Tom BERNARD

Department of Mechanical and Marine Engineering

End of Master Project

SOLARLAB

Under the supervision of Richard John Grant (Professor Mechanical and Marine Engineering)

External examiner:

Jerome Soto (Professor Energy Engineering)

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Introduction

1. Context

Worldwide, energy use in buildings corresponds to 17.5% of Green House Gases (GHG) emitted by human activities. [1] In 2021, the total operation of building accounted for 27% of total emission of Green House Gases including production of electricity and heat use in buildings and direct emissions in buildings. In order to get on track with the Net Zero Emission by 2050 Scenario [2], the sector needs to evolve decarbonising its practices: using renewable energy, insulating better buildings (cf. appendix 4), a new standard for new buildings… For example, to boost energy performance of buildings, the EU has decided in 2018, to establish a legislative framework defining different measures that will enable reducing our GHG emissions. One of this measure is about new buildings and the ambitious vision to be zero emission.[3]

Since 1980's, the concept of passive houses[1] has been introduced by Pr.Wolfgang Feist, the purpose of this concept is mainly ecological: use as less energy as possible for heating, cooling, lighting a building. It requires many characteristics: very good insulation, orientation of the house, efficient electrical devices… Since 1996, all the standards required have been identified to establish a certification.

2. Solar Laboratory in Høgskulen på Vestlandet

The Solar Laboratory, located in the University Høgskulen på Vestlandet in Bergen (Norway) has been designed to satisfy all the standards of a passive house. The laboratory is 12 m², uses a CMV2 [2] to heat the space, produces 3.36 kWc of electricity with solar panels and stores the electricity that has not been used in a battery. The purpose of this solar laboratory is to be off grid, which means that it only uses electricity produced and stored by solar panels and the battery.

The actual photovoltaic system in the passive house is composed of 6 polycrystalline photovoltaic panels (REC Solar 275) with a production capacity of 275W per panel and 6 monocrystalline photovoltaic panels (ASM6610M 285 – Astroenergy) with a production capacity of 285 W per panel. To convert DC (Direct Current) current in AC (Alternating Current) current, 3 sunny boys inverters (1500W power) are used.

[1] *Passive House is a building standard that is truly energy efficient, comfortable, and affordable at thesame time.*
[2] Controlled Mechanival Ventilation

To store the electricity produced a Power Oak ES5048 battery with a capacity of 20 kWh is used and integrates a battery inverter in his system. This battery is an on/off-grid hybrid solar energy storage system and is composed of 1 to 8 modular Li-ion battery modules. The maximum storage

capacity is 20 kWh. Concerning this battery, some problems have been identified 2 years ago, the discharge was quick even without energy consumption and the battery inverter was not good quality. Finally, a Tigo optimizer is connected to each solar panel with TS4-O modules, this device enables to manage the efficiency of solar panels, detects any kind of problem with solar panels such as shadow, mismatch of modules or degradation. (More information are given in Julie's report.)

A diagram illustrating the system can be found in the appendix 1.

Another battery inverter has been purchased last year, Sunny Island which is specifically designed for energy storage and battery charging. The aim of this purchased was to replace the poor-quality inverter, connecting the Sunny Island to the Li-On battery. SMA Sunny Islands are only compatible with a list of identified batteries and the actual Li-On battery is not part of this list.

One of the objectives of this semester was to identify from the list of compatible batteries and the work of the precedent Erasmus student Pierre, the battery that would fit with the actual photovoltaic system.

The main objective of this project was not related to the passive house but rather with the University directly. To determine the solar radiation the university receives, an electronical device called Pyranometer SMP11 has been purchased last year, the objective is to set it on the rooftop to log data, analyse them with the University of Bergen and then show the IRL solar radiation on a display located inside the solar laboratory for educational purposes. This pyranometer will enable mechanical and marine engineering to analyse their data according to solar radiation data received on the University and not those received by UiB.

Logging and saving solar radiation data

1. Context

The objective of this part is to communicate with a pyranometer to log data and to plot them on a display to compare those data with the one from the University of Bergen and educational purposes with a display.

At the beginning of the project, Harald Moen and Richard J.Grant explained that the system which communicates with the pyranometer was not really defined, and the purpose was to propose different options to log data easily.

The electronical devices available were: (cf appendix 2)

- A Kipp & Zonen SMP11 Pyranometer [5]
- Kipp & Zonen PMU485 Smart Setup Hub: RS485 Adapter enabling to convert a RS485 connection to a USB 2.0 connection. This device is useful for connecting the pyranometer to a computer.[6]

The software available to log data:

- SmartExplorer : log and save data with a frequency chosen, plot IRL data.[7]

The software is useful for observing if the communication between the pyranometer and the computer is working. The problem is that this solution would require a computer permanently located on the rooftop to log solar radiation data. The objective of the project is to get real time data from any computer at any time. That is why, the software could not be used for the project.

Another solution was to use a raspberry PI3 , a nano-computer, connected to the pyranometer saving data in his memory and transmitting IRL solar radiation data to a display located in the Solar Laboratory. To log data on the raspberry PI, a Python script needs to be created to establish connection with the pyranometer and execute different functions needed according to different objectives.

The last solution was to buy a datalogger from Kipp&Zonen, logging data with a high reliability and then sending data via e-mail or FTP server. This solution would be expensive and is not compatible with the idea of ploting data on a display.

The chosen solution is the one with a raspberry PI which works as a computer, and which can be remotely controlled with a SSH connection that will be explained later.

In comparaison, the University of Bergen uses a datalogger Fluke Helios I Computer Front End (CFE), a PC and a line printer.[8]

2. Creation of the Python Script

a. Programming approach

The 2 main objectives of the communication with the pyranometer are:

- Logging data continuously in a file with a certain frequency to analyze solar radiation received on HVL and compare them with those received on UiB.
- Plotting solar radiation data on a display located in the Solar Laboratory while the pyranometer is situated on HVL main building's rooftop.

Regarding those 2 objectives, it is necessary to create a python program which will be executed continuously, especially for saving data in files.

Before creating the python script, it was necessary to follow some tutorials and exploring what have been already done with a pyranometer and a raspberry PI.

The first step for creating the program is to communicate with the pyranometer knowing that the computer is a master (send request) and the pyranometer is a slave (execute request). The second step will be to save solar radiation data in a file (CVS, XLSX, DB).

The third step is to create a new file every X time in order to have a certain frequency and the same amount of data in each file without deleting the previous file. 4th step is to plot some data from a file without being animated. The 5th step was to open a window plotting in real time data with an update every X seconds.

The 6th step which is the most important one is to execute the 3rd step and the 5th step in the same program, i.e. plotting IRL solar radiation data while saving those data in a file. The 7th step is to test the pyranometer on the Solar Lab's rooftop compare solar radiation data received with the University of Bergen and analyse the differences. Finally, the last step is to make sure that the program works well continuously to mount the pyranometer on HVL's rooftop.

Before explaining the approach of the Python script's creation, it is necessary to explain all the specifications of each device used. Information written in blue are destinated to the next student for a better understanding of the project so far.

Pyranometer Resources: **Documents > General > 2022-23 2nd Semester – Work Tom > Resources > Pyranometer**

The SMP11 pyranometer can communicate with a computer thanks to a protocol named ModbusRTU. In the datasheet **KippZonen_Manual_Smart_Pyranometers**, Modbus RTU protocol is defined at the end of the document and all the functions that can be used are defined. Another document **Modbus_Application_Protocol_V1_1b3** can be helpful in order to understand better the protocol.

An example of a Modbus RTU program is showed in the Pyranometer manual, but it is written in C++ language. Fortunately, it also possible to use this protocol through different Python librariessuch as : minimalmodbus , pymodbus, EasyModbus.

Raspberry Pi Resources: **Documents > General > 2022-23 2nd Semester – Work Tom > Resources > Raspberry Pi**

All the step followed to be able to have a GUI (Graphical Interface) are written in the following file

Documents > General > 2022-23 2nd Semester – Work Tom > Resources > Installation of Rasbian on the raspberry

Working with a raspberry PI, involves working on a Linux OS. The OS called Raspbian had to be installed on a SD micro card before connecting the raspberry PI to a display. After installing Linux OS on the SD micro card, and put it inside the raspberry PI, the nano computer could be connected to a display with a HDMI cable to configure Wi-Fi, settings, SSH connection…

PMU485: nothing was required except connecting the pyranometer to it: **Documents > General > 2022-23 2nd Semester – Work Tom > Resources> Pyranometer_Connection_Diagram**

first step

```
import minimalmodbus
import time
from matplotlib import animation
import matplotlib.pyplot as plt


# # Creation of a ModbusInstrument object in order to communicate with computer
instrument = minimalmodbus.Instrument('COM5', 1)  #COM5 = com port, 1 is slave adress

# Modbus communication RTU settings (pyranometer datasheet)
instrument.serial.baudrate = 19200
instrument.serial.parity = minimalmodbus.serial.PARITY_EVEN
instrument.serial.bytesize = 8
instrument.serial.stopbits = 1
instrument.mode = minimalmodbus.MODE_RTU


#Initialize the differents variables that I will need in my programm.


list_time_mesure=[]
list_time=[]
list_time1=[]
list_data_r_pyrano = []
list_data_r_temper=[]

t_acquisition=600
data_r_pyrano_max=1000


time_reel =0

def plot():
    def animate(i):
        data_r = instrument.read_register(0x0006, functioncode=4) #first I ask to pyranometer to commmunicate
```

Figure 1 : program script showing the communication method with the pyranometer

The library minimalmodbus has been used for the python script because the code is quite easy to use, before using it on Pyzo it was necessary to install the library. the syntax of the line instrument.read.register(0x0006, functioncode=4) can be understood thanks to pyranometer manual.

All settings are defined in pyranometer datasheet: baud rate, parity, byte size, stop bits

Second step

At first, it seemed that the best option to save data was to create a data base file. The software DB Browser SQLite was installed. The library sqlite3 was installed on Pyzo to execute actions in the data base such as: writing data, deleting data … (cf. appendix 3)

Regarding the amount of data and the fact that there was no need to structure them, it appears that it would be easier to save those data in a CSV file. Furthermore, it was easier to create a new file with a certain frequency without deleting previous data on a CSV file rather than with a database.

```
    # write collected data to file, with open is a function that enables to open files such as csv or txt. Here
I want to open a csv file and write data acquired by the pyranometer. writerow enable me to indicate what I
want to write in the CSV file. "a" is used to write something at the end of the file. ("w" is also used to
write something but it deletes everything that was written before)
        with open(file_name, "a") as csvfile:
            file = csv.writer(csvfile, delimiter=';')
            if csvfile.tell() == 0:
                headers = ["Radiation", "Time"]
                file.writerow(headers)

            file.writerows(collected_data)
```

Figure 2: python script writing and opening a CSV file

"With open" method was used to write data in the CSV file, a description of the function is given in the figure above.

```
def data_csv():
    #the aim of this loop is to log data with a certain frequency . With the second loop while, we log data for
a certain time
    collected_data = []
    radiation = 0
    counter = 0
    while True:
        # get current date and time for file name, the aim is to create a new file each time the first loop
while is intialized.
        date = time.strftime("%Y%m%d_%H%M%S")
        file_name = "C:/Users/Tom Bernard/Desktop/{}.csv".format(date)


        # start new period of data collection, time is reset
        start_time = time.time()

        #list collected_data is reset at the beginning of the loop
        collected_data = []

        #the next loop communicate with the pyranometer during a certain time (20s in this case).
        while time.time() - start_time < 20:
            current_time = time.time() - start_time
            # get current time and radiation/temperature values, instrument.read_register is a way to
communicate with Modbus protocol. I used this protocol because it was specified in pyranometer manual
"KippZonen_Manual_Smart_Pyranometers.pdf"

            data_point = (radiation,time.strftime("%H:%M:%S "))
            radiation = instrument.read_register(0x0006, functioncode=4)
            print("Radiation value is: ", radiation,"W/m^2")
            collected_data.append(data_point) #with this method we add one value to collected_data (list)
            counter += 1

            time.sleep(2)
    #time.sleep enables me to log one data every 2 seconds
```

Figure 3: python script logging data with a certain frequency

The aim of this function is to create a new file any time it is necessary. First, variables are defined. Then, the exact time is obtained with time.strftime, this method gets the real time regarding the accuracy required (%Y : year, %m: month, %d: day, %H: hour, %M: minute, %S: second).

With the while loop, the program will receive data for 20 seconds and create a list named collected_data and add every 2 seconds a new solar radiation data.

3rd step:

This step consists of plotting data logged in a file. In order to do that, Matplotlib method seems to be the best option, especially because it is possible for the next steps to create an animated function. During this step, temperature and solar radiation data were expected to be plotted. It was the first time that the pyranometer was used outside next to the Solar Laboratory.

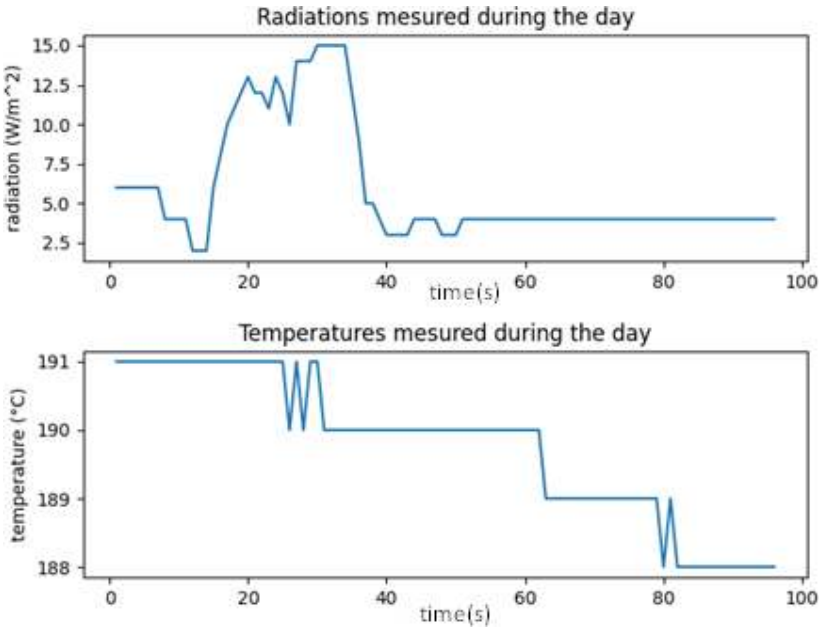


Figure 4: first solar radiation data logged

The code used to obtain the figure above has not been saved because it used data base to plot them in a Matplotlib window.

Radiations and temperatures were measured for 100s outside, just behind the solar lab on 22/03/2023. Radiations are updated regularly (almost each second) while temperatures are not close to the reality. Inside the Solar lab, the temperature is 20°C so it means that the thermometer is an inside thermometer and does not enable to register outside temperature. (Only 0.3°C regression in 100s).

Temperatures collected are in fact the body temperature of the pyranometer. This data will not be useful for the project. This figure's utility is just to show that only solar radiation data will be logged for the next steps.

5th step:

One of the main objective of this project is to get and show real time radiation data. To plot animated data, a specific class can be used in Matplotlib: "FuncAnimation". This class enables plotting real time data. Furthermore, it was important to show the duration of the executed program on the figure. Then, the program is flexible, it can acquire data for the time that we want with a specific acquisition time.

```
def plot():
    def animate(i):
        data_r = instrument.read_register(0x0006, functioncode=4) #first I ask to pyranometer to commmunicate me data that it acquires
        list_radiation=data_r  #I create a list that records all the data send by the pyranometer


    #I need to get the real time to be able to animate the plot with real time data, time.time() is a method that get the actual time.

        time_mesure=time.time()
        list_time_mesure.append(time_mesure)
        time_reel = time_mesure- list_time_mesure[0]

    #next loop enables me to define how long time I want to get datas from the pyranometer. If time_reel > t_acquisition then the loop is stoped.

        list_data_r_pyrano.append(list_radiation)
        list_time.append(time_reel)
        print("IR :",list_radiation,"W/m2")
        print(f'Time {time_reel}' )

        line.set_data(list_time,list_data_r_pyrano)
    #line.set_data() contains data that have to be retrieved.


        return line,

    fig=plt.figure() #First, I create a figure

    plt.gcf().subplots_adjust(left = 0.2, bottom = 0.2, right = 0.9, top = 0.9, wspace = 0, hspace = 0.4) #this line defines where the matplotlib window will appear on my laptop.

    line,=plt.plot([],[]) #here we define the plot element, empty lists those lists were defined thanks to the method line.set_data()

    #I define here how the matplotlib window will be organised : xlim, ylim are the scale of the x and y axis. xlabel, ylabel are titles of axys.
    plt.xlim(0,t_acquisition)
    plt.ylim(-5,data_r_pyrano_max)
    plt.xlabel("time in s")
    plt.ylabel("radiation")
    plt.title('Radiations mesured during the day')
    plt.grid()

    #FuncAnimation is a function that enables me to animate a plot, his syntaxe is well explained in matplotllib librayry.
    ani = animation.FuncAnimation(fig, animate, frames=30, interval=1000, repeat=False)

    plt.show() #show the plot
```

Figure 5: python script plotting function

The method used to animate the function is called line 84 calling the function named “animate”.

In this function, it is mandatory to define data that will be animated in the function. The method set_data enable the function to update data that will be plotted. That is why it is a list that will be updated thanks to a while loop.

Line 69 create a new object which is a window where plot can appear.

Plt.xxx is necessary to set all the characteristics of the window such as the title, the legend, the

scale…

plt.show is a mandatory method that make appears the figure.

6th step

The second main objective of this project is to log data in files to get historical data and compare them to those that are obtained in the University of Bergen (UiB).

First, logging data from the pyranometer were saved in a database, but it was not simple to create a new database without deleting the previous file. Finally, it was easier to create a new csv file without removing the previous one.

Working with data.stfrtime it is possible to create a file with a new name, a while loop is just needed to set the creation of csv file ‘s frequency. The program must work automatically, for example when the day is over, a file needs to be saved with all the data of the day and a new file must be created the day after ect....

```
def data_csv():
    #the aim of this loop is to log data with a certain frequency . With the second loop while, we log data for
a certain time
    data_0=(0,time.strftime("%H:%M:%S"))
    collected_data = []
    radiation = 0
    counter = 0
    while counter <= 576: #144 loop * 600s = 24 hours of logging data
        # get current date and time for file name, the aim is to create a new file each time the first loop
while is intialized.
        date = time.strftime("%Y%m%d")
        file_name = "/home/tom/Desktop/{}.csv".format(date)
        #the aim of the 2 previous line is to create a new file every day, we getthe time and then we set the
file name with the date

        # start new period of data collection, time is reset
        start_time = time.time()

        #list collected_data is reset at the beginning of the loop
        collected_data = []
        counter += 1
        #the next loop communicate with the pyranometer during a certain time (20s in this case).
        while time.time() - start_time < 600: #every 10 minutes the while loop check if the day changed thanks
to time:strftime
            current_time = time.time() - start_time
            # get current time and radiation/temperature values, instrument.read_register is a way to
communicate with Modbus protocol. I used this protocol because it was specified in pyranometer manual
"KippZonen_Manual_Smart_Pyranometers.pdf"
            data_0=(0,time.strftime("%H:%M:%S"))

            data = (radiation,time.strftime("%H:%M:%S"))
            radiation = instrument.read_register(0x0006, functioncode=4) #Modbus protocol wroking with minimal
modbus librairy
            print("Radiation value is: ", radiation,"W/m^2")

            if radiation > 1000 :
                collected_data.append(data_0)
            elif radiation < 0 :#with this method we add 0 to collected_data, during the night radiation data
are supposed to be =0 but there are values = 65534 and 65535
                collected_data.append(data_0)
            else:
                collected_data.append(data) #with this method we add one value to collected_data (list)


        time.sleep(300)
    #time.sleep enables me to log one data every 5 minutes
```

Figure 6: python script saving data in a CSV file.

The first loop reset all the parameters of the second loop each time the second loop is over. The second loop works for a certain amount of time and transfer data to a csv files. On the figure above, the loop that is logging data in a csv file works for 600 seconds (10 minutes) with a frequency of one data collected every 5 minutes.

Then, when this loop is over, the first one is called: it checks if the date is still the same, if not it creates, on the Desktop of the raspberry PI, a new file with the date updated. The list of collected data is reinitialized which means that the new CSV file will be empty. And the number of times

the loop has been called is updated. The first loop is called 576 times on the example above because the programme was executed for 4 days in a row (4*144 * 10 minutes = 4*24 hours)

With retrieving real time with the function stfr.time() a new file is created each time the first loop is called.

The function with condition “if” is necessary because during night some data reached 65534 or 65535 W/m². 65534 W/m² was an error of communication, 65535 corresponds to the initial value of the parameter “I0_device_type” and refers to the selected device type of the sensor

7th step

The 2 previous function work independently, the objectives is to run them at the same time. Python is working in a very simple way: the code is reading from the top to bottom so if 2 main functions are written, the first one will be executed before the other one. In this case, it is not possible to run one function after the other because they must be running all the time.

To execute those 2 functions in parallel, a threading module can be used but after running the program 10 seconds, it crashed by itself with an error message. Thanks to developer’s forums, it appears that threading was not optimised and safe to run with matplotlib, the module needed to plot IRL data. Otherwise, multiprocessing module is another module that is supposed to work with matplotlib.

Multiprocessing is a CPU bound while Threading is a I/O bound. Multiprocessing is supposed to be used for heavy duty math operation or for modifying images and videos quickly. Thus, it allows to use all the potential from the informatic system while Threading is mostly used for writing files. Threading seems to correspond to the but because of this error “UserWarning : Starting a Matplotlib GUI outside of the main thread will likely fail”.

“ProcessPoolexecutor” : is a function that uses multiprocessing.

Both programs work asynchronously but to end the program, data_csv execution must be finished and matplotlib windows must be close manually. If only one of the 2 functions is ended, the other one can still work properly.

The problem is that there is not a real timer that can be set to end plot function, because of the module animation. Indeed, the “frames” parameter specifies the number of times the animate function is called during the animation, and “interval” specifies the delay between 2 frames.

Combining “frame” and “interval” is possible but the time of final execution will not be the same regarding the device we use.

Example:

animation	device	Elapsed time	Factor time elapsed/(nb of frame*interval)
ani = animation.FuncAnimation(fig, animate, frames=20, interval=1000, repeat=False)	Raspberry PI	40s	2
	Personal Computer	20.5s	1.025
ani = animation.FuncAnimation(fig, animate, frames=90, interval=1000, repeat=False)	Raspberry PI	183.09 s	2.035
	Personal computer	92.52 s	1.0278
ani = animation.FuncAnimation(fig, animate, frames=600, interval=1000, repeat=False)	Raspberry PI	1220 s	2.035
	Personal computer	616.67s	1.0278

Figure 7 : tests realized to observe speed execution of the plotting function on 2 different computers

b. Errors obtained while running 2 programs with multiprocessing method

serial.serialutil.SerialException : [Errno 2] could not open port /dev/ttyUSB1: [Errno 2] No such file or directory: ‘/dev/ttyUSB1’

--> check if something is connected to USB port 1, sometimes it is just needed to change ttyUSB1 to ttyUSB0, ttyUSB2 for no evident reason.

serial.serialutil.SerialException : device reports readiness to read but returned no data (device disconnected or multiple access on port?

--> happens after execution of the program for X time, problem has not been solved for the moment (18/04/23)

--> the problem comes from the raspberry PI ((e.g., disconnected wires, data corruption due to noise, temporarily non-responsive serial device, intermittent wires, and more),

(https://raspberrypi.stackexchange.com/questions/111817/serial-serialutil-serialexception-device-reports-readiness-to-read-but-returned)

minimalmodbus.NoResponseError : no communication with the instrument (no answer)

>> exception in Tkinter Call back

--> acquire data for some time and then the error happens

--> error seems to come from minimalmodbus library --> maybe find another Modbus library more efficient (Pymodbus is not working with the program)

minimalmodbus.InvalideResponseError : Checksum error in rtu mode : "δ \x01" instead of 'ÕÊ'. The response is '\x04\x02\x00\x01xδ \x01' (plain response: '\x04\x02\x00\x01xdelta \x01')

>> exception in Tkinter Call back

serial.serialutil.SerialException: Cannot configure port, something went wrong. Original message: PermissionError(13, 'Access denied.', None, 5)

--> this error message informs that the access is denied. It means that maybe a program is already working with something connected on port 5. Most of the time, the USB serial needs to be disconnected from the port and connected again.

c. Solutions tried

When errors are printed on the execution window it only stops the execution of the function plotting solar radiation data, the other function is still executed. It means that there is only a communication error with the pyranometer that cannot send the data.

The function with multiprocessing method can work for 1 hour without any problem and be stopped by this kind of error.

The solution that was supposed to work is to raise exception with a method called try/except. If an exception or an error happens, with the try/except method the program should ignore the error and be recalled later to display the next data item. This solution did not work.

After a discussion with Endre Håaland (IT department in HVL), another solution was found using both functions but without the multiprocessing method.

First the function communicates with the pyranometer and saves data in a CSV file.

Then, there is a delay where the plot function is called to plot one or several data.

Finally with a while loop, the programs start again.

This solution can work but the main problem that appears is that: after the plotting function has been called, it is important that the matplotlib windows stays open while the while loop starts again and saves data in the csv file, but it is not possible. The matplotlib windows must be closed to enable the program to execute the line after.

8th step : take remotely control of raspberry PI

Another objective of this project is to get in real time data from any computer situated in the university. To achieve this objective, taking remotely control the raspberry PI is a solution. The Secure Shell protocol aka SSH, allows to remotely connect to a system from another device using. In this project, the objective is to remotely connect to a raspberry PI 3B to take control of it and mostly get graphic interface and watching radiation data's plotting.

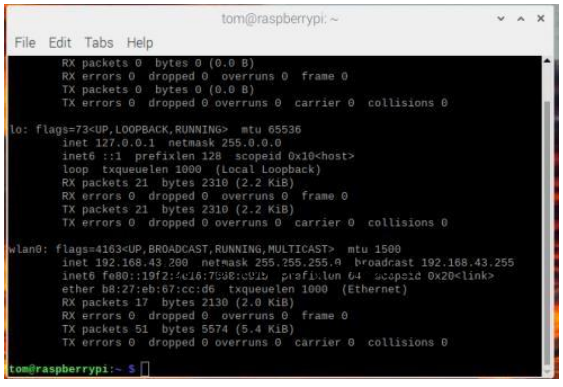
First, before getting the graphic interface from the raspberry pi, some configurations must be set in raspberry's configuration.

Open terminal

Write the following command: sudo raspi-config

3-Interface Options > I2 SSH >> Enable the SSH Server

Then on the device that will take remotely control of the raspberry PI, a software called "putty" needs to be installed, which is a client software that enables to remotely connect to servers using Telnet, This remotely connection is enabled by raspberry PI's IP address, that



can be obtained by hovering the mouse over the Wi-Fi symbol at the top of the raspberry pi GUI or by typing the following command in the terminal: sudo ifconfig.

It was necessary to set a fixed IP address to facilitate monitoring of the raspberry PI, otherwise IP address change all the time and SSH requires a known IP address to take control of the other device. To get the raspberry PI's IP address, it is necessary that the raspberry PI is connected to Internet. Eduroam is used in HVL which is a specific internet connection because it does not only require a password but also an username.[9]

The first solution that appeared to have a GUI, was to install a VNC viewer[10] software that enables to control a computer from another one using SSH protocol. Only one thing is mandatory to use this software, both computers need to be connected to the same WIFI.

Then, the raspberry PI only needs to have a power supply to switch on which is necessary to mount it on the university's rooftop.

Another solution was possible without using a VNC viewer, which is an easier way to observe radiation data in real time from any computer. From the command terminal of any computer, it is possible to take remotely control the raspberry PI knowing his IP address.

There were some issues with the raspberry connect to the Wi-Fi "eduroam" for 2 weeks in the beginning of May. There was no specific problem before, but now it does not even detect the signal from its place.

The python program is specific because it must plot radiation's data on the client computer and save files in the raspberry PI at the same time. To be able to run the program from the client computer the software Putty is used. The problem is that with Putty, only one window can appear on the client computer which means that the python program would run but no window would appear on the client computer.

A software called Xming, enables to execute the program on the raspberry PI, files will be created and saved on it while the IRL data will be plotted on the client computer.

Taking remotely control of the raspberry PI is possible thanks to SSH protocol but both computers need to be connected to the same wifi. Thus, it would not be possible to take remotely control of the raspberry PI from another localisation than the university.

However, the following idea could be a solution: buy a router for the raspberry PI to have continuous Wi-Fi when it will be located on HVL's rooftop. Then, thanks to a VPN, it would be possible to establisha SSH connection between every computer and the raspberry PI.[11]

Another idea has been shared by one Icam professor: make appears the plot on a web page using appach software. Everybody would be able to watch real time data without connecting to the raspberry PI

IP fixed adress : IP adress has te be fixed in order to take remotely control of the raspberry PI, the problem is that in the solar laboratory the Wi-FI is really bad which prevent me from fixing an IP adress. This can be done before mounting the pyranometer on the rooftop. **[12]**

Once the pyranometer will be mounted on the roof:

It will be useful to get files from the raspberry remotely: a software called WinSCP with SFTP protocol (SSH File Transfer protocol) can get and send files to a remote device. This solution means that someone must use WinSCP every month for example, I am not sure that we can integrate in the python program a function that sends files with a frequency.

3. Results

9th step: comparison of data with UIB (University of Bergen)

Even if the program needs to be upgraded, it is still possible to compare data between UiB and HVL. [13]

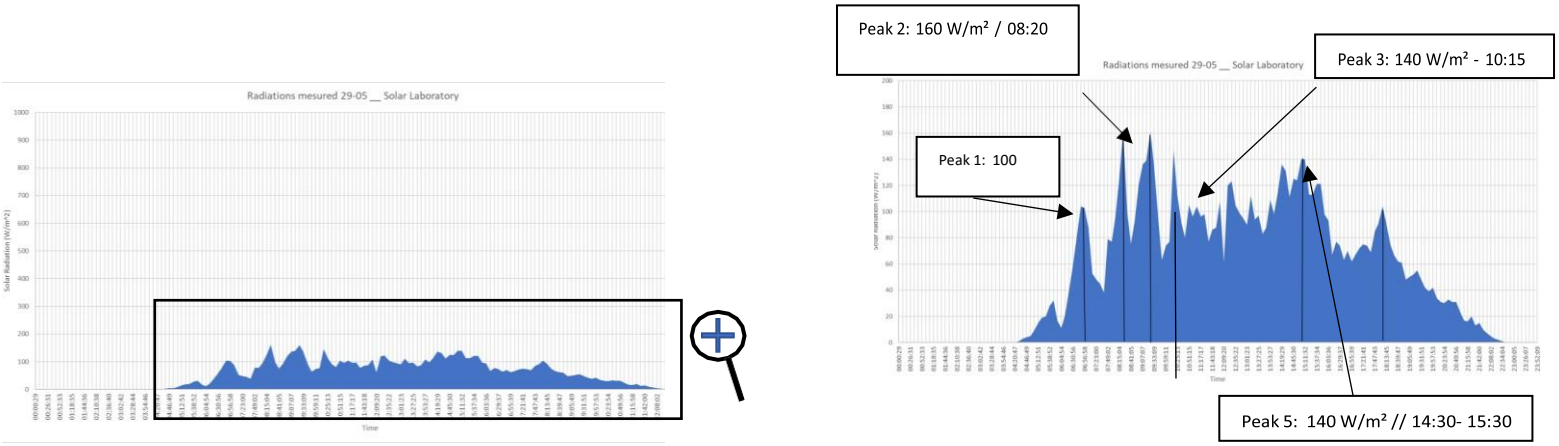


Figure 9 : evolution of solar radiation value with a sample every 2seconds (HVL)

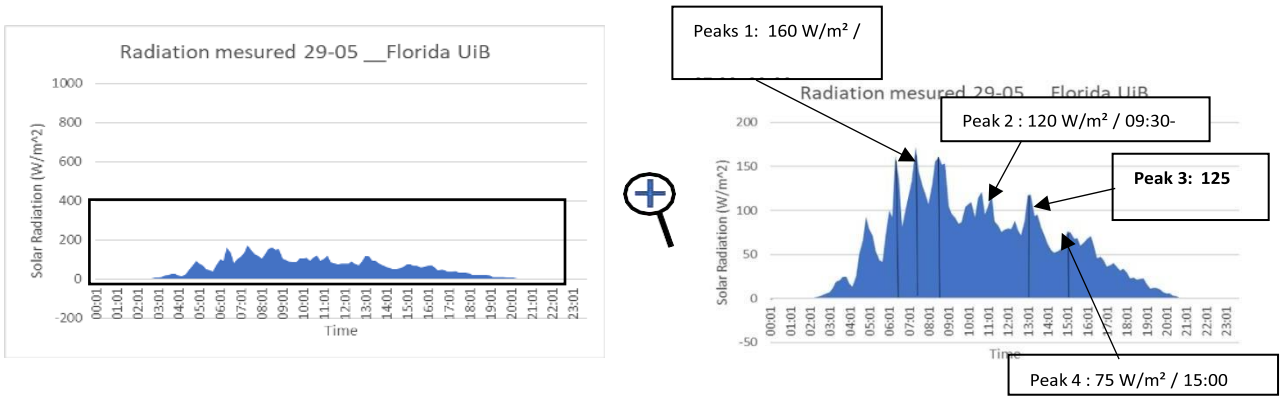


Figure 10 : evolution of solar radiation value with a sample every 10minutes (UiB)

a. Analyze one day :

At this point (29th may), solar radiation was mesured every 2 seconds for the Solar Laboratory, it was not really easy to obtain a plot with the same amount of values and interval of time than UiB's data. The curves show similar trends and show the same order of magnitude. The highest value for HVL is 160 W/m² while the highest one for UiB is around 170 W/m² and thos peaks are observed in the morning around 9:00 am.

Several differences are nevertheless occuring, peaks do not reach the same amount in the same time which makes sense because the weather is not exactly the same because of the distance between the 2 pyranometers. However, it is useful to observe solar radiation curve for a longer period and with the same time period on the abcisse in order to compare better the solar radiation.

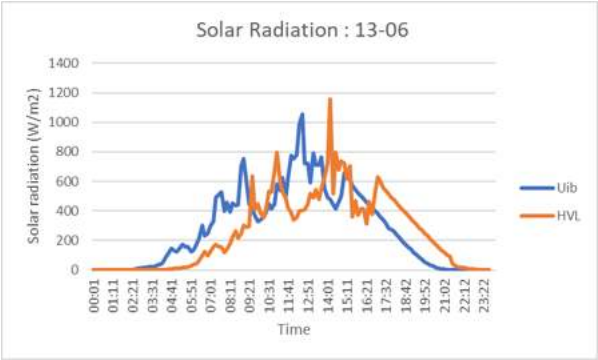


Figure 11 : chart representing 2 solar irradiation curves at2 different locations : HVL and UiB
Chart comporting a time error

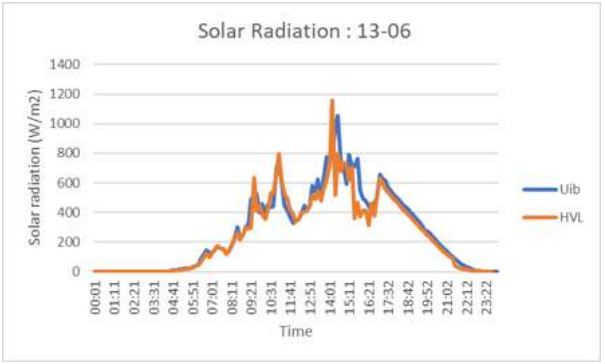


Figure 12 : chart representing 2 solar irradiation curves at2 different locations : HVL and UiB
Problem corrected

Data from Florida (UiB) have been moved by 2 hours after on the previous chart because there were some problems identified in the database:

- sunrise was 2 hours before the real one.
- The sunset happened 2 hours before what the forecast says.
- The problem is that with a data every 10 minutes the weather delay between the 2 localisation cannot be observed.

The only thing observable is the first radiation value received by UiB 10-15 minutes before HVL and last values are received 10-15 minutes after HVL. This is because electronic devices are mounted on higher buildings in Florida for UiB.

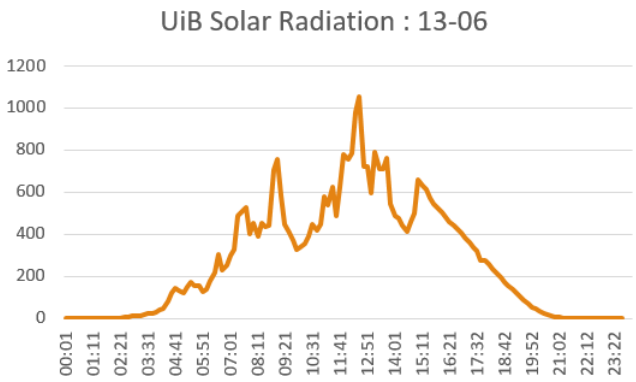


Figure 13: evolution of solar radiation value with a sample every 10 minutes (UiB)
Area under the curve : 393 245 W/m2

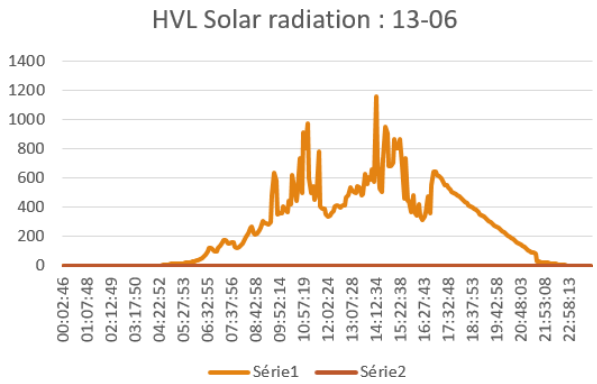


Figure 14: evolution of solar radiation value with a sample every5 minutes (HVL)
Area under the curve : 364 570 W/m2

The charts above, show that the number of samples per day has a real impact on the data observed. The area under the curve is 10% inferior for HVL radiation data with 2 times more data logged. With more frequently samples, the data are more accurates.

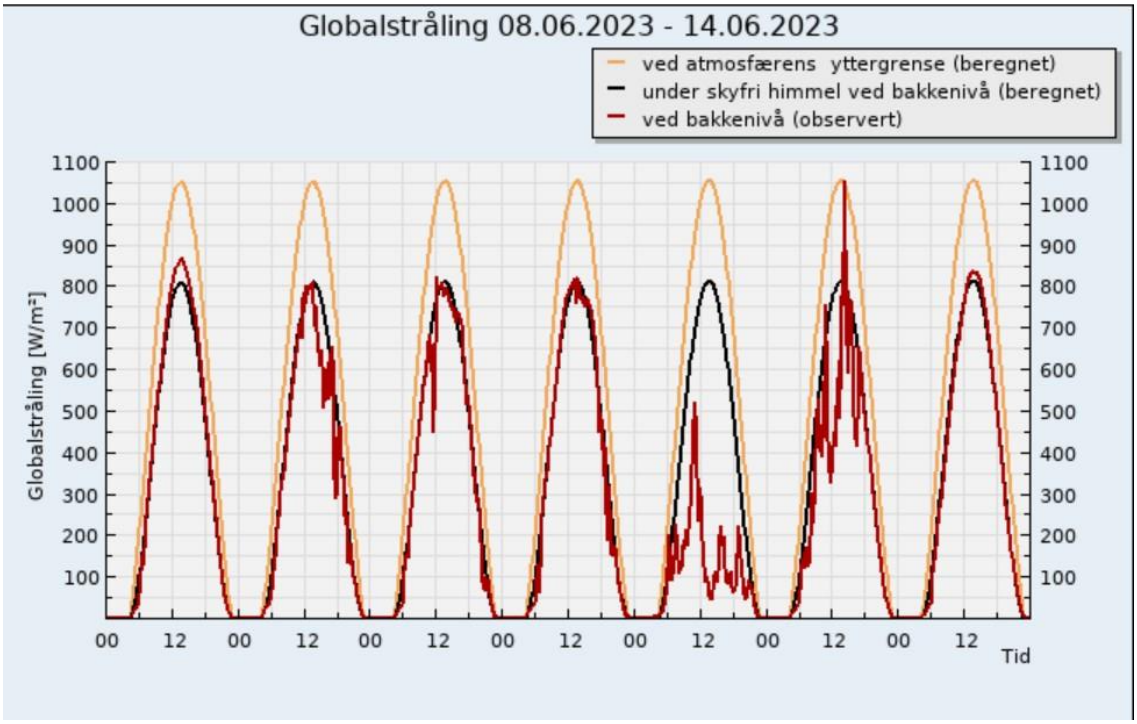


Figure 15: evolution of solar radiation value for a week(UiB)

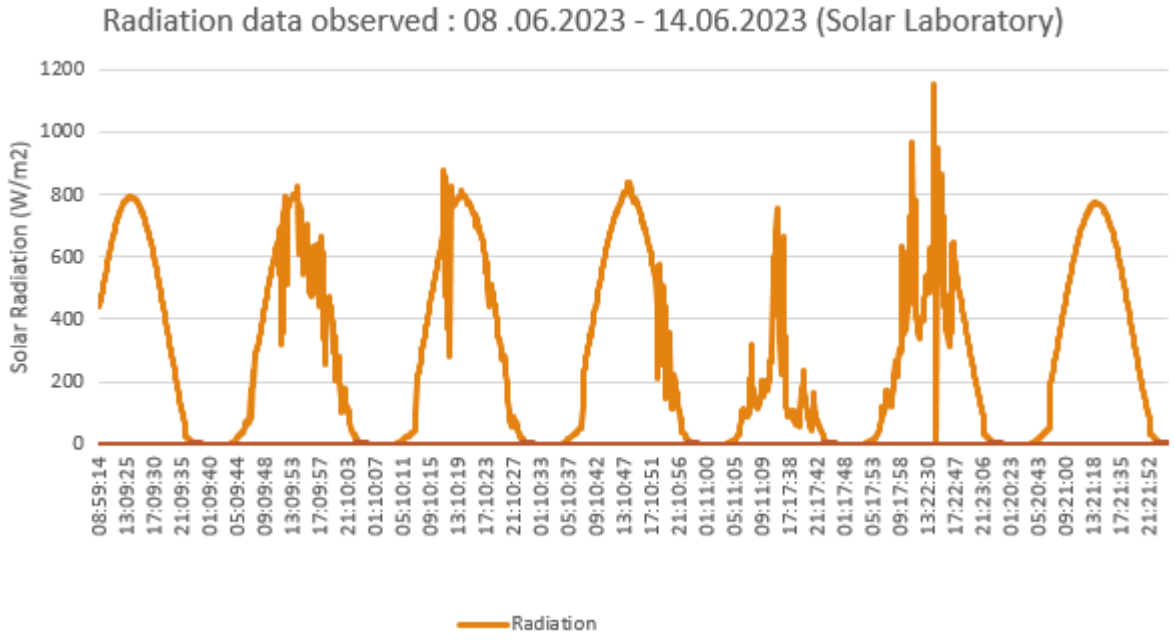


Figure 16: evolution of solar radiation value for a week(HVL)

From Thursday of 23rd week until Wednesday of 24th week, a comparison of solar radiation data has be realized. The details will not be analyzed but only the shape and peaks of solar radiation. On UiB data, the red curve indicates real radiation data, and the black curve indicates the maximum amount that can reach solar radiation. As shown above, those 7 days were very sunny, with 5 days that almost reached the highest amount of solar radiation the whole day. This black curve is not illustrated in HVL's chart but as well as UiB, curves reach 800 W/m² for 5 days. On those charts, what is interesting is the shape of the curve when the solar radiation was not stable, when clouds disturb the solar radiation to reach his highest amount possible. This concerns 13 th and 14th of June, once more shapes are very similar. 13th of June does not exceed 400 /m² for more than a small part of the day, but the peak do not reach the same value: 600 W/m² for UiB and 800 W/m² for HVL. This can be because clouds did not create shadow on the pyranometer located in HVL. For 14th of June, values are more similar, both charts show values exceeding 800 W/m² and 1000 W/m².

Batteries

1. Context

Since 2020, one ICAM student come each semester in HVL to work on the solar laboratory and the main objective is to convert it into a of grid passive laboratory. To becomes off grid, a Power Oak ES5048 battery was installed because the electricity production was quite low during winter, especially between November and February. Indeed, Julie Friard worked from August to December 2021, on the website Tigo and identified a minimal production of 100 Wh/day and a maximal amount of 1000 Wh/day during the winter.

In addition to this low electricity production, Julie Friard figured out that the discharge of the Power Oak ES5048 battery was too important even when electricity demand was low in the solar laboratory. This Power Oak ES5048 battery was composed of a 20-kWh battery and an inverter which converted DC current in AC current, but the battery's quality was too bad to meet the needs of the solar laboratory. Thus, another battery inverter, SMA 6.0H was installed in order to take care of the battery system management and replace the previous inverter.

Unfortunately, only few batteries are compatible with this inverter and the Power Oak battery was not. A communication between SMA inverters and the battery has been attempted in the end of 2022 without success.

Finally, it has been decided in the end of 2022, that a new battery was needed to replace the previous one. Thanks to the datasheet provided by SMA, many batteries have been identified to be compatible with the SMA 6.0H inverter. In 2022, a modular and reliable battery that could fit with solar laboratory's needs has been identified: BYD Battery – Box Premium LVS 20.0 with a storage capacity of 20 kWh. Other batteries and manufacturers have been studied but the modularity and the reliability of BYD plus datasheet installation have been found.

Because of price increases, a study of price trends between November 2022 (date when BYD Battery was identified as a solution for the solar laboratory) and March 2023 (project taken over by a new student) was necessary to identify if battery prices were still compatible with HVL's budget. (200 000 NOK) Furthermore, a review of the reliability of the suppliers was necessary to avoid having the same problems with the previous battery. Then, another review was necessary

after a discussion with Richard J.Grant to observe the other compatible batteries and their characteristics : modularity,capacity, price, supplier reviews, origin.Last thing that needed to be clarified was about battery's capacity: 20 kWh. This capacity is supposed to enable the solar laboratory to be autonomous for 2 days without any electricity production. This capacity has been estimated regarding a hypothesis of 5000 Wh energy consumption/day. In the next part, that hypothesis will be clearly explained to understand better the size of the battery required. This storage capacity will be the first thing to study because it will impact the purchase of the battery

2. Solar laboratory energy consumption

Before looking for a battery that would fit with the passive house and all the devices installed, it is important to identify the energy consumption of the passive house.

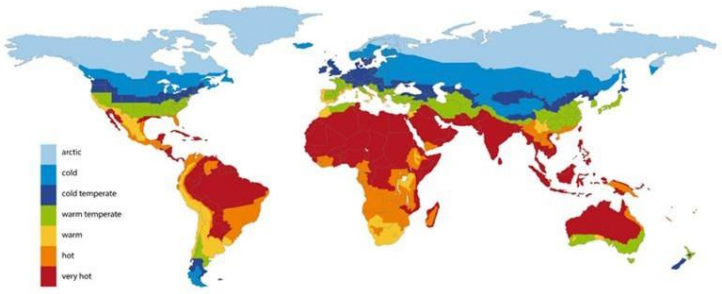
Regarding to Pierre's report, it appears that the solar laboratory energy consumption would reach 5 kWh/ day for 12 sqm (cf.appendix 5) which means 1800 kWh/year, hypothesis are not explained and are not similar with passive house's criteria.

a. Hypothesis

According to the documentation [14], heat demand of a certified passive house is supposed to be less or equal to 15 kWh/m²/ year for a 130 sq.m house or heat power 10 W/m²[3]. [15]

Climate zone according to PHPP	Heating	Cooling
	Max. heating demand	Max. cooling + dehumidification demand
	[kWh/(m²a)]	[kWh/(m²a)]
Arctic	35	equal to Passive House requirement[1]
Cold	30	
Cool-temperate	25	
Warm-temperate	20	
Warm	15	
Hot	15	
Very hot	15	

Figure 17 : heat demand accordingto climate zone



Rough outline of climate zones considered for Passive House components. Actual climate zone by location may vary.

Figure 18 : climate zones considered for passive house components

[3] Ventilation system in the solar laboratory has a nominal power of 1015 W, it seems that it is oversized for such a small area

As illustrated above, Bergen is situated in a Cold Climate zone according to PHPP[4]. This indicates that the maximum heating demand is 30 kWh/m2.year.

Regarding the electrical consumption, the total amount of primary energy requirements is set at 120 kWh/m²/ year. In comparison with Pierre's hypothesis, Solar Lab's energy consumption should reach:

$Q = S \times (QH + QP) = (30 + 90) \times 120 = \mathbf{1440\ kWh}$

$Q : Total\ Energy\ demand$

$QH = heat\ demand\ (kWh/m2)$

$QP = primary\ energy\ demand\ (kWh/m2)$

$S : surface\ of\ the\ Solar\ Laboratory\ (m2)$

According to passive house's criteria, energy consumption of the solar laboratory should be under 1440 kWh/year which corresponds to 6,6 kWh/day.

However, Solar laboratory is not certified as a passive house, it has been built to respect passive house standards but for example the door does not fit the requirements. Solar laboratory does not fit passive house's hypothesis, the floor area is way smaller than 130 m2 which has an impact on heat demands, internal heat gain and heat loss. Thus, heat loss will be calculated in the next part from hypothesis that will be explained.

Furthermore, the laboratory does not have big electronic devices such as dishwasher, laundry machine or television. An estimation of electricity consumption from all the devices functioning in the laboratory will be showed.

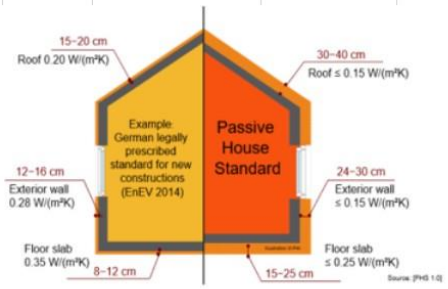
a. Heat demand calculation

According to Richard J.Grant, Solar Laboratory has been built respecting passive house criteria in terms of insulation. This does not mean that the laboratory will consume as much energy as a passive house because, as explained above, the surface area of the laboratory does not meet the criteria.

[4] Passive House Planning Package

What are passive house criteria in terms of insulation? **[16] [15]**

List of heat-loss surfaces			
surface	Utheoretical (W/m².K)	Umin	Umax
walls	0,08<X<0,15	0.08	0.15
windows	X<0,8	0.5	0.8
ground	X<0,15	0.06	0.15
roof	0,06<X<0,15	0.06	0.15
door	X<0,8	0.5	0.8



Comparison of typical U-values and wall thickness of typical German building stock and Passive House construction.

Figure 19: convection thermal coefficient values for passive house components

Houses lose heat from all surfaces (cf appendix 4), for a passive house very high insulations criteria are mandatory and available in the datasheets. To calculate the heat loss for the Solar Laboratory, the thermal convection coefficient, walls, windows, door, roof and ground surfaces are needed.

Data surfaces are available in the appendix, they represent the inside surfaces that have direct contact with the exterior. (cf appendix 6)

From the criteria given by the datasheets, 3 models have been created to estimate the lowest amount of heat loss, the biggest amount, and an average.

Minimal amount of heat loss: [17]

Thermical tranfert coefficient :

$$\sum Umin = U_{\min\ _walls} + U_{\min\ _roof} + U_{\min\ _ground} + U_{\min\ _windows} + U_{\max\ _door}$$

$$= 0{,}08 + 0{,}5 + 0{,}06 + 0{,}06 + 0{,}8 = 1{,}5\ W/K$$

Heat loss Coefficient[5] :

$$U_1 = \frac{\sum Umin \times A + \sum \psi_i . Li + \sum \chi_i . nj}{A}$$ [6]

A: surface of inside wall contact with exterior

A= 68,7m2

$U_1 = \frac{7,3}{68,7} = 0,107\ W/K.m^2$

Heating demand:

$$Q_h = \frac{U_1 \times UDD[7] \times \sum A \times 24}{1000} = 678\ \text{kWh/year}$$

Maximal amount of heat loss:

Thermical tranfert coefficient:

$$\sum Umax = U_{\max_walls} + U_{\max_roof} + U_{\max_ground} + U_{\max_windows} + U_{\max_door}$$

$$= 0,15 + 0,8 + 0,15 + 0,15 + 0,8 = 2,05\ W/K$$

Heat loss Coefficient:

$U_2 = \frac{13,22}{68,7} = 0,192\ W/K.m^2$

Heating demand :

$$Q_h = \frac{U_2 \times UDD \times \sum A \times 24}{1000} = 1221\ kWh/year$$

Average amount of heat loss :

Thermical tranfert coefficient :

$$\sum Uave = U_{\text{ave}_walls} + U_{\text{ave}_roof} + U_{\text{ave}_ground} + U_{\text{ave}_windows} + U_{\max_door}$$

$$= 0,115 + 0,65 + 0,105 + 0,105 + 0,8 = 1,9\ W/K$$

[6] For a passive house, thermal bridges are supposed to be remove, thus no thermal bridges will be consider in the calculation

[7] unified day degree (Degré jour unifié in French)[18]

$$U_3 = \frac{\sum Uave \times A + \sum \psi_i . Li + \sum \chi_i . nj}{A}$$

$U_3 = 0{,}15\ W/K.m^2$

Heating demand :

$$Q_h = \frac{U_3 \times UDD \times \sum A \times 24}{1000} = 950 kWh/year$$

	Heating demand (kWh/year)
Minimal amount	**678**
Average amount	**950**
Maximal amount	**1221**

Heating demand seems quite higher than passive house's criteria which were 360 kWh/year (30 kWh/m2.year).

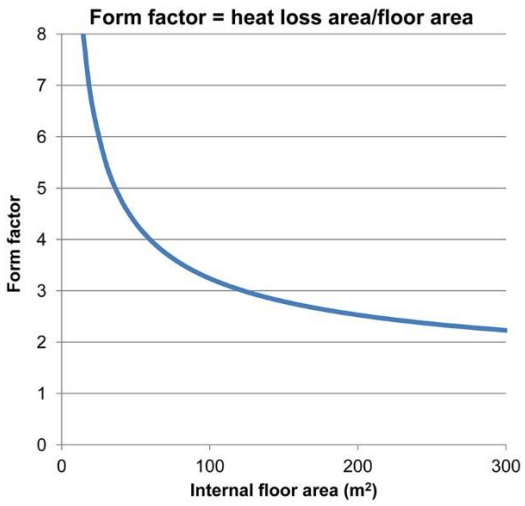


Figure 20 : chart illustrating the heat loss amount according to the floor area [19]

As illustrated on the plot above, bigger is the surface of the building, the lower the heat loss will be. In a study realised in 2015, a 45 sqm bungalow with ideal orientation and southerly aspect was consuming up to 40 kWh/sq.year, so more than twice the heat demand expected. In comparison with the solar laboratory, it would mean that the solar laboratory could consume up to 1000 kWh/year for the heat demand only. Even though, the bungalow respected passive house criteria in terms of insulation, windows, MVHR[8] the heating demand was way above the expectations. People thought about having extra insulation or better airtightness, but they finally

[8] Mechanical Ventilation Heat Recovery

concluded that with the heat gain, an extra insulation was not necessary *"When we looked at what the heat gain would be from our two occupants, their cooking and washing, and their modest low energy TV and fridge, it was clear that the place would overheat all year round. Our advice was that the passive house standard was the wrong standard for this size of house".*

Thus, it is necessary to pay attention to internal heat gain that can reduce significantly heat demand, especially in small buildings. *"Larger dwellings do tend to benefit more from their better form factor."*

b. Internal heat gain [20]

Internal heat gain are many and varied, they come from human, electronical devices, cooking, lighting… (cf.appendix 7)

As showed below, standards heat gains are situated between 2.1 W/m2 and 4.2 W/m2 for residentials buildings. The main hypothesis are that there is person maximum for 35 sqm, and there are big electronical devices such as : fridge, dishwasher, dryer used in the house.

[9]

Type of building	**Residential**	**Other residential accommodations (one room = 1 D.U.)**	**Other residential accommodations (shared flats)**
Use	10-Residential building: residential	10-Residential building: residential	10-Residential building: other
TFA calculation	Residential building (see PHPP Manual, Table 8)	Non-residential building (see PHPP Manual, Table 9)	Non-residential building (see PHPP Manual, Table 9)
Temperature winter	20 °C	20 °C	20 °C
Temperature summer	25 °C (with 12 g/kg)	25 °C (with 12 g/kg)	25 °C (with 12 g/kg)
Deviation possible?	No	No	No
Number of occupants	Standard occupancy in PHPP: determined on the basis of typical occupancy densities and the size of the dwelling unit	Same as residential	Same as residential
Deviation possible?	Yes, see: 2.5.4	Yes, see: 2.5.4 and PHPP Manual: 7.1.7	Yes, see: 2.5.4 and PHPP Manual: 7.1.7
IHG (selection)	2-Standard	2-Standard	3-PHPP calculation ('IHG' worksheet)
IHG winter	Standard calculation based on the size of the dwelling unit (2.1 to 4.1 W/m²)	Standard calculation based on the size of the dwelling unit (2.1 to 4.1 W/m²)	Project-specific
IHG summer	Max. between the IHG in winter and the calculation in the worksheet IHG	Max. between the IHG in winter and the calculation in the worksheet IHG	Project-specific

Figure 21: sheet illustrating internal heat gain standards for different passive houses.

Those hypotheses do not apply for Solar Laboratory heat gain, it is necessary to estimate heat gain from the sheet in the appendix. Furthermore, as the plot show below, internal heat gain, can reach 10 W/m2 for a passive house smaller than 100 m2, considering that one person occupies 35 m2.

[9] IHG : Internal Heat Gain

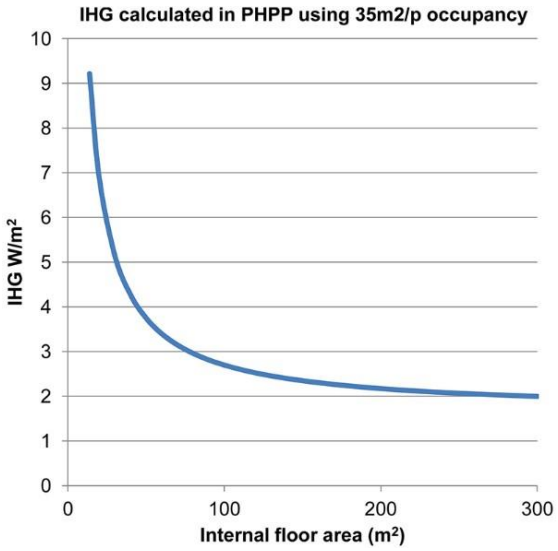


Figure 22 : chart illustrating the internal heat gain produced according to the floor area [19]

"The average human, at rest, produces around 100 watts of power."[21] according to the Standord University study. Lighting can produce up to 10 Watts of heat, and consumers electronics up to 44 W.

As a hypothesis, the total internal heat source of power in the solar laboratory reachs 120 W continuously. Even though, the plot above showed that the highest amount of internal heat gain cannot be more than 100W, the solar laboratory is different because a person occupies 12 m2 instead of 35 m2 for the plot hypothesis.

In the example situated in the appendix, total heat gain for a 134 sqm living are produces a heat available of 11,22 kWh/m2.year.

For the solar laboratory, the heat available from internal sources can reach:

$$IHG = \frac{Q_{gain} \times 219 \times 24}{1000} = 631\ kWh/year$$

$$IHG = \frac{Q_{gain} \times 219 \times 24}{1000 \times 12} = 631\ kWh/m^2.year$$

Qgain : heat produced by human body, electronic devices (100W)219

day/year : heating period (datasheet)

24/1000 : unit conversion W >> KWh

c. Final Heat demand:

	Heating loss (kWh/year)	IHG (kWh/year)	**Final Heat demand(kWh/year)**
Minimal amount	678	631	**47**
Average amount	950	631	**319**
Maximal amount	1221	631	**590**

Regarding the average amount of eating loss with an internal heat gain of 631 kWh/year, the final heat demand is very similar to what a passive house is supposed to consume in Nordic countries .

In addition, final heat demand could be lower than calculated if sunshine were considered.

3. Electrical consumption

Regarding the electrical consumption, the total amount of primary energy requirements is set at 120 kWh/m²/ year. Considering that the heat demand is set at 30 kWh /m²/ year, electrical consumption is not supposed to exceed 90 kWh/ m²/ year. However, for a 12 m² laboratory, uses many electronical devices: 3 inverters, 1 battery inverter, 1 MHRV working with circular electric duct heaters, lighting, and a computer with displays.

Ventilation flow in passive house is set at 20 m3/h/person. For the Solar laboratory, a Flexit unit 2 is used and create a ventilation flow up to 290 m3/h which is way oversized for the space. [15]

Figure 22: EPR demand for an average heat demand

Name	Power (W)	Use per day (h)	Ec: Consumption (kWh)	Ec: Consumption/year (kWh)
Ventilation system[1]	1015		0,986	360
circular electric duct heaters[2]	600			
Light bubles[15]	20	8	0,16	60
Sunny Island inverter (consumption)	25,8	8	0,21	75
Sunny Island inverter (no-load)[3] [22]	6,5	16	0,1	38,0
Sunny boys inverter (night mode) [23]	5	16	0,08	30
Sunny boys inverter	15	8	0,12	44
Computer in use[15]	32	7	0,22	82
Computer not in use	0,75	16	0,01	4
Router		24	0,14	51
[24] *Electric car*[4]	*3200*	*1,75*	*5600*	*2044,0*
Total without electric car (kWh/year)	1719,3		1880	**700**
Total	4920,05		7632,4	2785,8

Total amount of electricity consumption should be around **700 kWh/year** including an average heat demand and electricity demand for all electronical devices used in the Solar Laboratory

For a heat demand where the insulation is the minimal accepted, with the biggest thermal convection coefficient, the total EPR demand can reach **950 kWh**/year.

An electric consumption simulation has also been studied in case an electric would be charged with the solar laboratory during summer days. Indeed, 2 years ago, a project of V2H[10] was in reflexion to charge a BMW I3. This car has an energy consumption of 14.2 kWh/100 km. For the sizing of the battery capacity, it will be considered that the person using the car drives 100 kms per day.

4. Battery capacity needed.

a. Calculation

Thanks to some calculations the battery capacity can be estimated from:

- all theorical energy consumption and loses in the system.
- the autonomy of the battery that we would like to have.
- the depth of discharge of batteries that would fit in the passive house (DoD)11
- the voltage associated.

Description	**Name**	**Energy consumption calculated**	**Passive house criteria**
Energy consumption (kWh)	Ec	928	1500
Power of equipments (kW)	P	1719	1719
Energy production (kWh)	Ep	1160	1875
Autonomy of the battery (day)	N	5	5

[10] Vehicle 2 Home

[11] Depth of Discharge : "*the fraction or percentage of the battery's capacity which is currently removed from the battery with regard to its (fully) charged state. For fully charged batteries, the depth of discharge is connected tothe state of charge"* *[25]*

Dod (depth of discharge)	D	0.8	0.8
Voltage (V)	U	48	48

$$C_1 = \frac{E_p \times N}{D \times U}$$

Battery size = $C_1 \times U = \mathbf{7,25\ kWh}$

$$C_2 = \frac{E_p \times N}{D \times U}$$

Battery size = $C_2 \times U = \mathbf{11.7\ kWh}$

The autonomy of the battery can be changed in the sizing because the objective of the solar laboratory is to be off grid at some point. For an off grid design the autonomy of the battery needs to last many days because of the few sunshine during December and January, In the other hand, the battery will be oversized for summer, that is why charging an electric car would be interesting to use the capacity of the battery.

For summertime, it can be considered that the heat demand is the lowest scenario calculated previously. Furthermore, the electric consumption of the car reach 14,2 kWh/100 km. [24]

Description	**Name**	**Value**
Energy consumption (kWh)	Ec	5626.6
Power of equipments (kW)	P	1719.3
Energy production (kWh)	Ep	7033.3
Autonomy of the battery (day)	N	1.5
Dod (depth of discharge)	D	0.8
Voltage (V)	U	48

C_3 = 275 Ah

Battery size = 13,2 kWh

For this scenario, it is considered that the electric car will only be charged during summer, when the capacity of the battery is not used. The autonomy of the battery in this scenario. does not need to exceed 2 days because the electricity production is supposed to be way higher than in winter. 2 days is just a safety sizing in case the weather is very rainy for 2 days in a row.

b. Simulation

In order to check manual calculation for the sizing of a battery, 2 software have been used in order to simulate the photovoltaic system while modifying the capacity of a battery.

Some data were needed to execute those simulations: the solar installation system, the localisation, and the energy consumption.

PVGIS and PVSOL are the software used to identify the capacity of the battery that is required in the project. Previous student Pierre also did those simulations before but because of the differences in energy consumption hypothesis, simulations needed to be updated.

All details can be found in the document [26] : input data, website link, results, analyse, conclusion.

Input data :

Description	Value
Solar lab superficy	12 m2
Energy consumption	750-1250 kWh/year
Energy Production	1000-1500 kWh/year
Localisation	60.372, 5.341
Polycrystalline solar panels	6*275 W
Monocrystalline solar panels	6*285 W
Panel's slope	30-35°

For the simulations, 2 different energy consumption will be compared:

1000 kWh corresponding to the energy consumption calculated for Primary Energy Demand of the Solar laboratory.

1500 kWh corresponding to the energy consumption of a 12 m2 passive house regarding the passive house criteria (120 kWh/m2/year)

The second energy consumption is just simulated in order to not undersize the capacity of the battery and also to identify what changes when the energy consumption increases.

different battery capacity will be observed in order to identify if a 20 kWh battery is really

needed or if a smaller capacity would fit with solar laboratory's energy demand.

Electricity Production and Consumption

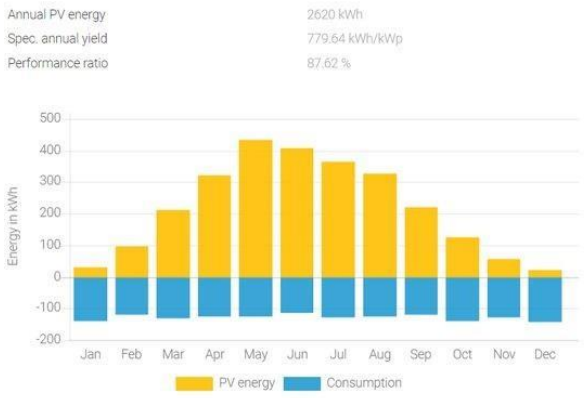


Figure 22: chart representing PV energy production and PV energy consumption along an average year (PV Sol Software)

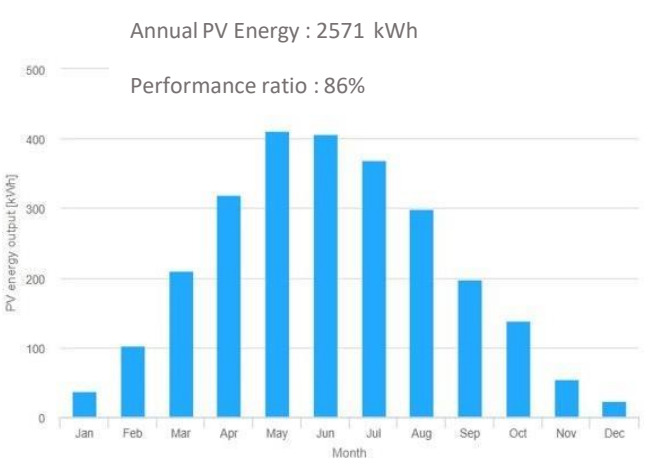


Figure 23: chart representing PV energy production along an average year (PVGIS)

With a total electricity production of 3,36 kWp from solar panels, without a battery to run the solar laboratory as an off-grid system, it appears that the energy demand will not be satisfied for 5 months. Indeed, the 1500 kWh consumption of the solar laboratory which correspond to around 120 kWh/month exceed the energy production from solar panels. From October to February, the energy production does not exceed 100 kWh/month and for March and September the energy demand would be barely satisfied.

Battery capacity sizing : PVGIS

Summary

Provided inputs:	
Location [Lat/Lon]:	60.372,5.341
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV installed [Wp]:	3360
Battery capacity [Wh]:	12000
Discharge cutoff limit [%]:	80
Consumption per day [Wh]:	1000
Slope angle [°]:	35
Azimuth angle [°]:	0

Simulation outputs:	
Percentage days with full battery [%]:	73.68
Percentage days with empty battery [%]:	13.82
Average energy not captured [Wh]:	6989.36
Average energy missing [Wh]:	499.38

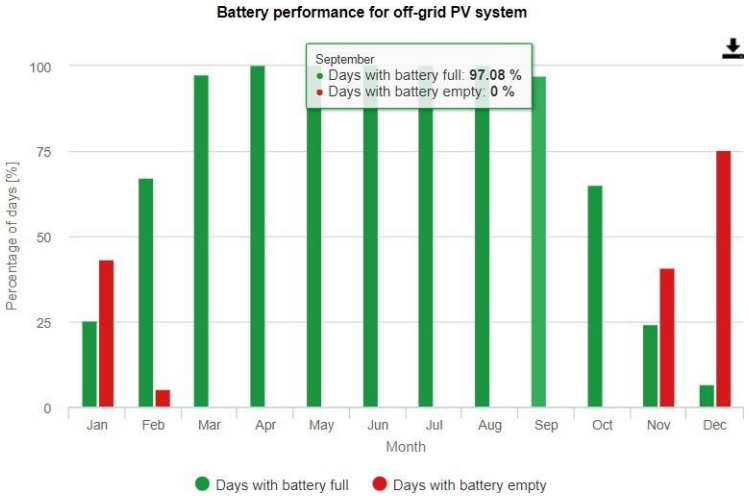


Figure 24: chart representing 12 kWh battery performance for off grid system for 1000 kWh energy consumption.

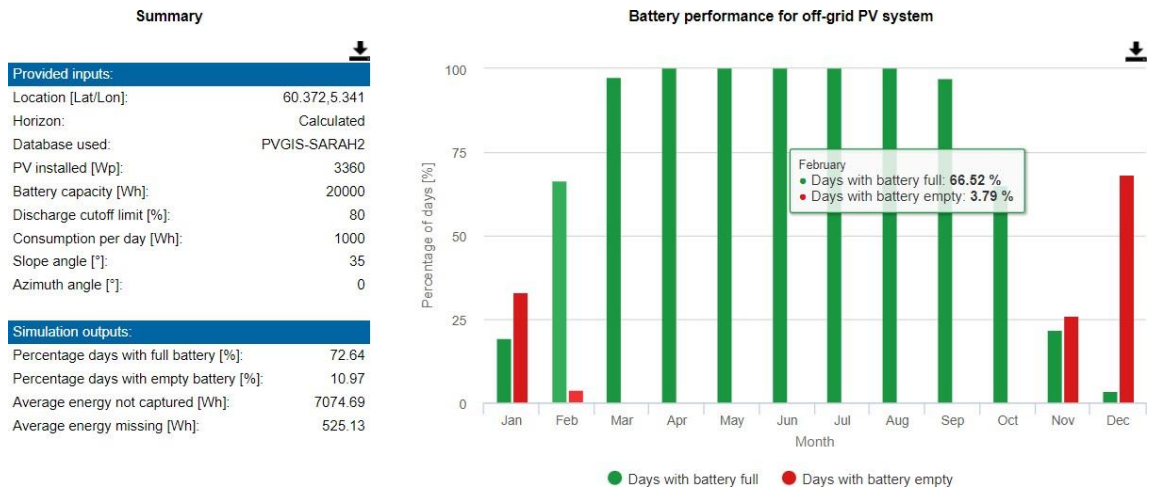


Figure 25: chart representing 20 kWh battery performance for off grid system for 1000 kWh energy consumption

In the 2 charts above, simulations have been done in order to observe if a 20-kWh battery was needed for the actual photovoltaic system. This simulation is based on a 1000 kWh consumption.

First, the percentage days with full battery are really similar for the 2 scenarios around 73%, it corresponds to the months where the electricity productions reachs is maximum : fron April to August and most of the time in March and September. The small variation observed is about the percentage day with empty battery that is a bit more important for the 12 kWh battery especially in November and January where the solar radiation are very low. For a low energy consumption, the 12-kWh battery would satisfy the solar laboratory's needs and seems better optimised for it. A 20 kWh would be oversized because it does not even make the solar laboratory an off grid system during winter.

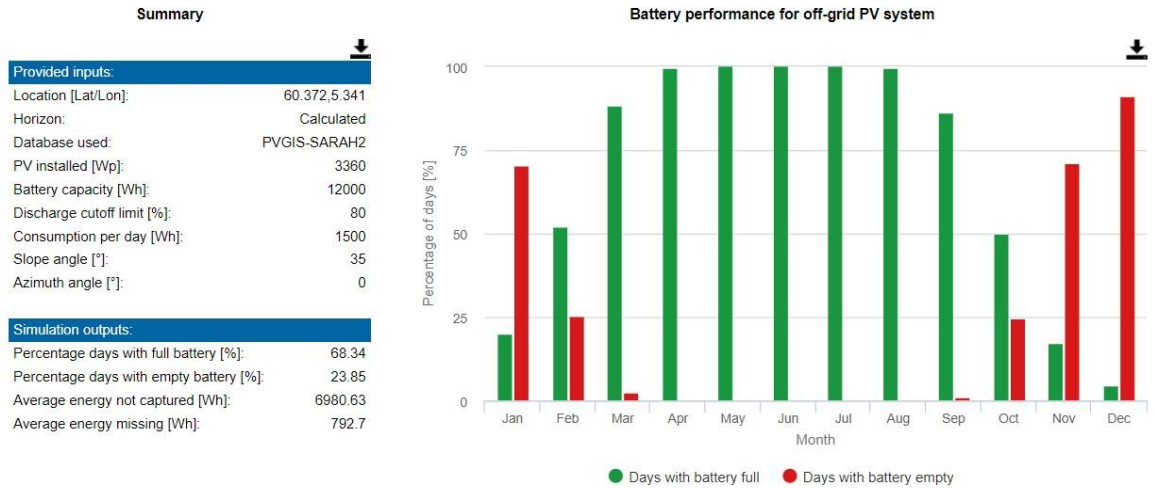


Figure 26: chart representing 12 kWh battery performance for off grid system for 1500 kWh energy consumption

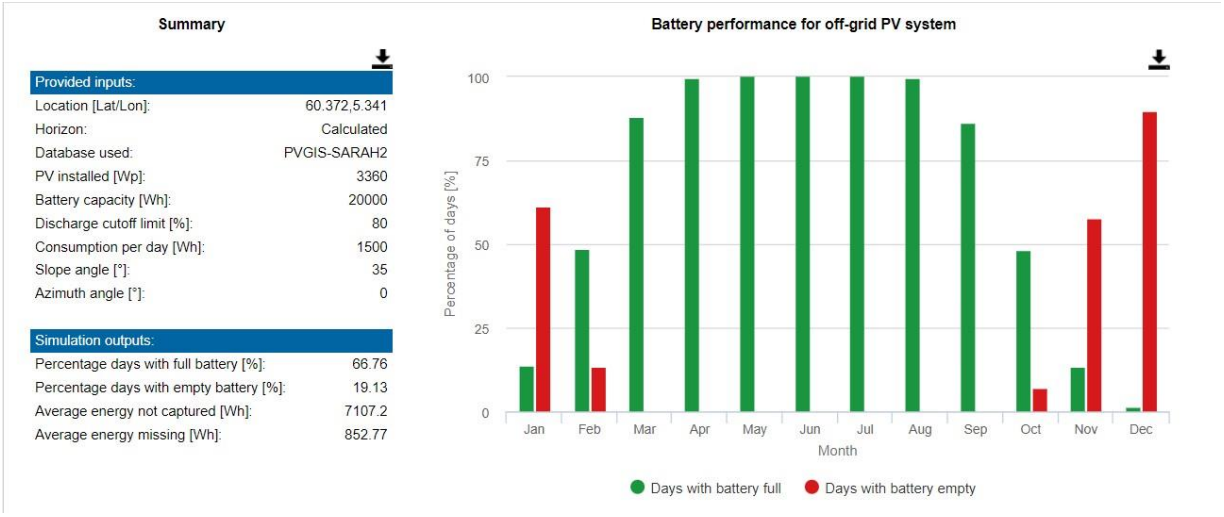


Figure 27: chart representing 20 kWh battery performance for off grid system for 1500 kWh energy consumption

In the 2 charts above, simulations have been done in order to observe if a 12-kWh battery would satisfy electricity demand if this one would increase to reach 1500 kWh per year.

The biggest impact of having a 12-kWh battery instead of a 20 kWh is the number of days where the battery will be empty. A 12 kWh would increase this number of days by 10 to 15% when solar radiation is very low: between October and March. One more time, the 20-kWh battery does not help Solar laboratory to work as an off-grid system. Another source of energy would be needed to satisfy energy demand during winter.

The energy demand during October, November and February could get benefits if a 20 kWh is purchased and 1500 kWh corresponds to the energy consumption. However, for the other months the 20 kWh would be oversized for a low energy consumption, 12 kWh seems interesting even if a EV needs to be charged.

The most important thing regarding those simulations is to keep control of the energy consumption during winter, if this value does not exceed 1000 kWh this meant that the battery will be drained less frequently.

Now that it has been demonstrated that a 12-kWh battery would satisfy the energy demand for 75% of the time, it is necessary to establish a list of battery that would fit with Solar laboratory's needs.

4. State of the art of batteries compatible with SMA

In 2022, a Sunny Island, battery inverter has been purchased in order to manage the electricity stored in the Power Oak Battery. Because an impossibility of communication between the battery and the battery inverter, it has been identified that a new battery needed to be purchase.A list of compatible batteries is given by SMA[27], and all the batteries have been analysed. To reduce this list to keep the most interesting batteries, some criteria have been defined:

- modularity
- compatibility with off grid system
- origin
- Warranty
- number of cycles
- availability
- Price

For all details about the 3 batteries selectionned, a sheet is available in the appendix.

Selected batteries

3 batteries have been identified in order to meet Solar Laboratory energy demand. Then, they have been compared regarding the criteria previously defined.

Manufacturer – Battery name	Capacity	Modularity	Origin	Compatible off Grid	Warranty	Number of cycles - Depth of Discharges	Availability	Price
BYD - Battery-Box Premium LVS 16.0	16 kWh	++	--	++	+	+	++	+
LG CHEM RESU 12 LI-IO	16,5 kWh	+-	+	--	+	+	+	+
Tesvolt TS25 14,4 Battery	14,4 kWh	++	++	++	+	++	-	--

Figure 29 : sheet comparing pros and cons for 3 batteries

Manufacturer – Battery name	Capacity	Modularity	Origin	Compatible off Grid	Warranty	Number of cycles - Depth of Discharges	Availability	Price
BYD - Battery-Box Premium LVS 16.0	16 kWh	cabinet where 1 to 6 4kWh batteries can be connected together. 4 kWh to 24 kWh	China	**Yes**	**10 years**	DoD : 100% Number of cycles : 6000 Design to last 20 years	many suppliers, but many stocks out	7700€ without VAT + 250€ delivery cost = **7950€** **(92400 NOK without VAT)**
LG CHEM RESU	16,5 kWh	2 batteries with the same voltage can be connected in parallel	**South Korea**	No (battery back up systems possible but no off grid systems)	60% 10 years	DoD : 95-100% Number of cycles : 6000 Design to last 20 years	many suppliers	8000€ for 10 LI-IO + 6,5 LI-IO 160€ network cable + 300€ connection box 250€ delivery cost = **8710€** **(100 100 NOK without VAT)**
Tesvolt TS25 14,4 Battery	14,4 kWh	cabinet where 2 to 4 4,8 kWh batteries can be connected together 9.2 to 19.2 kWh	**Germany**	**Yes**	10 years performance5 years product	DoD : 100% Number of cycles : 8000 **Design to last 30years**	few suppliers, few prices	15588€ without VAT + 890€ delivery cost = **16478€** **(192 500 NOK without VAT)** (might be negociated for 185 000 NOK)

Figure 30: sheet comparing all the characteristics of 3 different batteries

Regarding, the sheet above, BYD Battery and Tesvolt Battery seem to be the one that meet Solar Laboratory demands as well as the other requirements.

Indeed, LG CHEM Resu will not be purchased because after a discussion with SMA, it appears that the battery cannot be used in off grid systems which is one of the main requirements for the Solar Laboratory.

BYD battery, had been identified previously by the 2 precedents students because of its reliability, the cost and its availability from a wide range of suppliers. BYD is the market in electric car batteries and one of the leaders for off grid battery, the brand is omnipresent in photovoltaic suppliers. [28]

Tesvolt is a Gigafactory created in 2014 in Germany and plan to be one of the battery leaders in Europe in the next few years. [29] Batteries are manufactured in Germany and the company has an increasing partnership with SMA. .[30] Their market is mostly industrial and commercial batteries, but they also design residential batteries from 9,2 kWh capacity to 24 kWh for example. Their position as a European company is a big advantage in comparison with BYD batteries manufactured in China, but the battery price is high even though the battery has been designed to lasts 10 more years than most today's batteries.

On the 19th of june, many suppliers have been contacted about those 3 identified batteries :

Supplier	Country	Contact	Batteries	Answer	Quotation
Photovoltaïk-shop	Germany	krause@photovoltaik-shop.com	BYD 20.0 LG CHEM RESU 10.0 *2	appendix	YES
Perma-Batteries	France	contact@perma-batteries.com (Julien Allera)	Tesvolt T25 14.4	appendix	YES (battery ressources)
Getek	Norway	morten@getek.no	Tesvolt T25 14.4	Waiting for the quotation	
Nencom	Hungary	1@nencom.com	Tesvolt T25 14.4	No answer	
Inutec	Germany	info@inutec-int.com	BYD 12.0 or 16.0	No answer	
Upwatt	France	info@upwatt.com	LG CHEM RESU 2*10.0	No answer	
Suministrosdelsol	Spain	info@suministrosdelsol.com	Tesvolt T25 14.4	Do no have availability for Tesvolt Battery but they have for BYD	

At this point, Richard showed the sheet where the batteries are compared to his superior to decide which battery will be purchased.

2 quotations can be found in the appendix (cf.appendix 8 and 9).

Conclusion

The conclusion will be more personal regarding my 4 months project:

This project located in Bergen seemed interesting because of special climate conditions and a sunshine very different to France depending on the season. The concept of passive houses and designing an off-grid system were the reasons why I wanted to come to Bergen to carry out my final master's project.

Finally, when I arrived, I understood that I was going to work on a project around IT, in order to develop a Python script to log and analyse solar radiation data. Interested in renewable energies, I am aware that having skills of programming can be important, so I was motivated to improve my knowledge of Python language thanks to tutorials, forums, and projects realised by other people in the world. At the beginning, I mostly followed tutorials and learned some python functions, process, method for 3 weeks and then I started to code for logging data from the pyranometer.

I had some issues with the communication between my computer and the pyranometer because I did not read entirely pyranometer datasheet at the beginning of the project. For few days I tried to communicate with the pyranometer without using Modbus Protocol, so I failed several times without understanding why it did not work because no error messages appeared. I figured it out by myself that some information was available in pyranometer datasheets.

After couple of weeks trying to create a python code, I was able to create a database from pyranometers data and plotting real time data in another program. From this, things started to become more complicated because I wanted to run 2 functions (data in csv file + plot) in the same time so I kept following tutorials but some issues happened and without much knowledge of Python, it was really hard for me to understand what were the problems, and I did not have any professor that could answer my questions even the easiest one. Each issue or error took me a lot of time to be solved because I had to solve them by myself. I only get some help at the end of May after couple of weeks struggling on my python code, but I think that to progress in writing a python code a help is necessary along the whole project no only for one time.

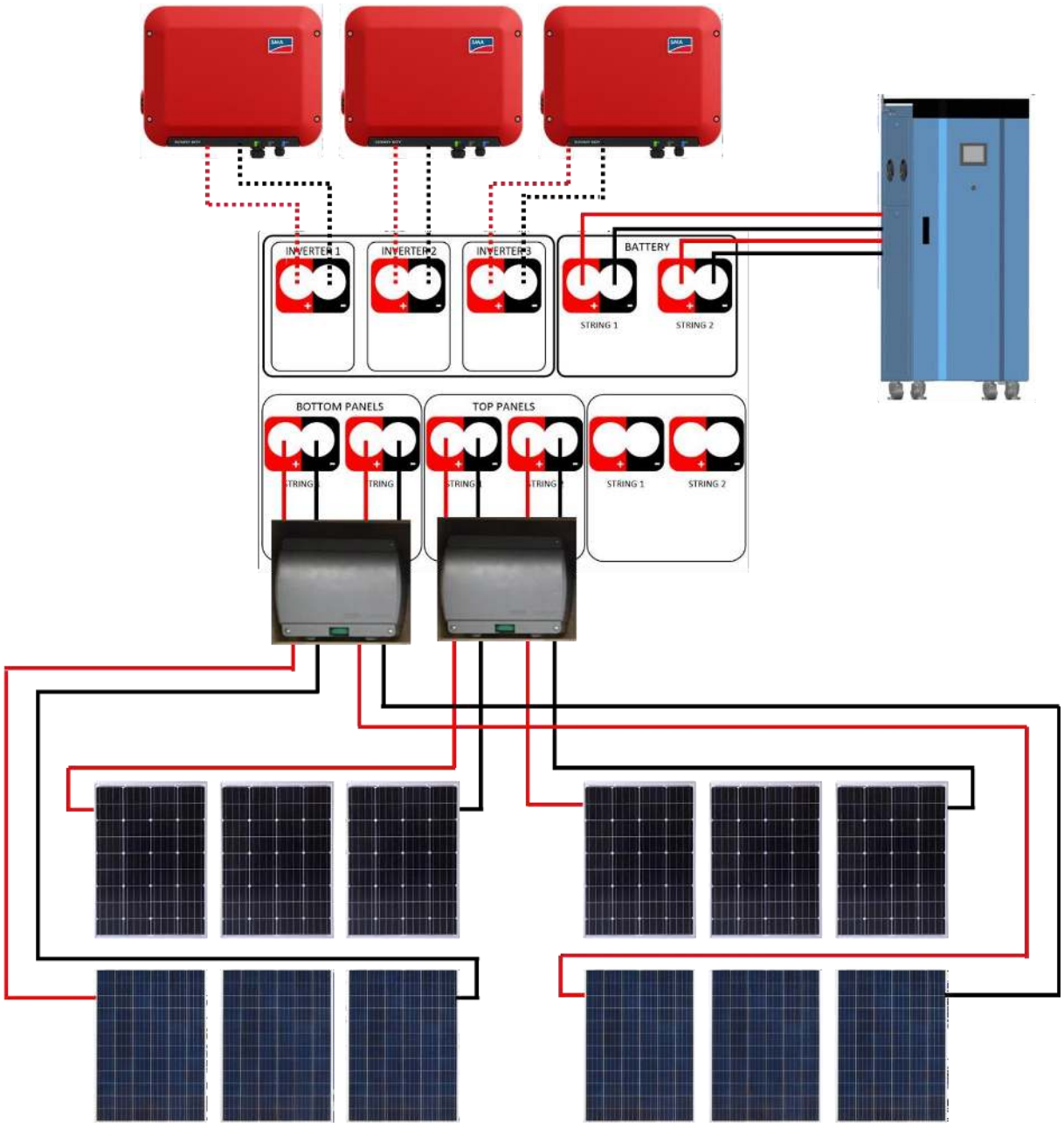
I really missed someone to ask my question during this project, it enabled me to develop more autonomy but to be honest, I also lost motivation sometimes and working alone did not help.

Working in autonomy had also some advantages because I was able to organise my schedule and Richard allowed me to take days off easily. This enabled me to discover Norway and itshmazing views, this Erasmus was mainly about ending my master with an abroad project, but it gave me

the opportunity me to meet many people, discover Norwegian culture and sports, speak English for 5 months which brought me a lot of soft skills.

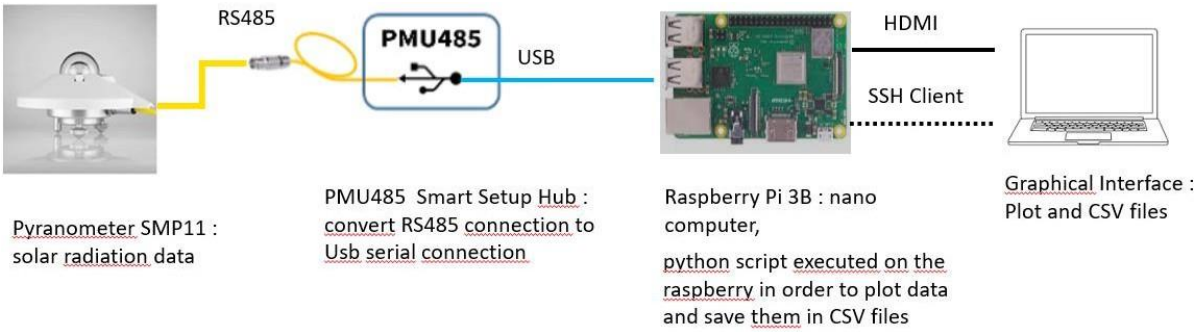
Even though, this project was difficult in terms of autonomous Programming, I would like to thank Richard and Harald for their availability and their time along the project. To integrate better Icam students in the university it would be interesting to follow some classes (about renewable energies or Norwegian language classes) or be part of the mechanical and marine department meeting PhD or other interns that work around other subjects.

Appendix



Appendix 1 : Solar installation system (Solar laboratory)

Appendix 2 : Logging system




```python
import sqlite3
import time

# connect to the database
conn = sqlite3.connect("C:/Users/Tom Bernard/Documents/_ICAM/_Cours/MSR/Project/formation_python/BDD/
mercechatgpt.db")
c = conn.cursor()

# create a table if needed
c.execute('''CREATE TABLE IF NOT EXISTS pyranometer
             (id INTEGER PRIMARY KEY AUTOINCREMENT,
              radiation TEXT,
              unit_r INTEGER,
              temperature TEXT,
              unit_t TEXT,
              time REAL)''')

# define new data
data_pyranometer = []
counter = 1
start_time = time.time()
radiation=0

while time.time() - start_time < 60:
    # get current time and radiation/temperature values
    current_time = time.time() - start_time
    data_pyranometer.append((radiation, "W/m^2", 10, "°C", counter))
    radiation += 20
    counter += 1
    time.sleep(2)

# insert data into the table
c.executemany("INSERT INTO pyranometer (radiation,unit_r,temperature,unit_t,time) VALUES (?, ?, ?, ?,?)",
data_pyranometer)

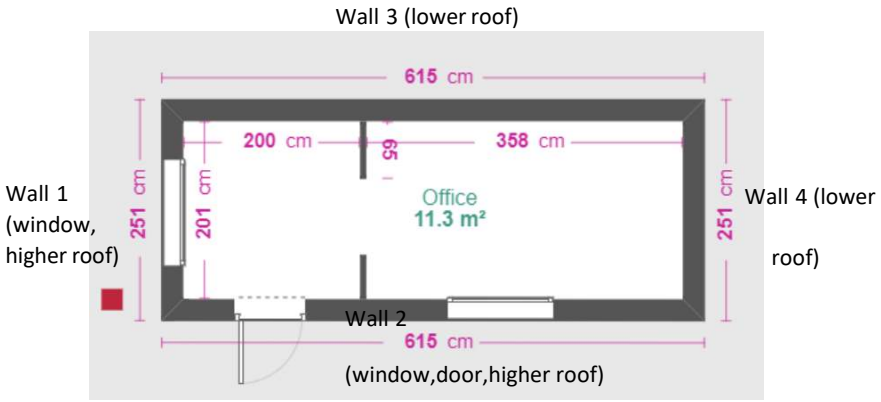
# commit the changes to the database
conn.commit()

# close the connection
conn.close()
```

Appendix 3 : First approach of saving data into a database



Appendix 4 : Heat loss in a house





Appendix 5 : Solar laboratory 2D-3D model

surface	area (m^2)
walls	37.05
windows	2.88
ground	12.61
roof	13.32
door	1.60

Appendix 6 : Solar Laboratory intern surfaces

Passive House planning: **INTERNAL HEAT GAINS**

Calculation: Internal heat household — Persons: 2.8 P — Living area: 134 m² — Heating demand: kWh/(m²a) — Heating period: 219 d/a

Column nr	1	2	3		4	5		6	7	8	9	10
Application	Existing (1/0), or number of people	Within the thermal envelope (1/0)	Norm consumption		Utilization factor	Frequency		Useful energy (kWh/a)	Included in electricity balance?	Availability	Used during time period (kh/a)	Internal heat source Winter (W)
Dishwashing	1	1	1.0	kWh/Amw	1.00	65	/(P*a)	187	*	0.30 /	8.76 =	6
Clothes washing	1	1	1.0	kWh/Amw	1.00	57	/(P*a)	157	*	0.30 /	8.76 =	5
Clothes drying with:	1	1	0.7	kWh/Amw	0.88	57	/(P*a)	90	*	0.70 /	8.76 =	7
Clothesline		1	0.0					0		0.80		
Energy consumed by evaporation	0	1	-3.1	kWh/Amw	0.60	57	/(P*a)	0	*(1- 0)*	0.00 /	8.76 =	0
Refrigerating	0	1	0.0	kWh/d	1.00	365	d/a	0	*	1.00 /	8.76 =	0
Freezing	0	0	0.0	kWh/d	0.90	365	d/a	0	*	1.00 /	8.76 =	0
or combination	1	1	0.4	kWh/d	1.00	365	d/a	150	*	1.00 /	8.76 =	17
Cooking	1	1	0.2	kWh/Amw	1.00	500	/(P*a)	278	*	0.50 /	8.76 =	16
Lighting	1	1	11.0	W	1.00	2.9	kh/(P*a)	89	*	1.00 /	8.76 =	10
Consumer electronics	1	1	250.0	W	1.00	0.55	kh/(P*a)	382	*	1.00 /	8.76 =	44
Household appliances/Other	1	1	50.0	kWh	1.00	1.0	/(P*a)	139	*	1.00 /	8.76 =	16
Auxiliary appliances (cf. aux Electricity sheet)											=	18
Other applications (cf. Electricity sheet)	0	0.0						0	*	0 /	8.76 =	0
Persons	3	1	80.0	W/P	1.00	8.76	kh/a	1948	*	0.55 /	8.76 =	122
Cold water	3	1	-16.9	W/P	1.00	8.76	kh/a				=	-47
DHW - circulation	1	1	70.4	W	1.00	8.76	kh/a	616	*	1.00 /	8.76 =	70
DHW - individual pipes	1	1	48.5	W	1.00	8.76	kh/a	425	*	1.00 /	8.76 =	48
DHW - storage	1	1	22.2	W	1.00	8.76	kh/a	195	*	1.00 /	8.76 =	22
Evaporation	3	1	-25.0	W/P	1.00	8.76	kh/a	-609	*	1.00 /	8.76 =	-69
Total											W	286
Specific demand											W/m²	2.14
Heat available from internal sources									219 d/a		kWh/(m²a)	11.2

Appendix 7 : Internal heat fains for a standard passive house

JK Jonathan Krause <Krause@photovoltaik-shop.com>
À : Tom Thibault Bernard
Mer 17/05/2023 09:46

Dear Mr. Bernard,

thank you for your enquiry. Weh ave a lot of enquiries at this time so we unfortunately can´t reply quickly to all.

We can deliver to Norway. I willl have to check the transportation costs as they are usually higher for batteries as they are risk freight.
I would assume the transportation costs to be 160-240€ dependign on how far north you are.

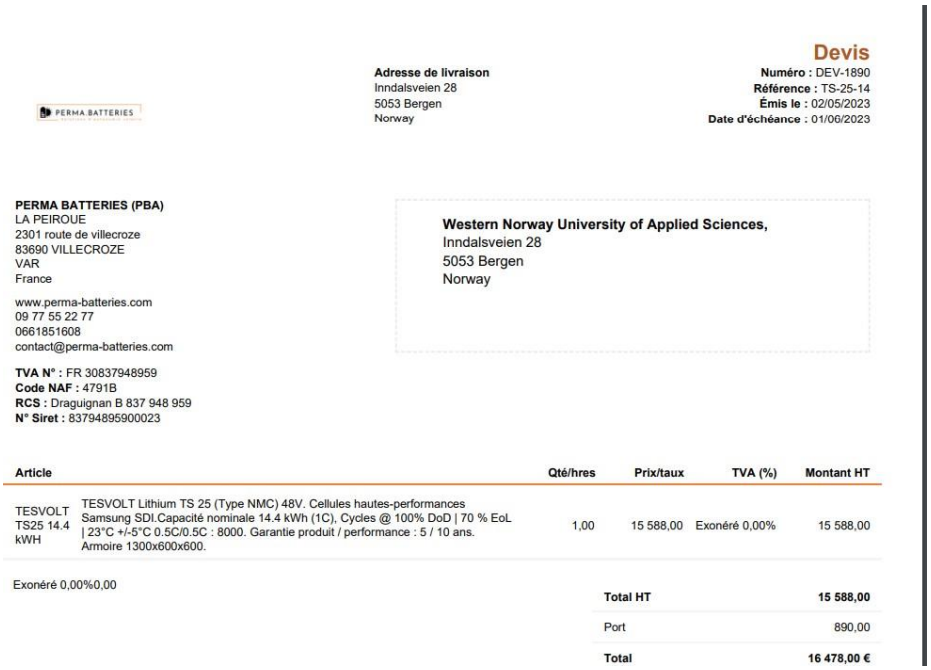
The delivery time is as follows:
BYD LVS 20 - available mid of october, with added shipping time of about 2-3 weeks.
LG Chem Resu 10 - available end of june, with added shipping time of about 2-3 weeks.

The costs would be
BYD LVS 20 - 9.930,92€ net.
2x Lg Chem 10.0 - 9466,66€ net. (the cable connection set, and network cable will be needed also for about 160€ and the connection box to connect two batteries is 284,16€)

Mit freundlichen Grüßen

Jonathan Krause

Appendix 8 : BYD and LG CHEM RESU quotations from photovoltaïk shop (german supplier)



PERMA BATTERIES

Adresse de livraison
Inndalsveien 28
5053 Bergen
Norway

Devis

Numéro : DEV-1890
Référence : TS-25-14
Émis le : 02/05/2023
Date d'échéance : 01/06/2023

PERMA BATTERIES (PBA)
LA PEIROUE
2301 route de villecroze
83690 VILLECROZE
VAR
France

www.perma-batteries.com
09 77 55 22 77
0661851608
contact@perma-batteries.com

TVA N° : FR 30837948959
Code NAF : 4791B
RCS : Draguignan B 837 948 959
N° Siret : 83794895900023

Western Norway University of Applied Sciences,
Inndalsveien 28
5053 Bergen
Norway

Article		Qté/hres	Prix/taux	TVA (%)	Montant HT
TESVOLT TS25 14.4 kWH	TESVOLT Lithium TS 25 (Type NMC) 48V. Cellules hautes-performances Samsung SDI.Capacité nominale 14.4 kWh (1C), Cycles @ 100% DoD | 70 % EoL | 23°C +/-5°C 0.5C/0.5C : 8000. Garantie produit / performance : 5 / 10 ans. Armoire 1300x600x600.	1,00	15 588,00	Exonéré 0,00%	15 588,00

Exonéré 0,00%0,00

Total HT	**15 588,00**
Port	890,00
Total	**16 478,00 €**

Appendix 9 : Tesvolt T25 battery quotation from perma-batteries (french supplier)

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