°P.**	**P. power (Wp)**	**Power (kWp)**	**Weight (kg)**	**Azimuth**	**Tilt**	**Relative tilt**	**Energy (kWh)**	**Yield (kWh/kWp)**	**ΣH_m (kWh/m^2/year)**	**Shading L. (%)**
1_1	Poly:Poly	6	275.00	1.65	108.00	173.58	35.00	35.00	1238.76	750.77	950.77	1.06
1_2	Violon crystalline PV Module:Mono	6	285.00	1.71	109.20	173.58	35.00	35.00	1294.62	757.09	950.77	0.27
2_1	Poly:Poly	6	275.00	1.65	108.00	173.58	35.00	35.00	1238.76	750.77	950.77	5.78
2_2	Violon crystalline PV Module:Mono	6	285.00	1.71	109.20	173.58	35.00	35.00	1294.62	757.09	950.77	4.94

Monthly Shading Losses (%)												
Face	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1_1	18.81	2.24	0.51	0.76	0.85	0.00	0.13	0.90	0.23	1.11	8.68	18.20
1_2	0.00	2.24	0.50	0.03	0.00	0.00	0.00	0.12	0.01	1.09	2.12	8.57
2_1	56.08	2.04	2.28	4.14	6.25	5.66	4.59	3.32	2.01	3.26	28.17	52.10
2_2	13.35	2.52	2.44	3.63	6.75	5.61	4.96	4.06	1.71	1.57	4.40	52.10
Mean	22.06	2.26	1.43	2.14	3.46	2.82	2.42	2.10	0.99	1.76	10.84	32.74

E_d (kWh/day)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1_1	0.53	1.62	3.24	5.16	6.33	6.86	5.68	4.70	3.15	2.22	0.82	0.32
1_2	0.56	1.70	3.38	5.40	6.62	7.16	5.94	4.91	3.29	2.32	0.86	0.34
2_1	0.53	1.62	3.24	5.16	6.33	6.86	5.68	4.70	3.15	2.22	0.82	0.32
2_2	0.56	1.70	3.38	5.40	6.62	7.16	5.94	4.91	3.29	2.32	0.86	0.34
∑	2.17	6.63	13.23	21.11	25.89	28.04	23.25	19.21	12.88	9.10	3.37	1.31

E_m (kWh/month)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1_1	16.42	45.39	100.32	154.81	196.28	205.70	176.16	145.60	94.44	68.98	24.73	9.94
1_2	17.16	47.44	104.84	161.79	205.13	214.97	184.10	152.16	98.70	72.09	25.84	10.40
2_1	16.42	45.39	100.32	154.81	196.28	205.70	176.16	145.60	94.44	68.98	24.73	9.94
2_2	17.16	47.44	104.84	161.79	205.13	214.97	184.10	152.16	98.70	72.09	25.84	10.40
∑	67.18	185.66	410.30	633.20	802.82	841.33	720.53	595.53	386.26	282.14	101.15	40.68

H_d (kWh/m^2/day)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1_1	0.41	1.20	2.40	3.88	4.82	5.29	4.47	3.68	2.46	1.69	0.63	0.25
1_2	0.41	1.20	2.40	3.88	4.82	5.29	4.47	3.68	2.46	1.69	0.63	0.25
2_1	0.41	1.20	2.40	3.88	4.82	5.29	4.47	3.68	2.46	1.69	0.63	0.25
2_2	0.41	1.20	2.40	3.88	4.82	5.29	4.47	3.68	2.46	1.69	0.63	0.25
Mean	0.41	1.20	2.40	3.88	4.82	5.29	4.47	3.68	2.46	1.69	0.63	0.25

H_m (kWh/m^2/month)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1_1	12.58	33.49	74.55	116.39	149.56	158.59	138.63	113.98	73.66	52.54	18.94	7.86
1_2	12.58	33.49	74.55	116.39	149.56	158.59	138.63	113.98	73.66	52.54	18.94	7.86
2_1	12.58	33.49	74.55	116.39	149.56	158.59	138.63	113.98	73.66	52.54	18.94	7.86
2_2	12.58	33.49	74.55	116.39	149.56	158.59	138.63	113.98	73.66	52.54	18.94	7.86
Mean	12.58	33.49	74.55	116.39	149.56	158.59	138.63	113.98	73.66	52.54	18.94	7.86

Yearly average				
Face	Edy (kWh/day)	Emy (kWh/month)	Hdy (kWh/m^2/day)	Hmy (kWh/m^2/month)
1_1	3.40	103.23	2.60	79.23
1_2	3.54	107.88	2.60	79.23
2_1	3.40	103.23	2.60	79.23
2_2	3.54	107.88	2.60	79.23
∑ or Mean	13.88	422.23	2.60	79.23

Groups analysis

Groups global results						
Solar panels	**N°P.**	**P. power (Wp)**	**Power (kWp)**	**Energy (kWh)**	**Yield (kWh/kWp)**	**Shading L. (%)**
Poly:Poly	12	275.00	3.30	2477.53	750.77	3.42
Violon crystalline PV Module:Mono	12	285.00	3.42	2589.25	757.09	2.61

Results for solar modules in each group (grouped by same tilt, azimuth and panel model)										
Group	**Model**	**N°P.**	**P. power (Wp)**	**Power (kWp)**	**Azimuth**	**Tilt**	**Energy (kWh)**	**Yield (kWh/kWp)**	**$\sum H_m$ (kWh/m^2/year)**	**Shading L. (%)**
1	Violon crystalline PV Module:Mono	12	285.00	3.42	173.58	35.00	2589.25	757.09	950.77	2.61
2	Poly:Poly	12	275.00	3.30	173.58	35.00	2477.53	750.77	950.77	3.42

Estimated system losses											
Group	**Soiling**	**Shading**	**Snow**	**Mismatch**	**Wiring**	**Connections**	**LID**	**Nameplate r.**	**Age**	**Syst. avai.**	**ESL**
1	2.00	2.61	0.00	2.00	2.00	0.50	1.50	1.00	0.00	3.00	13.73
2	2.00	3.42	0.00	2.00	2.00	0.50	1.50	1.00	0.00	3.00	14.45
Default	2.00	3.00	0.00	2.00	2.00	0.50	1.50	1.00	0.00	3.00	14.08

Combined system losses (%)				
Group	**T°**	**Refl.**	**Other**	**CSL**
1	-3.11	0.00	-4.74	-20.37
2	-3.11	0.00	-4.74	-21.03

Provided data				
Group	**Database**	**Module Type**	**Array Type**	**Calculate horizon**
1	PVGIS-SARAH	crystSi	Fixed (free-standing)	Yes
2	PVGIS-SARAH	crystSi	Fixed (free-standing)	Yes

Standard deviation of the monthly energy production due to year-to-year variation (kWh)													
Group	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
1	17.81	37.63	64.47	25.74	73.99	73.21	55.37	31.02	50.64	37.94	19.60	7.88	17.34
2	17.04	36.01	61.69	24.63	70.80	70.05	52.98	29.68	48.45	36.30	18.76	7.54	16.59

Monthly Shading Losses (%)												
Group	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	6.68	2.38	1.47	1.83	3.38	2.80	2.48	2.09	0.86	1.33	3.26	30.33
2	37.44	2.14	1.40	2.45	3.55	2.83	2.36	2.11	1.12	2.18	18.42	35.15
Mean	22.06	2.26	1.43	2.14	3.46	2.82	2.42	2.10	0.99	1.76	10.84	32.74

E_d (kWh/day)												
Group	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	1.11	3.39	6.76	10.79	13.23	14.33	11.88	9.82	6.58	4.65	1.72	0.67
2	1.06	3.24	6.47	10.32	12.66	13.71	11.37	9.39	6.30	4.45	1.65	0.64
∑	2.17	6.63	13.23	21.11	25.89	28.04	23.25	19.21	12.88	9.10	3.37	1.31

E_m (kWh/month)												
Group	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	34.33	94.88	209.67	323.58	410.26	429.94	368.21	304.33	197.39	144.18	51.69	20.79
2	32.85	90.78	200.63	309.62	392.56	411.39	352.32	291.20	188.87	137.96	49.46	19.89
∑	67.18	185.66	410.30	633.20	802.82	841.33	720.53	595.53	386.26	282.14	101.15	40.68

H_d (kWh/m^2/day)												
Group	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	0.41	1.20	2.40	3.88	4.82	5.29	4.47	3.68	2.46	1.69	0.63	0.25
2	0.41	1.20	2.40	3.88	4.82	5.29	4.47	3.68	2.46	1.69	0.63	0.25
Mean	0.41	1.20	2.40	3.88	4.82	5.29	4.47	3.68	2.46	1.69	0.63	0.25

H_m (kWh/m^2/month)												
Group	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	12.58	33.49	74.55	116.39	149.56	158.59	138.63	113.98	73.66	52.54	18.94	7.86
2	12.58	33.49	74.55	116.39	149.56	158.59	138.63	113.98	73.66	52.54	18.94	7.86
Mean	12.58	33.49	74.55	116.39	149.56	158.59	138.63	113.98	73.66	52.54	18.94	7.86

Yearly average				
Group	**Edy (kWh/day)**	**Emy (kWh/month)**	**Hdy (kWh/m^2/day)**	**Hmy (kWh/m^2/month)**
1	7.09	215.77	2.60	79.23
2	6.79	206.46	2.60	79.23
∑ or Mean	13.88	422.23	2.60	79.23

Nomenclature:

T°: Estimated losses due to temperature (using local ambient temperature).
Refl.: Estimated loss due to angular reflectance effects.
Other: Other losses (cables, inverter etc.)
CSL: Combined PV system losses.
N°P.: Number of panels.
P.power: Power of the solar panel (Wp).
Power: Nominal power of the given system (KWp).
Energy: AC energy (kWh).
Yield: Ratio between power and energy (kWh/kWp).
Face: Number assigned to the face with the solar array. (Activate layer TX:Face_names to see what it is).
Group: Number of the group of solar panels with same tilt, azimuth and model. Azimuth: Solar panel azimuth in grades.
Tilt: Solar panel tilt in grades.
Relative tilt: Angle between solar panel and roof in grades.
Shading losses = 100*(1 - solar energy that is potentially available at model site divided by the solar energy really receives solar panel due to shadows).
Solar Access =1 - Shading losses
E_d: Average daily electricity production from the given system (kWh/day).
E_m: Average monthly electricity production from the given system (kWh/month).
H_d: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2/day).
H_m: Average monthly sum of global irradiation per square meter received by the modules of the given system (kWh/m^2/month).
E_{dy}: Yearly average of E_d (kWh/day).
E_{my}: Yearly average of E_m (kWh/month).
H_{dy}: Yearly average of H_d (kWh/m^2/day).
H_{my}: Yearly Average of H_m (kWh/m^2/month).
$\sum H_m$: Yearly sum of H_m (kWh/m^2/year).

Appendix n°7 : PVWATTS report 2 SolarLab location



Results

Station and Model info							
	Lat	Lon	Elevation (m)	TZ	City	Country	Resource file
Station or Grid	60.299999	5.220000	50.00	1.0	Bergen	NOR	013110.tm3
Model	60.366750	5.347190	0.00	0.0	N/A	N/A	
Distance (km)	10.203						

Faces analysis

Faces global results							
Solar panels	N°P.	P. power (Wp)	P.weight (kg)	DC r. (kWp)	Energy (kWh)	Yield (kWh/kWp)	Shading L. (%)
Poly:Poly	12	275.00	18.00	3.30	2279.87	690.87	3.42
Violon crystalline PV Module:Mono	12	285.00	18.20	3.42	2383.18	696.84	2.61

Results for solar modules in each face												
Face	Model	N°P.	P. power (Wp)	DC r. (kWp)	Weight (kg)	Azimuth	Tilt	Relative tilt	Energy (kWh)	Yield (kWh/kWp)	$\sum H_m$ (kWh/m^2/year)	Shading L. (%)
1_1	Poly:Poly	6	275.00	1.65	108.00	173.58	35.00	35.00	1139.93	690.87	839.01	1.06
1_2	Violon crystalline PV Module:Mono	6	285.00	1.71	109.20	173.58	35.00	35.00	1191.59	696.84	839.01	0.27
2_1	Poly:Poly	6	275.00	1.65	108.00	173.58	35.00	35.00	1139.93	690.87	839.01	5.78
2_2	Violon crystalline PV Module:Mono	6	285.00	1.71	109.20	173.58	35.00	35.00	1191.59	696.84	839.01	4.94

Monthly Shading Losses (%)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1_1	18.81	2.24	0.51	0.76	0.85	0.00	0.13	0.90	0.23	1.11	8.68	18.20
1_2	0.00	2.24	0.50	0.03	0.00	0.00	0.00	0.12	0.01	1.09	2.12	8.57
2_1	56.08	2.04	2.28	4.14	6.25	5.66	4.59	3.32	2.01	3.26	28.17	52.10
2_2	13.35	2.52	2.44	3.63	6.75	5.61	4.96	4.06	1.71	1.57	4.40	52.10
Mean	22.06	2.26	1.43	2.14	3.46	2.82	2.42	2.10	0.99	1.76	10.84	32.74

E_d (kWh/day)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1_1	0.48	1.30	2.52	4.32	6.56	6.54	5.55	4.56	2.90	1.78	0.60	0.26
1_2	0.50	1.36	2.63	4.52	6.86	6.84	5.80	4.77	3.03	1.86	0.62	0.27
2_1	0.48	1.30	2.52	4.32	6.56	6.54	5.55	4.56	2.90	1.78	0.60	0.26
2_2	0.50	1.36	2.63	4.52	6.86	6.84	5.80	4.77	3.03	1.86	0.62	0.27
∑	1.96	5.31	10.30	17.67	26.84	26.77	22.69	18.65	11.85	7.29	2.44	1.06

E_m (kWh/month)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1_1	14.85	36.34	78.04	129.60	203.42	196.34	171.98	141.33	86.89	55.25	17.86	8.03
1_2	15.53	38.00	81.58	135.47	212.61	205.22	179.76	147.73	90.84	57.76	18.68	8.40
2_1	14.85	36.34	78.04	129.60	203.42	196.34	171.98	141.33	86.89	55.25	17.86	8.03
2_2	15.53	38.00	81.58	135.47	212.61	205.22	179.76	147.73	90.84	57.76	18.68	8.40
∑	60.75	148.68	319.25	530.15	832.05	803.13	703.48	578.13	355.46	226.03	73.07	32.85

H_d (kWh/m^2/day)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1_1	0.36	0.92	1.76	3.10	4.96	4.86	4.16	3.43	2.09	1.30	0.44	0.20
1_2	0.36	0.92	1.76	3.10	4.96	4.86	4.16	3.43	2.09	1.30	0.44	0.20
2_1	0.36	0.92	1.76	3.10	4.96	4.86	4.16	3.43	2.09	1.30	0.44	0.20
2_2	0.36	0.92	1.76	3.10	4.96	4.86	4.16	3.43	2.09	1.30	0.44	0.20
Mean	0.36	0.92	1.76	3.10	4.96	4.86	4.16	3.43	2.09	1.30	0.44	0.20

H_m (kWh/m^2/month)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1_1	11.01	25.65	54.61	93.04	153.72	145.81	129.05	106.46	62.81	40.34	13.12	6.24
1_2	11.01	25.65	54.61	93.04	153.72	145.81	129.05	106.46	62.81	40.34	13.12	6.24
2_1	11.01	25.65	54.61	93.04	153.72	145.81	129.05	106.46	62.81	40.34	13.12	6.24
2_2	11.01	25.65	54.61	93.04	153.72	145.81	129.05	106.46	62.81	40.34	13.12	6.24
Mean	11.01	25.65	54.61	93.04	153.72	145.81	129.05	106.46	62.81	40.34	13.12	6.24

Yearly average				
Face	Edy (kWh/day)	Emy (kWh/month)	Hdy (kWh/m^2/day)	Hmy (kWh/m^2/month)
1_1	3.12	94.99	2.30	69.92
1_2	3.26	99.30	2.30	69.92
2_1	3.12	94.99	2.30	69.92
2_2	3.26	99.30	2.30	69.92
∑ or Mean	12.78	388.59	2.30	69.92

Groups analysis

Groups global results

Solar panels	NºP.	P. power (Wp)	DC r. (kWp)	Energy (kWh)	Yield (kWh/kWp)	Shading L. (%)
Poly:Poly	12	275.00	3.30	2279.87	690.87	3.42
Violon crystalline PV Module:Mono	12	285.00	3.42	2383.18	696.84	2.61

Results for solar modules in each group (grouped by same tilt, azimuth and panel model)

Group	Model	NºP.	P. power (Wp)	DC r. (kWp)	Azimuth	Tilt	Energy (kWh)	Yield (kWh/kWp)	$\sum H_m$ (kWh/m^2/year)	Shading L. (%)
1	Violon crystalline PV Module:Mono	12	285.00	3.42	173.58	35.00	2383.18	696.84	839.01	2.61
2	Poly:Poly	12	275.00	3.30	173.58	35.00	2279.87	690.87	839.01	3.42

Estimated system losses

Group	Soiling	Shading	Snow	Mismatch	Wiring	Connections	LID	Nameplate r.	Age	Syst. avai.	ESL
1	2.00	2.61	0.00	2.00	2.00	0.50	1.50	1.00	0.00	3.00	13.73
2	2.00	3.42	0.00	2.00	2.00	0.50	1.50	1.00	0.00	3.00	14.45
Default	2.00	3.00	0.00	2.00	2.00	0.50	1.50	1.00	0.00	3.00	14.08

Provided data

Group	Database	Module Type	Array Type	dc_ac_ratio	inv_eff	gcr
1	intl	Standard	Fixed - Open Rack	1.1	97	
2	intl	Standard	Fixed - Open Rack	1.1	97	

Monthly Shading Losses (%)

Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	6.68	2.38	1.47	1.83	3.38	2.80	2.48	2.09	0.86	1.33	3.26	30.33
2	37.44	2.14	1.40	2.45	3.55	2.83	2.36	2.11	1.12	2.18	18.42	35.15
Mean	22.06	2.26	1.43	2.14	3.46	2.82	2.42	2.10	0.99	1.76	10.84	32.74

E_d (kWh/day)

Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.00	2.71	5.26	9.03	13.72	13.68	11.60	9.53	6.06	3.73	1.25	0.54
2	0.96	2.60	5.03	8.64	13.12	13.09	11.10	9.12	5.79	3.56	1.19	0.52
∑	1.96	5.31	10.30	17.67	26.84	26.77	22.69	18.65	11.85	7.29	2.44	1.06

E_m (kWh/month)

Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	31.06	76.00	163.17	270.94	425.22	410.44	359.53	295.46	181.67	115.53	37.36	16.80
2	29.69	72.69	156.08	259.21	406.83	392.68	343.96	282.66	173.79	110.50	35.72	16.05
∑	60.75	148.68	319.25	530.15	832.05	803.13	703.48	578.13	355.46	226.03	73.07	32.85

H_d (kWh/m^2/day)

Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.36	0.92	1.76	3.10	4.96	4.86	4.16	3.43	2.09	1.30	0.44	0.20
2	0.36	0.92	1.76	3.10	4.96	4.86	4.16	3.43	2.09	1.30	0.44	0.20
Mean	0.36	0.92	1.76	3.10	4.96	4.86	4.16	3.43	2.09	1.30	0.44	0.20

H_m (kWh/m^2/month)

Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	11.01	25.65	54.61	93.04	153.72	145.81	129.05	106.46	62.81	40.34	13.12	6.24
2	11.01	25.65	54.61	93.04	153.72	145.81	129.05	106.46	62.81	40.34	13.12	6.24
Mean	11.01	25.65	54.61	93.04	153.72	145.81	129.05	106.46	62.81	40.34	13.12	6.24

Yearly average

Group	Edy (kWh/day)	Emy (kWh/month)	Hdy (kWh/m^2/day)	Hmy (kWh/m^2/month)
1	6.53	198.60	2.30	69.92
2	6.25	189.99	2.30	69.92
∑ or Mean	12.78	388.59	2.30	69.92

Appendix n°8 : Unnelandsvegen first case study for Simona

Performance of Grid-connected PV

PVGIS estimates of solar electricity generation

Latitude,Longitude: 60.36811056829677 5.479216575622559
Bergen, NO Norway

Faces analysis

Faces global results							
Solar panels	N°P.	P. power (Wp)	P.weight (kg)	Power (kWp)	Energy (kWh)	Yield (kWh/kWp)	Shading L. (%)
florida:test	3429	1000.00	18.00	3429.00	2432234.64	709.31	0.05

Results for solar modules in each face												
Face	Model	N°P.	P. power (Wp)	Power (kWp)	Weight (kg)	Azimuth	Tilt	Relative tilt	Energy (kWh)	Yield (kWh/kWp)	$\sum H_m$ (kWh/m^2/year)	Shading L. (%)
1	florida:test	3429	1000.00	3429.00	61722.00	197.78	35.00	35.00	2432234.64	709.31	875.91	0.05

Monthly Shading Losses (%)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	0.00	0.20	0.16	0.02	0.00	0.00	0.10	0.08	0.00	0.00	0.00
Mean	0.00	0.00	0.20	0.16	0.02	0.00	0.00	0.10	0.08	0.00	0.00	0.00

E_d (kWh/day)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	522.50	2882.73	6652.48	10310.81	12505.37	13763.98	11612.35	9501.85	6348.68	4417.12	1149.74	89.05
∑	522.50	2882.73	6652.48	10310.81	12505.37	13763.98	11612.35	9501.85	6348.68	4417.12	1149.74	89.05

E_m (kWh/month)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	16197.40	80716.34	206226.76	309324.30	387666.45	412919.28	359982.70	294557.33	190460.53	136930.63	34492.30	2760.62
∑	16197.40	80716.34	206226.76	309324.30	387666.45	412919.28	359982.70	294557.33	190460.53	136930.63	34492.30	2760.62

H_d (kWh/m^2/day)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.21	1.01	2.31	3.63	4.46	4.96	4.27	3.48	2.32	1.58	0.43	0.06
Mean	0.21	1.01	2.31	3.63	4.46	4.96	4.27	3.48	2.32	1.58	0.43	0.06

H_m (kWh/m^2/month)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	6.56	28.18	71.48	108.77	138.28	148.87	132.35	107.88	69.66	48.96	12.98	1.94
Mean	6.56	28.18	71.48	108.77	138.28	148.87	132.35	107.88	69.66	48.96	12.98	1.94

Yearly average				
Face	Edy (kWh/day)	Emy (kWh/month)	Hdy (kWh/m^2/day)	Hmy (kWh/m^2/month)
1	6663.66	202686.22	2.40	72.99
∑ or Mean	6663.66	202686.22	2.40	72.99

Groups analysis

Groups global results						
Solar panels	N°P.	P. power (Wp)	Power (kWp)	Energy (kWh)	Yield (kWh/kWp)	Shading L. (%)
florida:test	3429	1000.00	3429.00	2432234.64	709.31	0.05

Results for solar modules in each group (grouped by same tilt, azimuth and panel model)										
Group	Model	N°P.	P. power (Wp)	Power (kWp)	Azimuth	Tilt	Energy (kWh)	Yield (kWh/kWp)	$\sum H_m$ (kWh/m^2/year)	Shading L. (%)
1	florida:test	3429	1000.00	3429.00	197.78	35.00	2432234.64	709.31	875.91	0.05

Estimated system losses											
Group	Soiling	Shading	Snow	Mismatch	Wiring	Connections	LID	Nameplate r.	Age	Syst. avai.	ESL
1	2.00	0.05	0.00	2.00	2.00	0.50	1.50	1.00	0.00	3.00	11.47
Default	2.00	3.00	0.00	2.00	2.00	0.50	1.50	1.00	0.00	3.00	14.08

Combined system losses (%)				
Group	T°	Refl.	Other	CSL
1	-3.31	0.00	-5.40	-19.02

Provided data				
Group	Database	Module Type	Array Type	Calculate horizon
1	PVGIS-SARAH	crystSi	Fixed (free-standing)	Yes

Standard deviation of the monthly energy production due to year-to-year variation (kWh)													
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1	9315.11	24818.60	60037.52	28853.54	75774.28	74181.24	55294.33	26611.97	56076.22	39353.93	11263.91	931.11	16875.51

Monthly Shading Losses (%)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	0.00	0.20	0.16	0.02	0.00	0.00	0.10	0.08	0.00	0.00	0.00
Mean	0.00	0.00	0.20	0.16	0.02	0.00	0.00	0.10	0.08	0.00	0.00	0.00

E_d (kWh/day)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	522.50	2882.73	6652.48	10310.81	12505.37	13763.98	11612.35	9501.85	6348.68	4417.12	1149.74	89.05
∑	522.50	2882.73	6652.48	10310.81	12505.37	13763.98	11612.35	9501.85	6348.68	4417.12	1149.74	89.05

E_m (kWh/month)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	16197.40	80716.34	206226.76	309324.30	387666.45	412919.28	359982.70	294557.33	190460.53	136930.63	34492.30	2760.62
∑	16197.40	80716.34	206226.76	309324.30	387666.45	412919.28	359982.70	294557.33	190460.53	136930.63	34492.30	2760.62

H_d (kWh/m^2/day)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.21	1.01	2.31	3.63	4.46	4.96	4.27	3.48	2.32	1.58	0.43	0.06
Mean	0.21	1.01	2.31	3.63	4.46	4.96	4.27	3.48	2.32	1.58	0.43	0.06

H_m (kWh/m^2/month)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	6.56	28.18	71.48	108.77	138.28	148.87	132.35	107.88	69.66	48.96	12.98	1.94
Mean	6.56	28.18	71.48	108.77	138.28	148.87	132.35	107.88	69.66	48.96	12.98	1.94

Yearly average				
Group	Edy (kWh/day)	Emy (kWh/month)	Hdy (kWh/m^2/day)	Hmy (kWh/m^2/month)
1	6663.66	202686.22	2.40	72.99
∑ or Mean	6663.66	202686.22	2.40	72.99

Appendix n°9 : Second case study on Unnelandsvegen field

Performance of Grid-connected PV

PVGIS estimates of solar electricity generation

Latitude,Longitude: 60.36811056829677 5.479216575622559
Bergen, NO Norway

Faces analysis

Faces global results

Solar panels	N°P.	P. power (Wp)	P.weight (kg)	Power (kWp)	Energy (kWh)	Yield (kWh/kWp)	Shading L. (%)
farm_test:farm	1897	385.00	18.00	730.34	677789.23	928.04	0.08

Results for solar modules in each face

Face	Model	N°P.	P. power (Wp)	Power (kWp)	Weight (kg)	Azimuth	Tilt	Relative tilt	Energy (kWh)	Yield (kWh/kWp)	$\sum H_m$ (kWh/m^2/year)	Shading L. (%)
1	farm_test:farm	1897	385.00	730.34	34146.00	197.78	30.00	30.00	677789.23	928.04	1126.36	0.08

Monthly Shading Losses (%)

Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	0.00	0.22	0.21	0.04	0.06	0.01	0.13	0.11	0.00	0.00	0.00
Mean	0.00	0.00	0.22	0.21	0.04	0.06	0.01	0.13	0.11	0.00	0.00	0.00

E_d (kWh/day)

Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	180.29	910.57	1882.94	2969.91	3545.08	3511.27	3181.62	2681.25	1837.44	1173.37	323.84	33.51
∑	180.29	910.57	1882.94	2969.91	3545.08	3511.27	3181.62	2681.25	1837.44	1173.37	323.84	33.51

E_m (kWh/month)

Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	5589.04	25495.91	58371.11	89097.37	109897.45	105337.96	98630.15	83118.64	55123.32	36374.45	9715.05	1038.78
∑	5589.04	25495.91	58371.11	89097.37	109897.45	105337.96	98630.15	83118.64	55123.32	36374.45	9715.05	1038.78

H_d (kWh/m^2/day)

Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.33	1.45	3.00	4.83	5.86	5.89	5.40	4.52	3.06	1.93	0.56	0.10
Mean	0.33	1.45	3.00	4.83	5.86	5.89	5.40	4.52	3.06	1.93	0.56	0.10

H_m (kWh/m^2/month)

Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	10.27	40.73	93.00	144.81	181.52	176.82	167.40	140.06	91.94	59.80	16.92	3.09
Mean	10.27	40.73	93.00	144.81	181.52	176.82	167.40	140.06	91.94	59.80	16.92	3.09

Yearly average

Face	Edy (kWh/day)	Emy (kWh/month)	Hdy (kWh/m^2/day)	Hmy (kWh/m^2/month)
1	1856.96	56482.44	3.09	93.86
∑ or Mean	1856.96	56482.44	3.09	93.86

Groups analysis

Groups global results						
Solar panels	N°P.	P. power (Wp)	Power (kWp)	Energy (kWh)	Yield (kWh/kWp)	Shading L. (%)
farm_test:farm	1897	385.00	730.34	677789.23	928.04	0.08

Results for solar modules in each group (grouped by same tilt, azimuth and panel model)										
Group	Model	N°P.	P. power (Wp)	Power (kWp)	Azimuth	Tilt	Energy (kWh)	Yield (kWh/kWp)	$\sum H_m$ (kWh/m^2/year)	Shading L. (%)
1	farm_test:farm	1897	385.00	730.34	197.78	30.00	677789.23	928.04	1126.36	0.08

Estimated system losses											
Group	Soiling	Shading	Snow	Mismatch	Wiring	Connections	LID	Nameplate r.	Age	Syst. avai.	ESL
1	2.00	0.08	0.00	2.00	2.00	0.50	1.50	1.00	0.00	3.00	11.49
Default	2.00	3.00	0.00	2.00	2.00	0.50	1.50	1.00	0.00	3.00	14.08

Combined system losses (%)				
Group	T°	Refl.	Other	CSL
1	-3.02	0.00	-4.01	-17.61

Provided data				
Group	Database	Module Type	Array Type	Calculate horizon
1	PVGIS-ERA5	crystSi	Fixed (free-standing)	Yes

Standard deviation of the monthly energy production due to year-to-year variation (kWh)													
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1	1271.41	6654.93	13298.19	7120.62	11683.69	14644.92	10075.22	7034.50	7210.49	6043.90	2253.34	266.42	2897.81

Monthly Shading Losses (%)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	0.00	0.22	0.21	0.04	0.06	0.01	0.13	0.11	0.00	0.00	0.00
Mean	0.00	0.00	0.22	0.21	0.04	0.06	0.01	0.13	0.11	0.00	0.00	0.00

E_d (kWh/day)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	180.29	910.57	1882.94	2969.91	3545.08	3511.27	3181.62	2681.25	1837.44	1173.37	323.84	33.51
∑	180.29	910.57	1882.94	2969.91	3545.08	3511.27	3181.62	2681.25	1837.44	1173.37	323.84	33.51

E_m (kWh/month)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	5589.04	25495.91	58371.11	89097.37	109897.45	105337.96	98630.15	83118.64	55123.32	36374.45	9715.05	1038.78
∑	5589.04	25495.91	58371.11	89097.37	109897.45	105337.96	98630.15	83118.64	55123.32	36374.45	9715.05	1038.78

H_d (kWh/m^2/day)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.33	1.45	3.00	4.83	5.86	5.89	5.40	4.52	3.06	1.93	0.56	0.10
Mean	0.33	1.45	3.00	4.83	5.86	5.89	5.40	4.52	3.06	1.93	0.56	0.10

H_m (kWh/m^2/month)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	10.27	40.73	93.00	144.81	181.52	176.82	167.40	140.06	91.94	59.80	16.92	3.09
Mean	10.27	40.73	93.00	144.81	181.52	176.82	167.40	140.06	91.94	59.80	16.92	3.09

Yearly average				
Group	Edy (kWh/day)	Emy (kWh/month)	Hdy (kWh/m^2/day)	Hmy (kWh/m^2/month)
1	1856.96	56482.44	3.09	93.86
∑ or Mean	1856.96	56482.44	3.09	93.86

Performance of Grid-connected PV

PVGIS estimates of solar electricity generation

Latitude,Longitude: 60.36811056829677 5.479216575622559
Bergen, NO Norway

Faces analysis

Faces global results							
Solar panels	N°P.	P. power (Wp)	P.weight (kg)	Power (kWp)	Energy (kWh)	Yield (kWh/kWp)	Shading L. (%)
farm_test:farm	1888	385.00	18.00	726.88	513027.34	705.79	0.10

Results for solar modules in each face											
Face	Model	N°P.	P. power (Wp)	Power (kWp)	Weight (kg)	Azimuth	Tilt	Relative tilt	Energy (kWh)	Yield (kWh/kWp)	$\sum H_m$ (kWh/m^2/year)	Shading L. (%)
1	farm_test:farm	1888	385.00	726.88	33984.00	197.78	30.00	30.00	513027.34	705.79	872.21	0.10

Monthly Shading Losses (%)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.50	0.00	0.21	0.20	0.04	0.06	0.01	0.12	0.11	0.01	0.00	1.27
Mean	0.50	0.00	0.21	0.20	0.04	0.06	0.01	0.12	0.11	0.01	0.00	1.27

E_d (kWh/day)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	106.08	583.31	1373.94	2171.37	2667.21	2948.58	2484.34	2016.31	1324.33	894.76	230.91	19.92
∑	106.08	583.31	1373.94	2171.37	2667.21	2948.58	2484.34	2016.31	1324.33	894.76	230.91	19.92

E_m (kWh/month)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	3288.34	16332.60	42592.19	65141.05	82683.47	88457.38	77014.45	62505.51	39729.85	27737.64	6927.19	617.67
∑	3288.34	16332.60	42592.19	65141.05	82683.47	88457.38	77014.45	62505.51	39729.85	27737.64	6927.19	617.67

H_d (kWh/m^2/day)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.21	0.97	2.25	3.60	4.48	5.01	4.31	3.48	2.29	1.52	0.42	0.06
Mean	0.21	0.97	2.25	3.60	4.48	5.01	4.31	3.48	2.29	1.52	0.42	0.06

H_m (kWh/m^2/month)												
Face	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	6.39	27.08	69.76	108.06	139.00	150.34	133.50	108.00	68.64	46.98	12.45	2.01
Mean	6.39	27.08	69.76	108.06	139.00	150.34	133.50	108.00	68.64	46.98	12.45	2.01

Yearly average				
Face	Edy (kWh/day)	Emy (kWh/month)	Hdy (kWh/m^2/day)	Hmy (kWh/m^2/month)
1	1405.55	42752.28	2.39	72.68
∑ or Mean	1405.55	42752.28	2.39	72.68

Groups analysis

Groups global results						
Solar panels	N°P.	P. power (Wp)	Power (kWp)	Energy (kWh)	Yield (kWh/kWp)	Shading L. (%)
farm_test:farm	1888	385.00	726.88	513027.34	705.79	0.10

Results for solar modules in each group (grouped by same tilt, azimuth and panel model)										
Group	Model	N°P.	P. power (Wp)	Power (kWp)	Azimuth	Tilt	Energy (kWh)	Yield (kWh/kWp)	$\sum H_m$ (kWh/m^2/year)	Shading L. (%)
1	farm_test:farm	1888	385.00	726.88	197.78	30.00	513027.34	705.79	872.21	0.10

Estimated system losses											
Group	Soiling	Shading	Snow	Mismatch	Wiring	Connections	LID	Nameplate r.	Age	Syst. avai.	ESL
1	2.00	0.10	0.00	2.00	2.00	0.50	1.50	1.00	0.00	3.00	11.50
Default	2.00	3.00	0.00	2.00	2.00	0.50	1.50	1.00	0.00	3.00	14.08

Combined system losses (%)				
Group	T°	Refl.	Other	CSL
1	-3.41	0.00	-5.34	-19.08

Provided data				
Group	Database	Module Type	Array Type	Calculate horizon
1	PVGIS-SARAH	crystSi	Fixed (free-standing)	Yes

Standard deviation of the monthly energy production due to year-to-year variation (kWh)													
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1	1850.96	4964.64	12107.31	5988.09	15984.64	15772.20	11639.30	5582.91	11444.14	7797.95	2219.57	207.08	3508.84

Monthly Shading Losses (%)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.50	0.00	0.21	0.20	0.04	0.06	0.01	0.12	0.11	0.01	0.00	1.27
Mean	0.50	0.00	0.21	0.20	0.04	0.06	0.01	0.12	0.11	0.01	0.00	1.27

E_d (kWh/day)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	106.08	583.31	1373.94	2171.37	2667.21	2948.58	2484.34	2016.31	1324.33	894.76	230.91	19.92
∑	106.08	583.31	1373.94	2171.37	2667.21	2948.58	2484.34	2016.31	1324.33	894.76	230.91	19.92

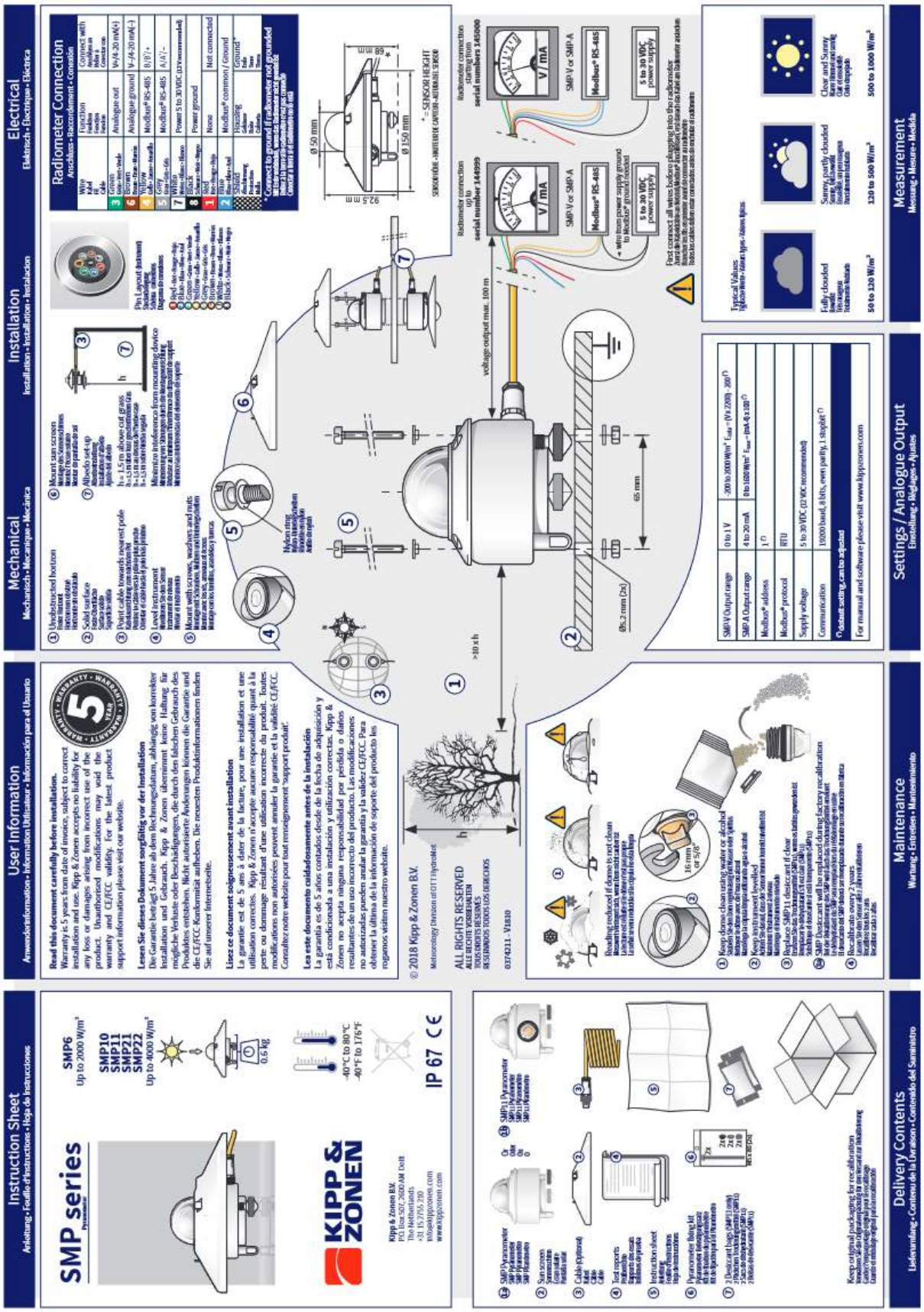
E_m (kWh/month)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	3288.34	16332.60	42592.19	65141.05	82683.47	88457.38	77014.45	62505.51	39729.85	27737.64	6927.19	617.67
∑	3288.34	16332.60	42592.19	65141.05	82683.47	88457.38	77014.45	62505.51	39729.85	27737.64	6927.19	617.67

H_d (kWh/m^2/day)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.21	0.97	2.25	3.60	4.48	5.01	4.31	3.48	2.29	1.52	0.42	0.06
Mean	0.21	0.97	2.25	3.60	4.48	5.01	4.31	3.48	2.29	1.52	0.42	0.06

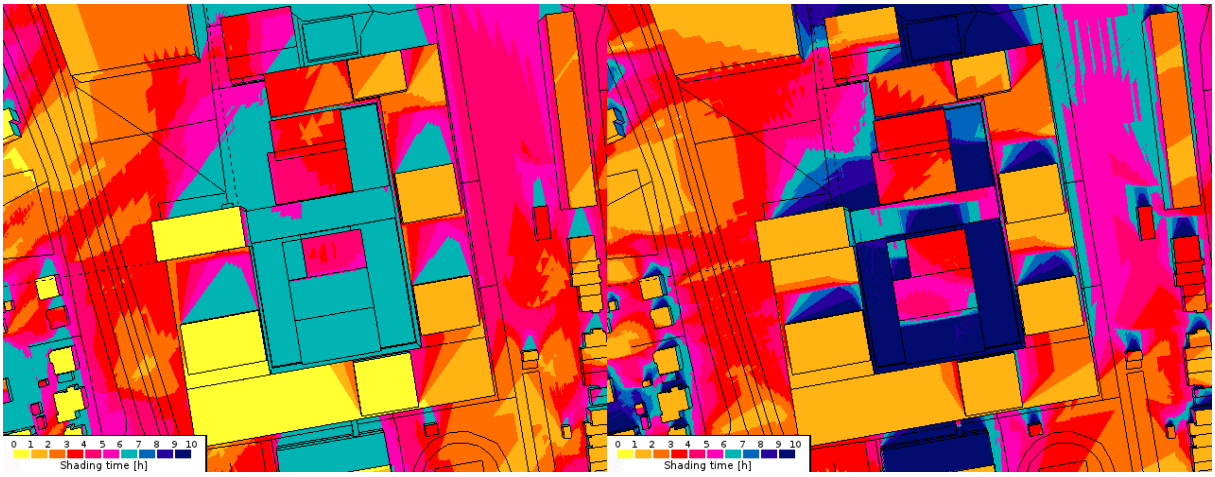
H_m (kWh/m^2/month)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	6.39	27.08	69.76	108.06	139.00	150.34	133.50	108.00	68.64	46.98	12.45	2.01
Mean	6.39	27.08	69.76	108.06	139.00	150.34	133.50	108.00	68.64	46.98	12.45	2.01

Yearly average				
Group	Edy (kWh/day)	Emy (kWh/month)	Hdy (kWh/m^2/day)	Hmy (kWh/m^2/month)
1	1405.55	42752.28	2.39	72.68
∑ or Mean	1405.55	42752.28	2.39	72.68

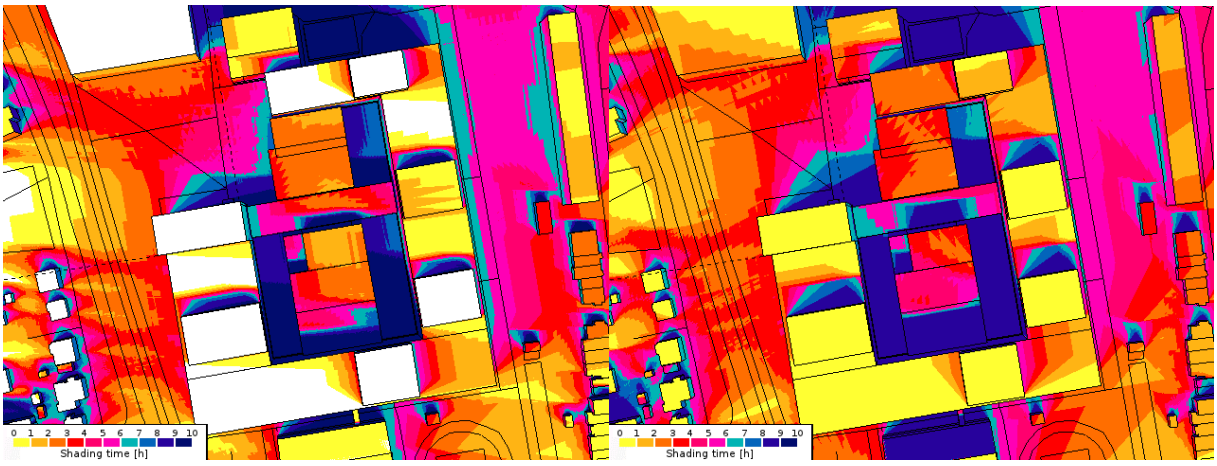
Appendix n°11 : Instruction sheet pyranometer SMP11



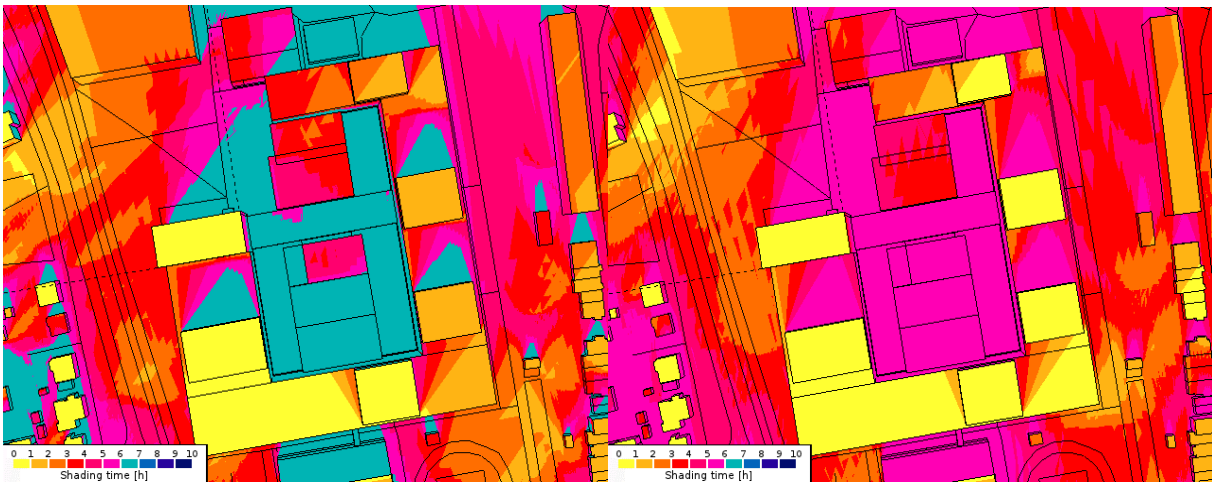
Appendix n°12 : Monthly Shadow analysis on the top of the campus



21 January 21 February



21 March 21 October



21 November 21 December