

Design, Installation and Commissioning of a Solar-Powered Water Pumping System

by

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Conception, installation et mise en service d'un système de pompage d'eau à énergie solaire

Carlos Enrique HERNANDEZ BORJAS

RÉSUMÉ

L'eau est l'un des besoins humains fondamentaux, pourtant aujourd'hui, 2 milliards de personnes dans le monde subissent un stress hydrique au moins un mois de l'année. La disponibilité de l'eau potable est identifiée comme l'un des problèmes majeurs du monde. Les Nations Unies l'ont souligné comme l'un des objectifs de développement durable et des nombreuses autres initiatives ont suivi.

Plusieurs technologies existent pour résoudre cette problématique, maintenant nous avons besoin de la volonté en tant que communauté mondiale pour y parvenir. L'une des solutions techniques possibles est la généralisation des systèmes de pompage d'eau photovoltaïques (PVPS). Le PVPS a l'avantage de pouvoir être utilisé dans des endroits éloignés, d'être facile à mettre en œuvre et d'être rentable.

Le but de cette étude est de concevoir, construire, tester et comparer deux systèmes de pompage complets, l'un avec batterie et l'autre sans. Dans un premier temps, les systèmes à petite échelle seront installés et testés à l'Héliolab Michel Trottier sur le toit de l'ETS. Ensuite, un système à grande échelle sera conçu pour une installation et des tests ultérieurs, sur un site de cas réel.

Les résultats ont montré qu'un système alimenté par batterie est plus efficace et flexible, tandis qu'un système à entraînement direct est plus économique. Combiner le PVPS avec un réservoir et ajuster la consommation aux conditions météorologiques est avantageux. Les conditions hivernales ont un impact important sur la production d'énergie solaire. La surveillance à distance est très pratique, en particulier pour les applications autonomes.

La pré-conception d'un cas réel d'application dans la région sub-saharienne a démontré la faisabilité de systèmes moins chers.

Il est recommandé d'améliorer le système de contrôle, de concevoir un support mécanique portable pour les panneaux solaires et leurs composants, et de tester dans différentes conditions de fonctionnement, y compris l'utilisation d'un réservoir.

Mots-clés : pompage d'eau photovoltaïque, communautés isolées, hors réseau, dimensionnement, systèmes d'énergie solaire

Design, installation and commissioning of a solar-powered water pumping system

Carlos Enrique HERNANDEZ BORJAS

ABSTRACT

Water is one of the basic human needs, yet today, 2 billion people in the world experience water stress at least one month of the year. The availability of drinking water is identified as one of the world's major problems. The United Nations have highlighted it as one of the Sustainable Development Goals and many other initiatives followed.

Several technologies exist to solve this problem, now we need the will as a global community to achieve this. One of the possible technical solutions is the widespread implementation of photovoltaic water pumping systems (PVPS). PVPS has the advantage that it can be used in remote locations, is easy to implement and is cost-effective.

The purpose of this study is to design, build, test and compare two complete pumping systems, one with a battery and a second without. Initially, the small-scale systems will be installed and tested at the Héliolab Michel Trottier on the roof of ÉTS. Then, a full-scale system will be designed for later installation and testing, at a real case site.

The results showed that a battery-driven system is more efficient and flexible, while a direct-driven system is more economical. Combining the PVPS with a reservoir and adjusting the consumption to the weather condition is advantageous. Winter conditions have an important impact on solar energy production. Remote monitoring is very convenient, especially for stand-alone applications.

The pre-design of a real case application in the sub-Saharan region demonstrated the feasibility of cheaper systems.

It is recommended to improve the control system, design a portable mechanical support for the solar panels and their components, and test under different operating conditions including the use of a reservoir.

Keywords: photovoltaic water pumping, isolated communities, off-grid, sizing, solar energy systems

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LIST OF ABBREVIATIONS

AC	Alternative Current
CP	Centrifugal Pump
DNI	Direct Normal Irradiance
DHI	Diffuse Horizontal Irradiance
DC	Direct Current
DP	Displacement Pump
e.m.f.	Electro-motive force
ETS	École de Technologie Supérieure
FH	Friction Head
GHI	Global Horizontal Irradiance
LLP	Loss of Load Probability
MPP	Maximum PowerPoint
MPPT	Maximum Power Point Tracker
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
PHS	Pump Hydro System
PVPS	Photovoltaic Water Pumping System
PV	Photovoltaic
SAM	System Advisor Model, made by NREL
SOC	State Of Charge
SOF	State Of Filling
STC	Standard Conditions

SH	Static Head
T3E	Energy Technologies and Energy Efficiency
TDH	Total Dynamic Head
TMY	Typical Meteorological Year
UN	United Nations
VFD	Variable Frequency Drives
WHO	World Health Organization

LIST OF SYMBOLS

α_{SC}	Temperature dependence coefficient of ISC	%/°C
β_{OC}	Temperature dependence coefficient of VOC	%/°C
ω	Angular speed rad/s	
η_{mp}	Efficiency of motor-pump	
Φ	Magnetic flux Wb or V.s	
a	Ideality factor parameter	V
E_p	Energy of the pump	W
I	Irradiance	W/m ²
I_h	Horizontal irradiance	W/m ²
I_p	Perpendicular irradiance	W/m ²
I_D	Current through a diode	A
I_L	Photocurrent	A
$I_{L,ref}$	Photocurrent at STC	A
I_0	Diode reverse saturation current	A
I_a	Current through motor armature	A
I_{SC}	Short-circuit current	A
L_a	Armature inductance	H
M_S	Number of modules in series	
M_P	Number of modules in parallel	
P_e	Electric Power	W
Q	Water flow rate	L/min
K_E	Electromagnetic constant of a motor	V.s.rad-1
K_m	Torque constant of a motor	N.m.A-1
R_{load}	Resistance at the terminal of a PV cell or module	Ω
R_S	Resistance in series with R_{load}	Ω
R_{SH}	Resistance shunt, in parallel with R_{load}	Ω
R_a	Intrinsic armature resistance of a motor	Ω
T_m	Torque of a motor	N.m
T_p	Torque of a pump	N.m

V_OC Open-circuit voltage V

V_a Voltage at terminals of motor armature V

W Power W

W_p Unit for peak power of a photovoltaic module W

INTRODUCTION

Water, one of humans' basic needs. We can live weeks without food, but only days without water. (Spector, 2018).

Nowadays, 2 billion people worldwide experience water stress at least a month during the year, a quarter of healthcare facilities lack basic drinking water, and with the continuing population growth and droughts, the situation will continue to worsen. (<https://www.un.org/sustainabledevelopment/water-and-sanitation/>).

Lack of water is a trigger for hunger, health issues and underdevelopment. It can cause entire populations to be displaced from their original settlement and even generate wars.

Available drinking water is identified as one of the world's major problems. The United Nations have highlighted it as one of the Sustainable Development Goals: to *Ensure availability and sustainable management of water and sanitation for all*. Many other initiatives have followed.

Several technologies exist to tackle this problem, now we need the will as a world community to get it done.

One of the possible technical solutions is the widespread implementation of photovoltaic water pumping systems (PVPS). PVPS has the advantage that it can be used in remote locations, is easy to implement and is cost-effective. The motivation to address this issue is to make a water pumping solution available for remote locations at an affordable price.

The purpose of this study is to design, build, test and compare two complete pumping systems. First, the small-scale systems will be installed and tested at the Héliolab Michel Trottier on the roof of ÉTS. Then, a full-size system will be designed for later installation and testing, on a real case site.

Ultimately, a water pumping system for rural areas will be available for global commercialization. It will be affordable, and easy to transport and install. The system will make it possible to have or facilitate access to water for rural communities with a low environmental impact.

The specific objectives of the study are limited to:

- Design and install a small-scale photovoltaic water pumping system,
- Compare two similar systems, one with a battery and a second without,
- Pre-design a full-size system.

Other activities that lay outside of the scope of the present study are:

- Optimization of the small-scale PVPS,
- Installation and testing of a full-size PVPS,
- Commercialisation of final PVPS design.

This thesis is divided into five chapters. Chapter 1 proposes a literature review of relevant scientific articles starting with the water needs across the world, then the principles of PVPS, the factors of its design, their alternatives usages, means of measurement and existing simulation tools. Chapter 2 presents the methodology to design and optimize the systems to be tested with relevant details of the complete experimental installation, data acquisition and commissioning. Chapter 3 proposes selected results and their associated discussions. Based upon the previous results, Chapter 4 briefly presents the design and simulation of the performance of a full-scale system as a potential type of application in rural locations. The last chapter involves a summary and concluding remarks.

CHAPTER 1

LITERATURE REVIEW

1.1 Defining the water need

The United Nations estimates that human beings' basic needs are met by at least 50 litres of water a day. In comparison, in developed countries, the average water usage could go up to 600L per day. (United Nations, 2019).

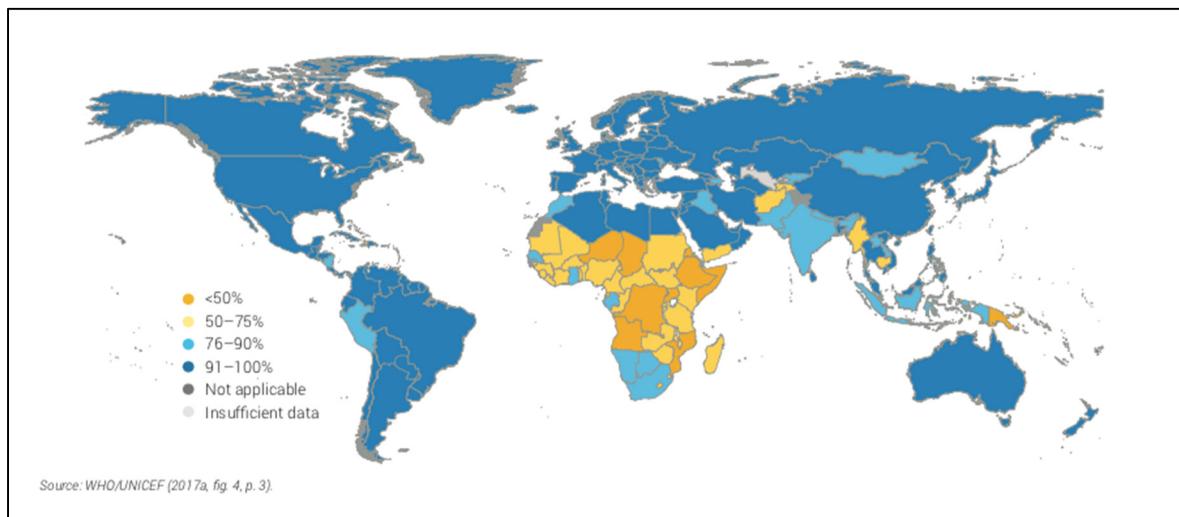


Figure 1.1 Proportion of the population using at least basic drinking water services, 2015
Taken from UN (2019, p. 19)

Clear water is highlighted as one of the Sustainable Development Goals to *Ensure availability and sustainable management of water and sanitation for all*. UN indicates that 30% of the world population does not have access to safe drinking water, where half of them are in Sub-Saharan Africa, as shown in Figure 1.1. In such areas, getting water becomes a daily task for girls and women, a time and effort that could be used more productively for their personal and community development. (United Nations, 2019).

Figure 1.2 show a common method for women to bring water to their while Figure 1.3 the burden of collecting water distribution by gender and age.



Figure 1.2 Common method for women to bring water to their village
Taken from UN (2019, p. 49)

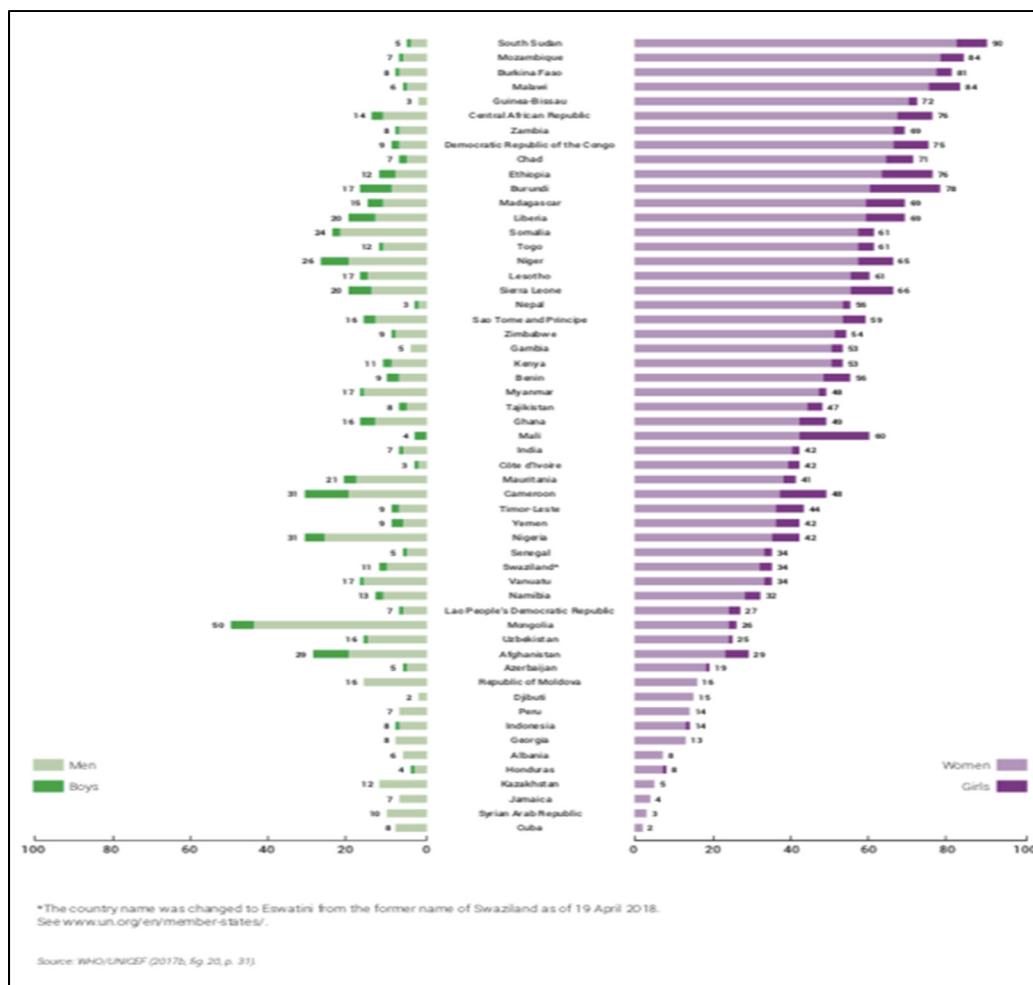


Figure 1.3 Burden for collecting water in rural areas, by gender and age (%), in countries where at least 1 in 10 households have water off premises
 Taken from UN (2019, p. 50)

Nonetheless, not all water necessities are for drinking needs. Hygiene and sanitation are also important as cooking, cleaning, washing, agriculture, etc. Then, comfort and entertainment.

Impacts of the lack of clean water range from many health problems to personal care and social issues. There is a problem of absenteeism from school for teenage girls when the premises are not well provided with clean water. (United Nations, 2019).

Water availability helps improve the Human Development Index. Access to water means more health, more crops, more food, and more revenue. During a study completed in poor rural areas of the Michoacan State of Mexico, it was calculated the impact of the water, electricity and food availability and trade between several municipalities for farming, industry, and human consumption. It was shown that the exchange among the communities can potentially increase the HDI of all of them. (Martínez-Guido, González-Campos & Ponce-Ortega, 2019).

On another extreme, in a case study made on the water consumption of remote Australian aboriginal villages in harsh isolated locations, it was found the average household could use up to 1500L/person/day. These villages are located in desert areas and tropical islands. They noted that up to 86% of the usage was for outdoor activities such as watering the land to avoid dust, cooling surfaces, cleaning the house and fishing boats or just playing. (Beal et al., 2017)

Many factors play a role in such high consumption: their environment, cultural customs, and even political issues. These aboriginal groups do not pay for water or electricity services as they feel is their right to the land that was taken by the westerners, so it is a controversial matter. (Beal et al., 2017)

Based on a 4-person family group, it is chosen a target amount of 400L/day per household for this study.

1.2 PVPS principles

The basics of a Photovoltaic Pumping System (hereafter PVPS, sometimes also called Photovoltaic Solar Pumping System - PVSPS) is the use of solar energy as a power source to displace the water mass.

Historically water has been transported from its source to its consumption location manually or by gravity. Water pumps can be traced back to 200 BC with Archimedes' inventions, but it

is not until the invention of the electric motor that we can have modern electrical pumps. (Pumps & Systems, 2011).

With the recent advances in photovoltaic technologies, the pairing of using the sun to move water can be found in many applications. The principle is to convert the sun's energy into electricity, use the electricity to move an electrical motor, to move a water pump, to raise the water.

The principal components of a PVPS are:

- Solar panel, or array,
- Pump-motor,
- Controlling devices.

1.2.1 Based on the energy storage, PVPS can be battery-coupled or direct driven.

A battery-coupled system will include a charge controller and a battery which allows longer pumping time, including shaded days, mornings, evenings and even nights. Obviously, the use of batteries tends to increase the cost and reduce the efficiency of the system. It is sometimes less recommended. (Sontake & Kalamkar, 2016).

A directly driven system will use a pump controller or converter to connect the solar array to the pump. Pumping is directly linked to solar irradiance so the system will only operate during daylight under sufficient conditions. The loss of water delivered is usually compensated with a larger water storage tank. (Sontake & Kalamkar, 2016). Figure 1.4 shows a typical schematic of both system types.

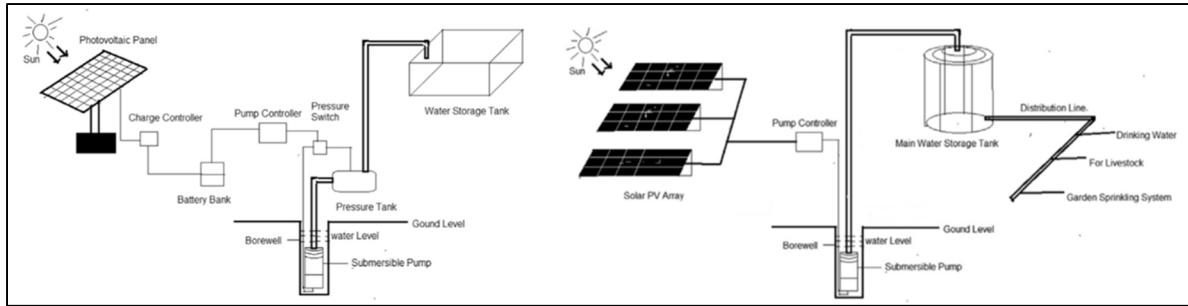


Figure 1.4 Schematic of typical solar PV water pumping system, battery-couple (left), direct-driven (right)
Taken from Sontake & Kalamkar (2016, p. 1041)

1.2.2 Based on the pump type: surface mounted (suction) or deep well (submersible)

Surface pumps can be used to move water long distances and at high elevations but are limited in their suction capability if required to pull water from deep wells. They usually have higher mechanical issues and failure rates, for example, loss of suction water and pumping air will cause the pump to overheat and fail. One of their advantages is that they do not require digging a well. (Sontake & Kalamkar, 2016).

Deep-well or submersible pumps must be completely underwater to push the liquid up the column. As they are installed in underground wells, they are more protected from climate and freezing conditions. Their overall efficiency tends to be higher than suction pumps. (Sontake & Kalamkar, 2016).

1.2.3 Based on power input: DC or AC

A solar panel produces direct current therefore in a certain way, connecting a DC water pump would make more sense. DC pump motors are usually with brushes, which wear out and require more maintenance; or brushless, making them more efficient, silent and reliable. A DC pump will make the system limit the power losses compared to an AC pump but on the other hand, DC systems usually work on lower voltages than AC systems, then higher amperage

means thicker wire and stronger protective devices, increasing the system's costs. (Sontake & Kalamkar, 2016).

An AC pump will additionally require an inverter to convert DC power to AC. The extra component will decrease the system's efficiency. An advantage of this type of pump is that it could be connected to the electrical grid as a hybrid system. AC pumps can work on multiple electrical phases and can couple more powerful motors. They are most efficient for larger systems. (Sontake & Kalamkar, 2016).

1.3 Factors of PVPS design

A study made by Watson and others. analyses the impact of operational flexibility and load-sizing on the overall system cost. They introduced the principle of loss of power supply probability (LPSP) during their calculations and noted that 100% output reliability is rarely required in real conditions. In the first part of their study, a reference system was simulated to operate for a fixed 8hrs a day throughout the year and compared to a flexible operating schedule that best matches the characteristic of the solar irradiance in that location, it would operate more hours on longer sunny days and less on cloudy or shorter days while averaging 8hrs/day for the year. Such operation improves the overlap of the load with the solar irradiance and the PV power profile thus requiring a smaller battery bank. The analysis demonstrates a 39% cost reduction of the system and requires a smaller PV array. It is highlighted that flexible operation is cost-effective if the cost of product storage is lower than the PV system cost savings. (Watson et al., 2018)

The second part of the study considers optimizing the load sizing. It is assumed a fixed energy output (Wh) while the system size and the operating hours vary inversely. For example, a 1kW PV system running for 2hrs will have the same output as a 0.5kW system running for 4hrs. With this approach, it was found that an additional 5% could be saved from the reference system. (Watson et al., 2018)

After combining both methods, a total of 43% of the cost could be saved. (Watson et al., 2018)

Another important factor when designing a PVPS is the storage tank. The tank, in a similar way to a battery, will store the surplus of water pumped, instead of electricity, to be used when there is a deficit in demand. The size of the tank has to be big enough so the water will not overflow and be wasted but small enough to limit the initial installation cost. Another factor to consider is the possibility of growing bacteria and waterborne disease transmission, because a tank too large will stagnate water longer, and the material of the tank also has to be considered. As an example, a study case in the Sahara Desert noted that in hot climates steel or PVC tanks heat the water inside faster than concrete tanks, thus increasing the risk of bacterial growth, and even though they are cheaper they should be avoided. During this study, it was calculated that for a defined LPSP, or in this case the ratio of the volume of water deficit to the volume required, the size of the PV array is inversely proportional to the size of the tank. The Sahara is one of the locations which receives the most solar radiation in the world so their daily water need can be met with low storage capacity. Another significant conclusion is that the month with the largest production deficit, December, corresponds with the seasonal low water needs. The study continued with an economic analysis of the PV system and tank size including LPSP, initial and maintenance costs, and pumping head factors providing recommendations on their particular circumstances. (Bouzidi, 2013).

1.4 Alternative usages

There are many applications for which PVPS can be applied. Taking it one step further, a PVPS can be used as a part of a Pump Hydro System (PHS). These systems consist in using solar energy to pump water from a low reservoir to a higher reservoir to later use the gravity force of the water mass to generate electricity through a hydroelectric turbine. It is best applicable where optimal solar conditions are met and the geography permits it. The reservoir, which is sometimes a dam, takes up about 90% of the total cost of the project. Energy storage is a global concern for renewable energy systems and PHS is a solution for large grid-scale systems, under favourable conditions. (Javed et al., 2019).

Another common application of solar pumping is an electro-dialysis reversal (PV-EDR) desalination system. Not only will the PV array pump the saltwater but will also power the desalination plant to filter, process and deliver it ready for consumption. It is particularly interesting in these types of systems that both the water consumption and production are linked to the weather and solar irradiance: the sunnier (and hotter) the day will be, the greater the water usage but also the larger PV energy produced. (Watson et al., 2018)

Irrigation is an additional main use of pumped water, especially in rural areas where electricity and water distribution systems are less accessible. Special attention has to be given when designing a PVPS for irrigation because of the nature of water demand. Crops works by season and the different periods of the harvest have very different consumption of water. As an example, in a case study in Xining, China, growing Alfalfa presents variable water demand during the harvest season from May to September. The precipitations for the period are also incorporated in the simulation as it is a very important factor because they satisfy an important amount of the produced water need, and they are also variable throughout the year (Campana, Li & Yan, 2012). Another example is a project planned by an NGO (Twende Solar) to irrigate a fig farm in Peru; it is planned to use a 3-phase 15 HP submersible pump power by a 15kW solar array for 1.5 ha of plantation (<https://twendesolar.org/tarpuy-peru>).

Livestock watering is yet another common PVPS application. The demand is more linear compared to irrigation, and much larger than human consumption.

1.5 Measurements

To control the performance of the system and especially in experimental tests, it is key to make precise and accurate measurements of parameters. Typical measurement points for an experimental PVPS are carried out at the panel, at the battery (if applicable) and at the pump.

At the first point of control is important to measure the PV output current and voltage. Additionally, the temperature and the solar irradiance. Solar irradiance measurement can be performed by a pyrometer or a solarimeter. (Kaldellis, Meidanis & Zafirakis, 2011).

The battery voltage and charging current can be done by an MPPT and battery monitor. Alternatively, an ammeter and voltmeter are sufficient. The battery state of charge can be calculated by a battery monitor. (Kaldellis, Meidanis & Zafirakis, 2011).

Finally, the flow rate of pumped water (volume/time) for a predetermined head (h) can be measured by a tube flow meter (LoFlow). (Kaldellis, Meidanis & Zafirakis, 2011).

1.6 **Simulation tool (software)**

PVPS systems are an important investment therefore it is preferable to avoid oversizing them. However, undersizing it will result in a shortage of water supply. To optimize the system size will be best to predict its output as precisely as possible by simulation.

There is many software available to simulate the performance of photovoltaic systems, they can help predict the output and reliability in order to optimise the system design. Some are useful for grid-tied applications only, while others can include the storage capacity of an off-grid configuration, and some can go deeper and incorporate a water pumping system. In the next paragraphs are a summary of some pertinent simulation tools.

PV watts, developed by the US National Renewable Energy Laboratory (NREL), allows estimating energy production worldwide. Using parameters such as geolocation, the array's tilt and azimuth the tool can estimate the solar radiation and energy produced monthly and even hourly. A .csv format output allows the user to make different data treatments. Since a PVPS is directly linked to the solar radiation received this information is very useful to calculate the system water output. The tool is free to use online. (<https://pvwatts.nrel.gov/>).

PV Syst, a software that allows to design and size the entire photovoltaic pumping system. It permits to integrate shading analysis for a fixed predetermined location. As a result, the software simulates the energy production, its performance, and graphically shows the energy gains and losses thru a Sankey diagram. Other parameters can be simulated such as grid storage component ageing and weather. It is paid software to be installed on the computer to be used. (Sharma, Sharma & Tiwar, 2019).

HOMER is a simple and user-friendly tool developed by the NREL. It can analyze off-grid and on-grid micro-systems allowing a techno-economical assessment and environmental analysis. It provides simulation, optimization, and sensitivity evaluation. (<https://www.homerenergy.com/>).

Pvpumpingsystem, an in-house software developed by the t3e Group, ETS, is a python-based tool that allows to simulate photovoltaic water pumping systems. The software considers factors such as weather data for a particular location, irradiance on a tilted plane, solar panel data (V, A, efficiency), absorption, the type of coupling (direct or thru MPPT), water pump parameters and the loss of load probability. As a result, the tool provides a factorial sizing of the PV system and the pump. (Gualteros Martinez, 2017).

1.7 Summary

The review of relevant scientific articles carried out here can be grouped into 3 categories:

- studies involving the water need and its impacts, such as the amount of water required, their usage and the impact on their population,
- studies designing or modelling PVPS, describing the systems' components and operation and a software simulation for sizing, performance, and economic analysis,
- studies designing or modelling alternative types of systems, for pumping systems powered by wind, used for desalination plants or storage for hydro-electric generation.

Table 1.1 represents a summary of all articles with respect to these categories:

Table 1.1 Literature review summary

Article	Water impact	PVPS design & modelling	Alternate systems design & modelling
Beal et al., 2017	X		
Bouzidi, 2013		X	
Campana, Li & Yan, 2012	X	X	
Gualteros Martinez, 2017		X	
Javed et al., 2019		X	X
Kaldellis, Meidanis & Zafirakis, 2011		X	
Maisanam et al., 2017		X	
Martínez-Guidoa, González-Campos & Ponce-Ortega, 2019	X		
Santibañez-Aguilar et al., 2020	X	X	
Sharma, Sharma & Tiwar, 2019		X	
Sontake & Kalamkar, 2016		X	
Sreewirote, Noppakant & Pothisarn. 2017		X	
Watson et al., 2018		X	X
Yaichi et al., 2019		X	

CHAPTER 2

METHODOLOGY

2.1 System design

The system design starts with the amount of water need, then a pump was chosen to comply with the target. Following, the amount of energy required to operate the pump. To compare, 2 similar systems are designed: one with direct electricity from the solar panel to the pump, the second with an energy storage option.

From commercially available components the following were chosen:

- 1 gallon per minute centrifuge water pump,
- 100-watt solar panel,
- DC-DC converter from 24V to 12V,
- MPPT 20Amps,
- 12V 90Ah AGM battery,
- Battery monitor,
- Protective devices (fuses, breakers, etc).

2.1.1 Photo-Voltaic Pumping System #1

This system is designed to power the water pump directly from the solar panel. However, since the panel's output power ranges from 17.9V to 21.6V and the pumps operate with 12V it requires a direct current converter.

The pump will start to operate at approximately 1.5A and up to 2.5A. This means that it will operate when there is enough solar irradiation to provide 1.5A and will shut off the rest of the time. Typically, it will start working in the morning until late afternoon. A diagram for PVPS #1 is shown in Figure 2.1.

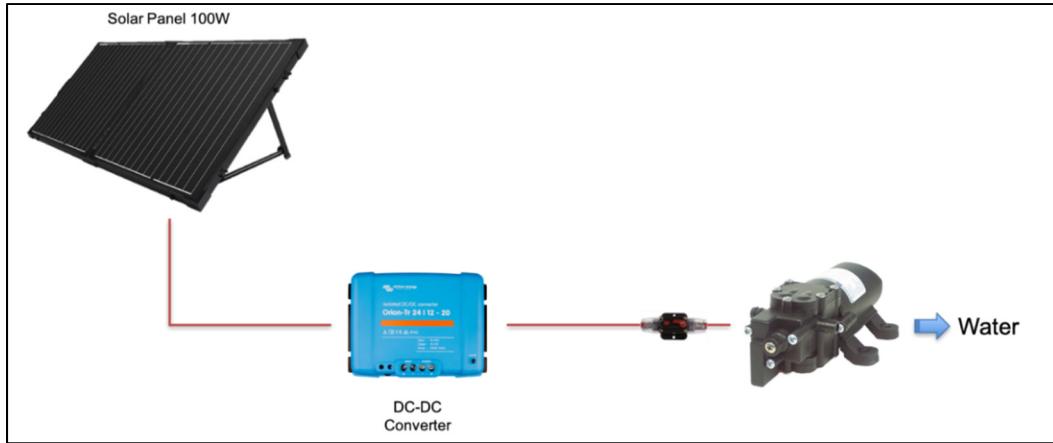


Figure 2.1 Diagram of PVPS #1

2.1.2 Photo-Voltaic Pumping System #2

This system is designed to charge a battery by the solar panel, which in turn will power the water pump. The pump operates at 12V therefore the battery is also 12V, and since the panel's output power ranges from 17.9V to 21.6V it requires a charge controller. An MPPT is used for this purpose. Typically, the pump can operate any time of the day until the battery is depleted and will restart the next day when the battery recharges sufficiently. A diagram for PVPS #2 is shown in Figure 2.2.

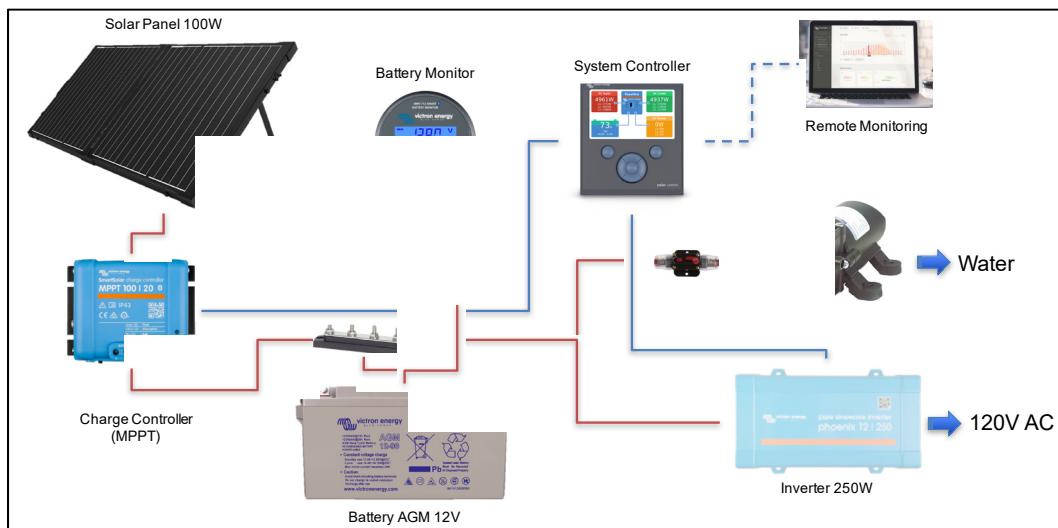


Figure 2.2 Diagram of PVPS #2

2.1.3 Load definition

Defining the electrical load is a key element of a photovoltaic system design. The departure point is a baseline of 400L/day of water usage.

Using a commonly available 12V water pump of 1 gallon per minute (3.7854 L/min) at the full regime for a pressure of 10 PSI (7 bar) the current drawn is 1.7 amps at 12V (see Figure 2.3 and Table 2.1).

The pump running time:

$$400 \text{ L/day} / 3.7854 \text{ L/min} = 106 \text{ min/day} \quad (2.1)$$

The pump's energy consumption:

$$E_p = 12 \text{ V} \times 1.7 \text{ A} \times 106/60 \text{ h} = 36 \text{ Wh} \quad (2.2)$$

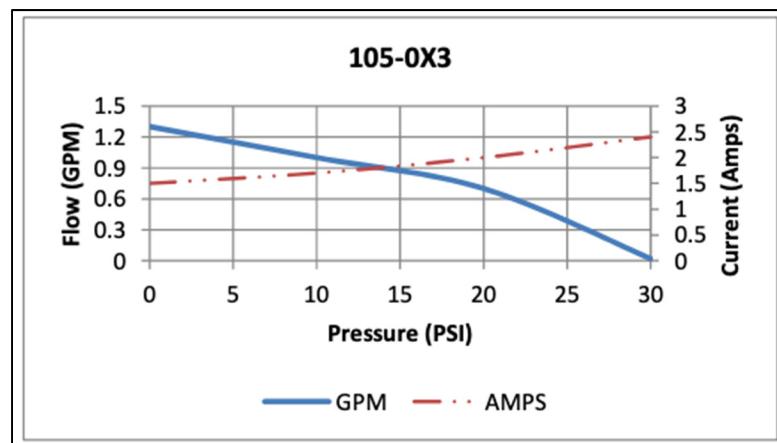


Figure 2.3 Water pump regime as a function of pressure

Table 2.1 Typical water pump performance at 12V under several pressures

PRESSURE		FLOW		CURRENT
BAR	PSI	GPM	LPM	AMPS
0	0	1.3	4.9	1.5
0.7	10	1.0	3.7	1.7
1.4	20	0.7	2.6	2.0
2.1	30	0.2	0.7	2.4

2.1.4 Battery storage

PVPS #2 includes a battery for energy storage. A typical off-grid application considers a 50% depth of discharge for the battery and a 3-day autonomy. The required storage capacity is calculated as follows:

$$Avg \frac{Wh}{day} \div Dc \text{ system voltage} = Amps - hours ; \quad (2.3)$$

$$\begin{aligned} Amps - hours \div \text{depth of discarge} \times \text{days of autonomy} \\ = \text{battery bank amps - hour} \end{aligned} \quad (2.4)$$

$$36Wh / 12 V = 3 Ah ; \quad 3 Ah / 50\% \times 3 = 18 Ah \quad (2.5)$$

For such system, the minimum required is a 12V battery with an 18Ah capacity. A 12V battery system is chosen to simplify the installation since most dc appliances are powered by 12V, including the water pump.

A commonly available 12V battery with a capacity of 90Ah is used.

2.1.5 Solar array calculation

The photovoltaic array is calculated from the required load at the specific location.

For Montréal (Lat, Lon: 45.49, -73.54) with a south-facing solar array at 45° tilt, the solar radiation ranges between 2.54 kWh/m²/day (in December) to 5.54 kWh/m²/day (in July) for an annual average of 4.44 (kWh/m²/day), as seen in Figure 2.4.

The worst-case scenario is used, 2.54 kWh/m²/day.

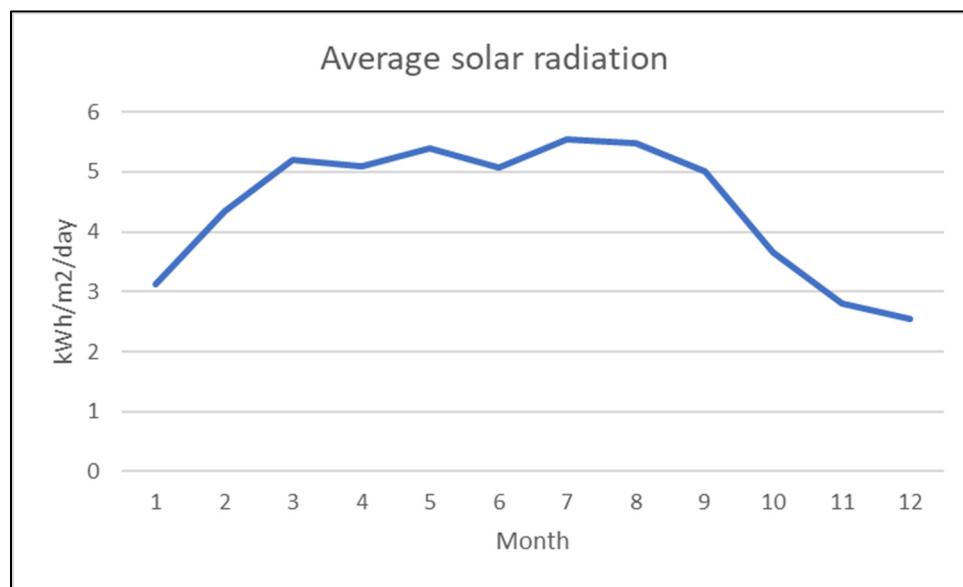


Figure 2.4 Average solar radiation for Montreal, CA

$$Avg \frac{Wh}{day} \times system derate factor \quad (2.6)$$

$$\begin{aligned} &\times charge controller efficiency \\ &\times battery efficiency \times peak sun h per day \\ &= total array watts \end{aligned}$$

$$36Wh \div 0.8 \div 0.98 \div 0.8 \div 2.54h = 22.6 W \quad (2.7)$$

The minimal requirement for system #2 is 22.6 W_p of a solar array, a commonly available panel of 100W is used.

By doing the analysis backwards, the total available Wh and Ah in a day are:

$$100W \times 0.8 \times 0.98 \times 0.8 \times 2.54h = 159.3 \text{ Wh} \quad (2.8)$$

$$159.3\text{Wh} \div 12V = 13.3Ah \quad (2.9)$$

2.1.6 MPPT

The 100W module open circuit voltage is 22.3 V. Temperatures lower than 25°C (standard testing conditions) increase the output voltage. Considering a minimum for Montreal of -30°C the maximum voltage to consider is:

$$22.3V (1 + (-30^\circ\text{C} - 25^\circ\text{C}) \times -0.28\%/\text{^\circ C}) = 25.7 \text{ V} \quad (2.10)$$

The charge controller must be compatible with a maximum input voltage of 25.7V. Likewise, lower temperatures increase the power output of the solar module. A similar consideration is taken:

$$100W (1 + (-30^\circ\text{C} - 25^\circ\text{C}) \times -0.37\%/\text{^\circ C}) = 120.35 \text{ W} \quad (2.11)$$

The maximum current that could be converted by a charge controller is:

$$120.35 \text{ W} \div 12V = 10.03 \text{ A} \quad (2.12)$$

A charge controller type MPPT with an input of 100V and an output of 20A was chosen.

2.1.7 Dc-dc converter

PVPS #1 powers the water pump directly from the solar module. Since the module's optimum operating voltage (Vpm) output is 17.9V and the pump's input is 12V a dc-dc converter is required.

Similar to the previous calculation, the maximum current that could be converted by a dc-dc converter is:

$$120.35 \text{ W} \div 12\text{V} = 10.03 \text{ A} \quad (2.13)$$

A dc-dc converter 24V to 12V with a maximum output of 20A was chosen. The voltage input range for the selected dc-dc converter is 16-35V.

For the pump to work at full capacity the minimum current needs to reach 1.7A.

$$I \times V \div \text{converter efficiency} = \text{minimum solar output} \quad (2.14)$$

$$1.7A \times 12V \div 88\% = 23.2W \quad (2.15)$$

A solar panel's efficiency is reduced in low luminosity, however, the minimum solar irradiance for a 100W to reach 23.2 W output is approximated to

$$\frac{23.2W}{100W} \times 1000W/m^2 = 232W/m^2 \quad (2.16)$$

a typical sunny winter day irradiance is shown in Figure 2.5:

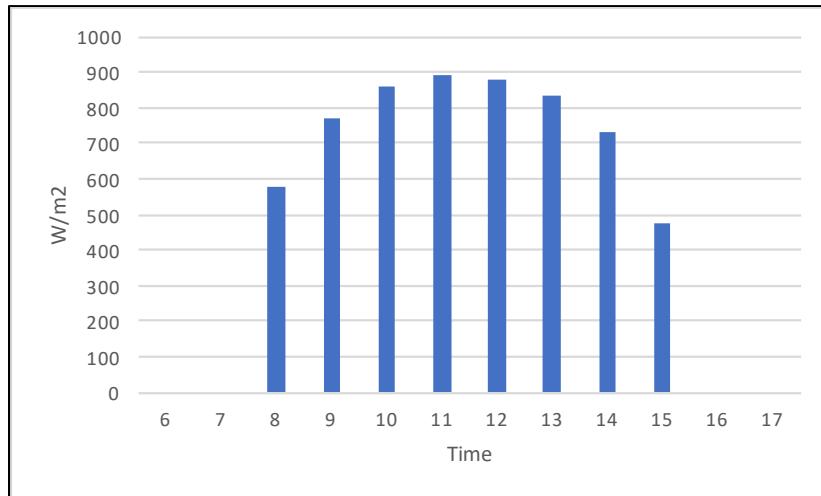


Figure 2.5 Irradiance for December 13, Montreal –
source PVWatts

From 8h to 15h all corresponding solar irradiances are above the 232 W/m^2 floor, the pump could be powered for 8 hrs.

2.1.8 Wiring

The cross section for each wire is calculated depending on the maximum current.

2.1.8.1 Array to MPPT/DC-DC

Wiring from the solar panel to the mppt or the dc-dc converter must consider the solar module output, the environmental effect, and the regulating safety coefficient.

$$\begin{aligned} \text{Array current (I}_{\text{sc}}\text{)} \times \text{environmental effect} \times \text{safety coefficient} & \quad (2.17) \\ = \text{max current} \rightarrow \text{wire size} \end{aligned}$$

$$5.86 \text{ A} \times 1.25 \times 1.25 = 9.16 \text{ A} \rightarrow \text{AWG}\#16 \text{ or higher} \quad (2.18)$$

2.1.8.2 MPPT to Battery

The mppt has a maximum output of 20 A.

$$\begin{aligned} \text{MPPT output current} \times \text{safety coefficient} &= \text{max current} \\ &\rightarrow \text{wire size} \end{aligned} \quad (2.19)$$

$$20 \text{ A} \times 1.25 = 25 \text{ A} \rightarrow \text{AWG#10 or higher} \quad (2.20)$$

2.1.8.3 DC-DC Convertor to pump

The dc-dc converter has a maximum output of 20 A.

$$\begin{aligned} \text{Dc - dc converter output current} \times \text{safety coefficient} &= \text{max current} \\ &\rightarrow \text{wire size} \end{aligned} \quad (2.21)$$

$$20 \text{ A} \times 1.25 = 25 \text{ A} \rightarrow \text{AWG#10 or higher} \quad (2.22)$$

2.1.8.4 Battery to pump

The maximum current output from the battery is given from the load drawn.

$$\begin{aligned} \text{Pump's maximum input current} \times \text{safety coefficient} &= \text{max current} \\ &\rightarrow \text{wire size} \end{aligned} \quad (2.23)$$

$$2.5 \text{ A} \times 1.25 = 3.13 \text{ A} \rightarrow \text{AWG#16 or higher} \quad (2.24)$$

2.1.9 Solar array support structure

Solar panels were installed side by side to provide the same tilt (45°) and azimuth (180°).

A wooden structure was designed and built to hold both panels, see Figure 2.7. An additional consideration was taken for wind loads at the location and snowfall accumulation.

Wind load calculation considers an average wind speed of below 22km/h for the last 10 years with a record speed of 117km/h gust. Such measurements were recorded from the Montreal airport weather data, see Figure 2.6.

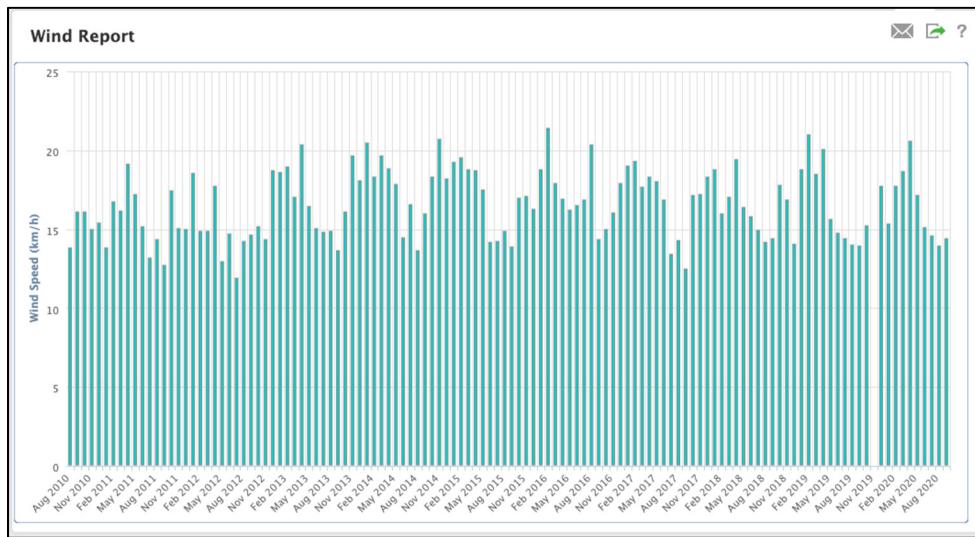


Figure 2.6 Montreal wind speed average – source PulseEnergy.com

Detailed calculation of wind load can be found in ANNEX II.

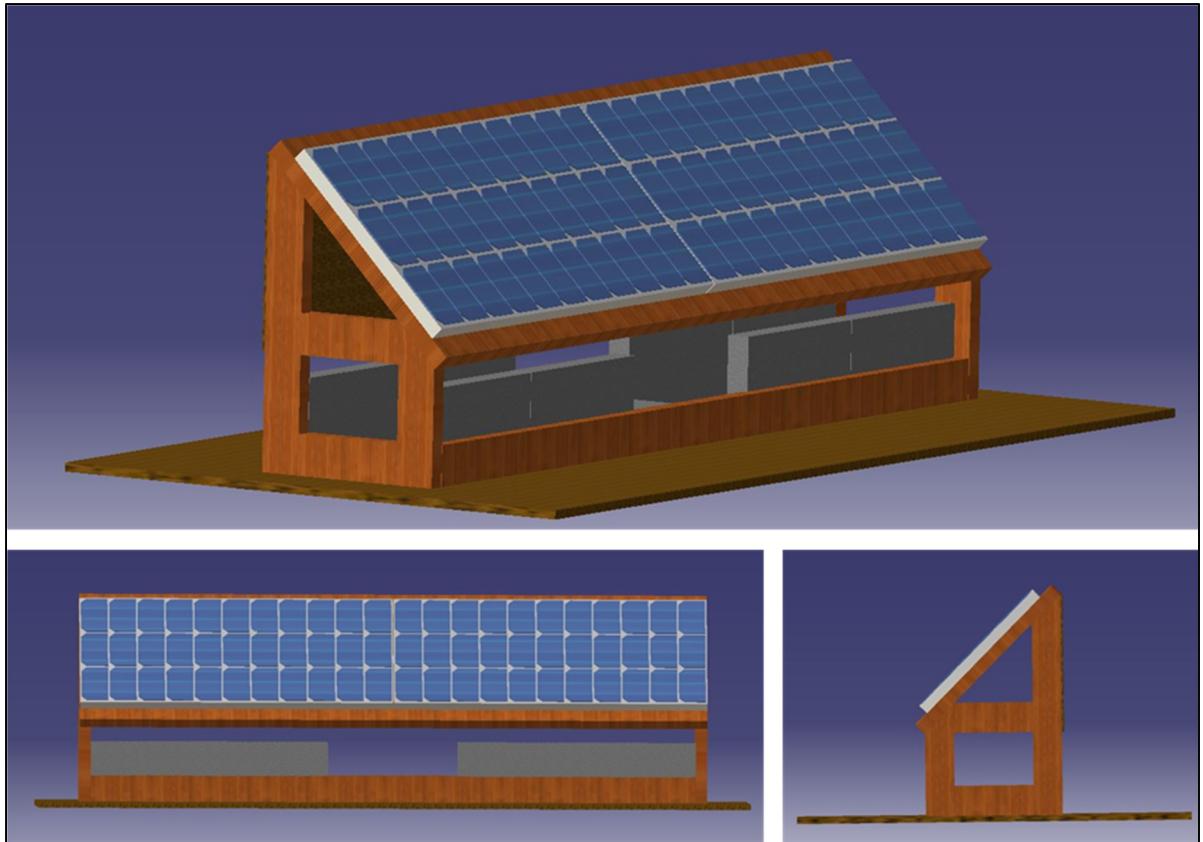


Figure 2.7 Overview of solar panel mechanical support

Panels have 4 attachment points with commercially available brackets.

2.1.10 Control panel

The main solar control components are installed on a common board with the battery positioned next to it. The control panel and the battery are housed inside the Heliolab.

2.1.11 System installation layout

Figure 2.8 shows an aerial view of the system installation on the roof of the ETS building A.

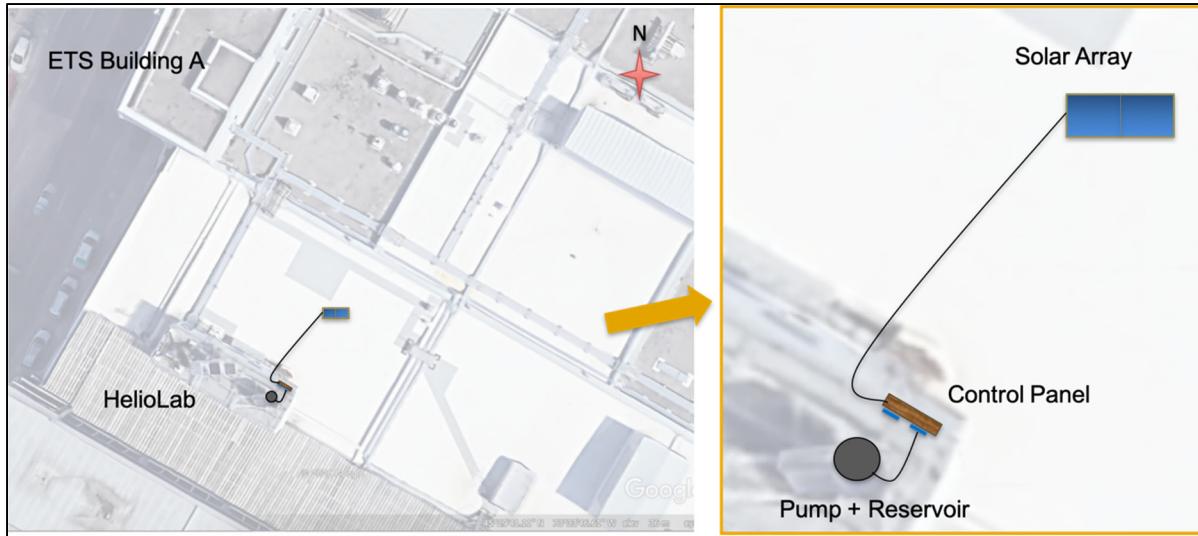


Figure 2.8 System installation layout

Figure 2.9 illustrates the layout of the control panel, located inside the HelioLab.

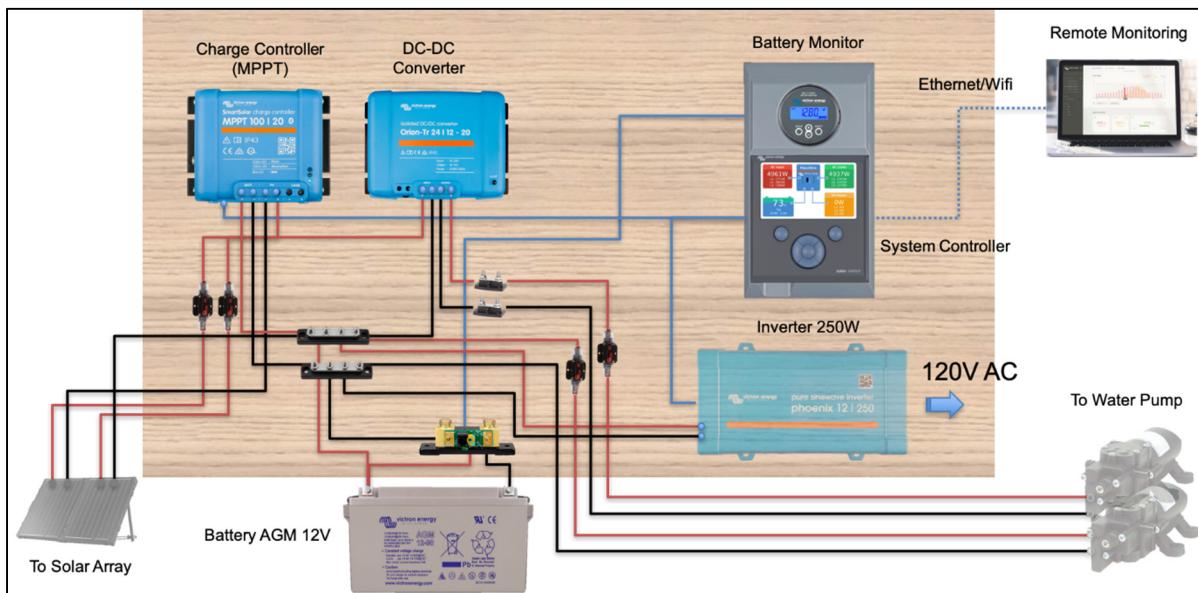


Figure 2.9 Control panel layout

Figure 2.10 illustrates the layout of the pumping system and reservoir, also located inside the HelioLab.

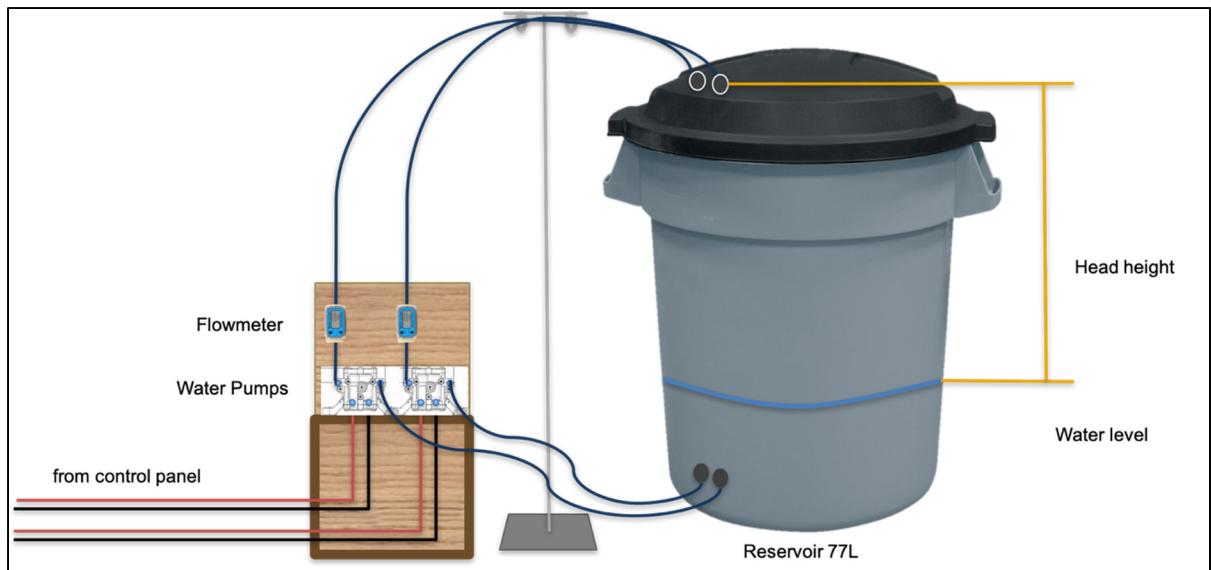


Figure 2.10 Pump and reservoir layout

2.2 System installation

Both systems were installed inside the Heliolab, on the roof of the ETS. It is possible to either monitor live the system status from the site or get an overview remotely for PVPS #2.

Both systems are installed with the same tilt and azimuth. They will work under the same environmental condition (irradiance, temperature).

2.2.1 Structure installation

The wooden support structure was assembled directly on site. It was then ballasted with 120kg of sand and anchored to a fixed point on the building. Finally, the two solar panels were attached to the wooden structure. Figure 2.11 to Figure 2.15 shows the different steps of the structure installation.



Figure 2.11 Wooden structure assembly



Figure 2.12 Structure fixation



Figure 2.13 Completed support structure

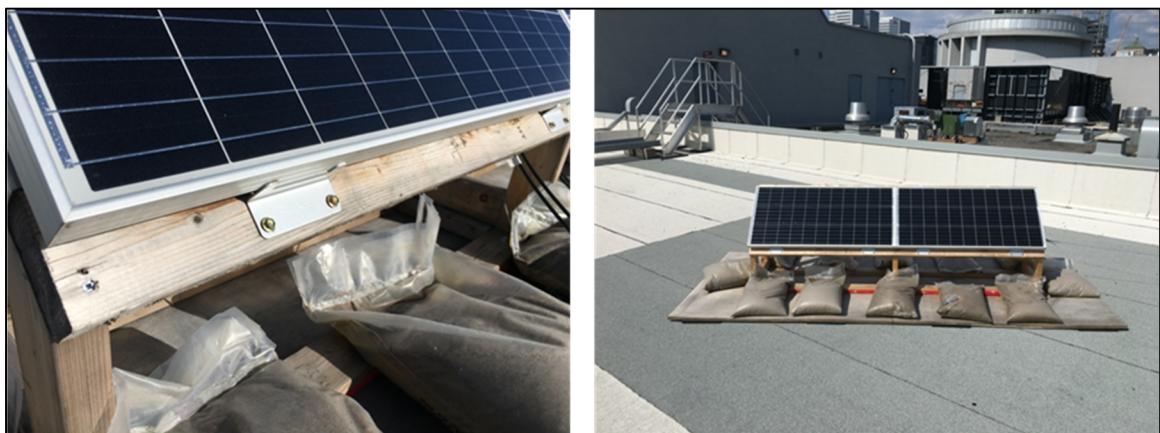


Figure 2.14 Solar panel attachments

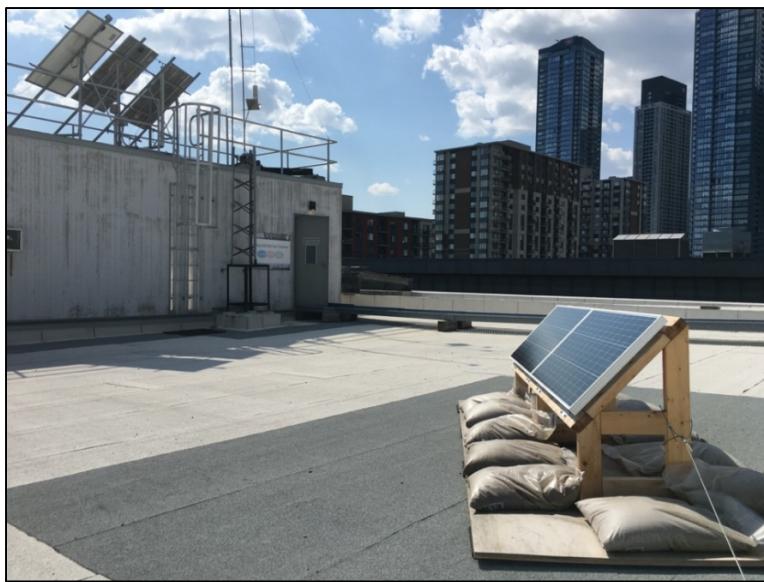


Figure 2.15 Completed solar array installation

2.2.2 Control panel installation

A wooden board was used to hold the solar components and control the systems. Figure 2.16 and Figure 2.17 shows the different steps of the control panel installation.

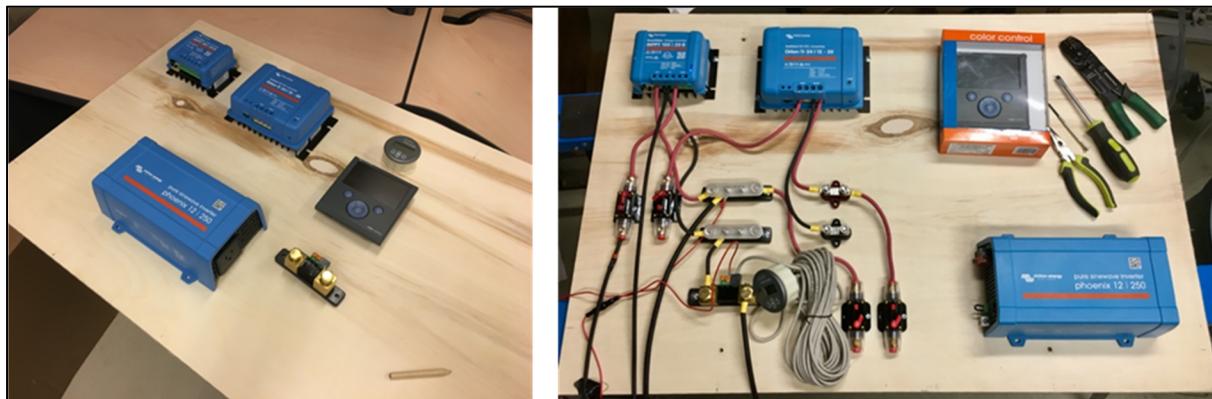


Figure 2.16 Control panel installation



Figure 2.17 Completed control panel

2.2.3 Pumping systems installation

The pumping systems were installed in proximity to the control panel. A wooden support holds the pumps. Figure 2.18 shows the pumping system installation.



Figure 2.18 Pumping system installation

The water intake and output are at the same level; thus, the head height is considered to be zero.

2.3 Measurements and data acquisition

The main parameters that need to be measured are the water flow, weather (solar irradiance, outside temp, inside temp?), PV yield, battery's state of charge, voltage, and amperage at different points. It was achieved by the combination of two parallel data acquisition protocols: Victron Energy cloud solution and Arduino. Figure 2.19 shows the Arduino installation layout.

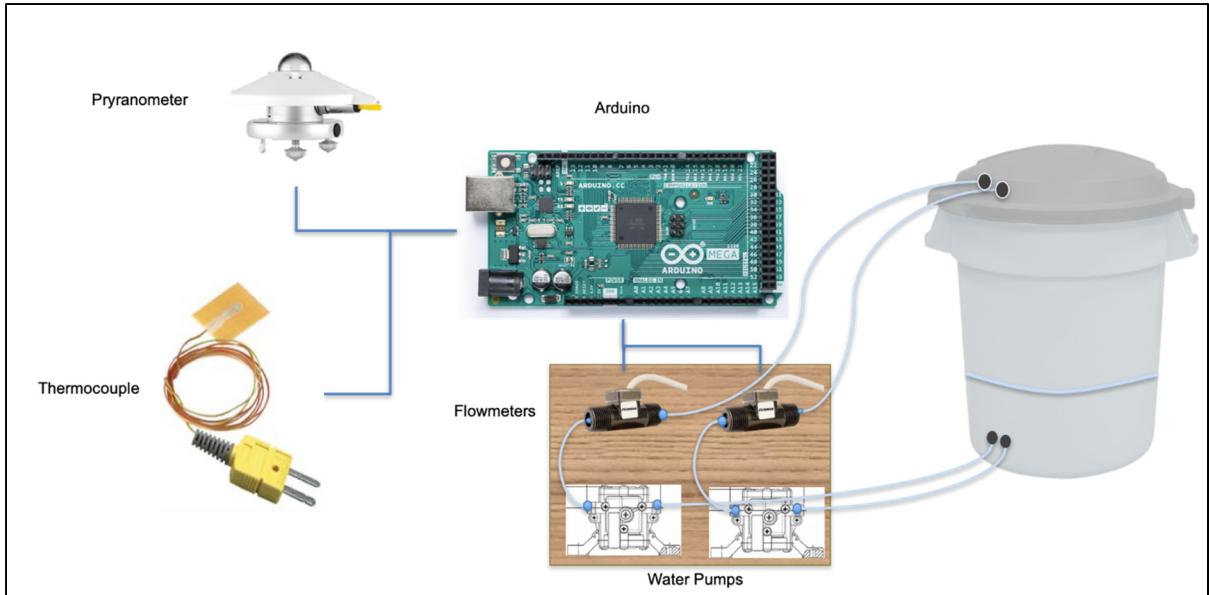


Figure 2.19 Arduino installation layout

2.3.1 Data acquisition via Victron Energy cloud solution

Victron Energy offers their own, free of charge, data acquisition system called Victron Remote Management (VRM). It is compatible with many of their products and allows to store and monitor different parameters from the system. Figure 2.20 and Figure 2.21 show typical VRM web interfaces.

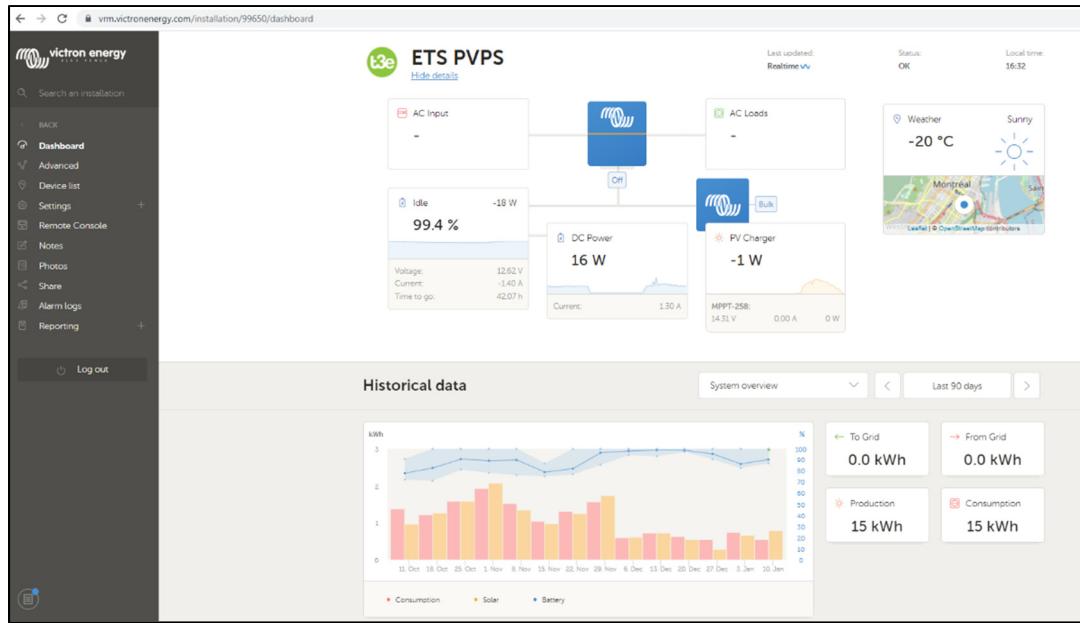


Figure 2.20 Typical view of data monitoring of solar system (Victron Energy) – Dashboard

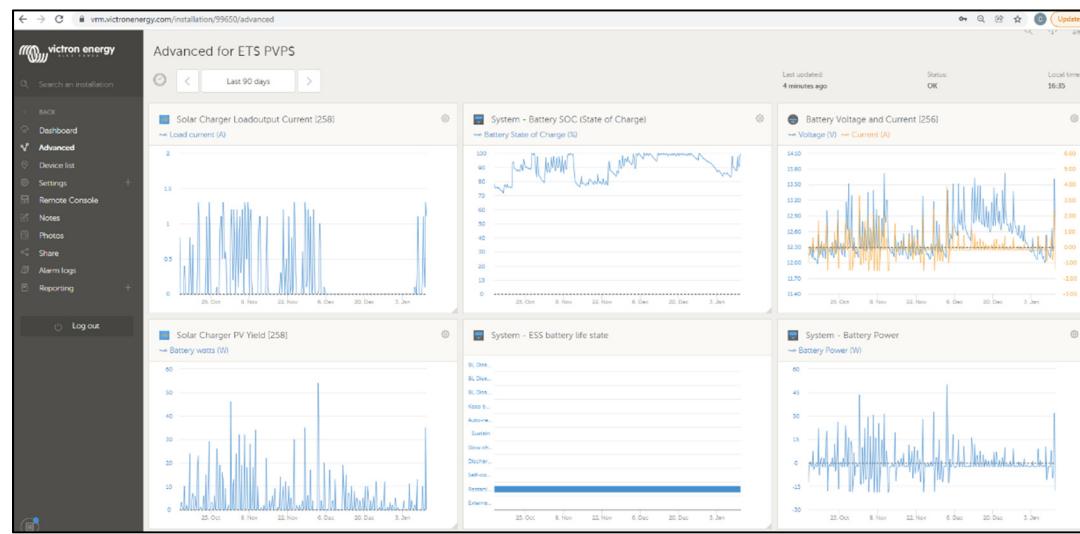


Figure 2.21 Typical view of data monitoring of solar system (Victron Energy) - Advanced

Table 2.2 lists the available monitored parameters:

Table 2.2 VRM available parameter

System	Solar Charger	Battery
PV Yield	Summary	Summary
Grid	PV Yield	SOC (State Of Charge)
AC Consumption	Battery Voltage and Current	History
AC Genset	PV Voltage and Current	Voltage and Current
Battery Power	Load output Current	Starter Battery Voltage
Battery Voltage And Current	Battery Temperature	Battery Temperature Sensor
Battery SOC (State of Charge)	Relay State	BMS Charge and Discharge Limits
DC System		Mid-point voltage
Signal RSSI		Monitor relay state
Relay 1 State		Monitor external relay state
ESS battery life state		

Available download formats:

Download .csv	Download kWh .csv
Download .xls	Download kWh .xls

2.3.2 Data acquisition via Arduino

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button - and turn them into an output.

The open-source Arduino Software (IDE) makes it easy to write code and upload it to the board. This software can be used with any Arduino board.

(Source: <https://www.arduino.cc/en/Guide/Introduction>)

An Arduino MEGA board, Arduino touch screen and in-house developed “motherboard” were used. A sample of this board with screen is shown in Figure 2.22.

All measured parameters are saved on a SD memory card every minute.

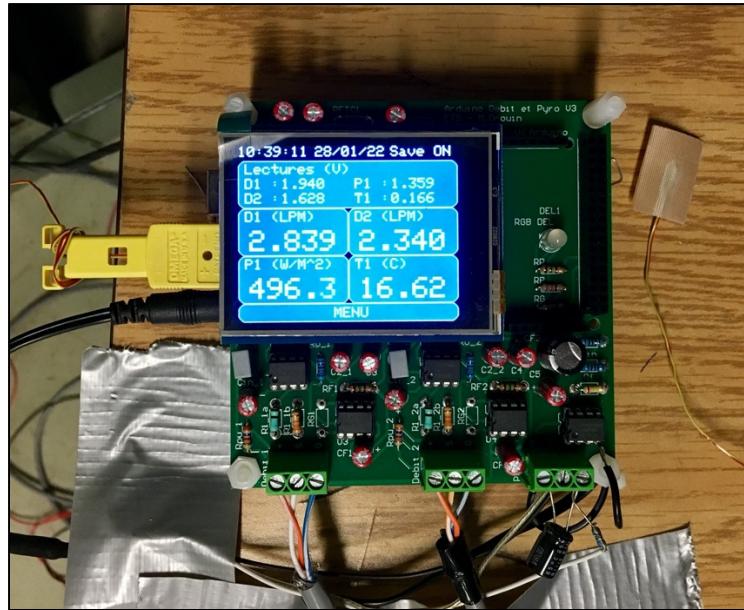


Figure 2.22 The Arduino board with its touchscreen

The parameters acquired by Arduino are: D1: Pump 1 flow rate in Liter per minute; D2: Pump 2 flow rate in Liter per minute; P1: Total horizontal irradiance in W/m^2 ; T1: Room temperature in Celsius.

2.3.2.1 Solar irradiance

A calibrated pyranometer is used to measure the local solar irradiance. It is installed on the horizontal plane to be able to compare the real solar irradiance on-site to solar data available from other locations thru different websites and/or software. The pyranometer can capture the direct and diffuse solar radiation. Figure 2.23 shows the pyranometer used and its installation at the Heliolab.



Figure 2.23 Pyranometer

The pyranometer's output signal is in microvolts, it is then converted into solar irradiance by the Arduino using the following formula:

$$E_{solar} = \frac{U_{emf}}{S} \quad (2.25)$$

where,

E_{solar} [W/m²] = Solar Irradiance,

U_{emf} [μ V] = Output Voltage,

S [μ V/W/m²] = Sensitivity.

Pyranometer model: CMP3 from Kipp & Zonen. Sensitivity: $11.02 \times 10\mu$ V/W/m²

2.3.2.2 Water flow

A flowmeter is essential to quantify the amount of water pumped by each system. Each pumping system had a flowmeter installed downstream from the pump. The model used was Omega FTB2003-C. Figure 2.24 shows the flowmeter installation.



Figure 2.24 Water flow meter

The flowmeter's output signal is a square wave signal, whose frequency varies linearly with the flow rate. The signal produces 4600 pulses per litre for an output frequency range between 76 – 1150 Hz.

2.3.2.3 Temperature

Arduino can read and store the room temperature thru a temperature sensor.

2.4 System commissioning

The whole system needed to be commissioned before any testing could be started.

2.4.1 Solar panel commissioning

The solar array was verified for structural integrity, ballast load, support attachment, panel attachment, orientation, and tilt. Afterwards, the array was tested for wire connection, continuity, output voltage, and current.

2.4.2 Control panel commissioning

A portable 100W solar panel was used to test the control panel and verify the operability of the MPPT, dc convertor, battery monitor, system controller, and the optional inverter, as shown in Figure 2.25.

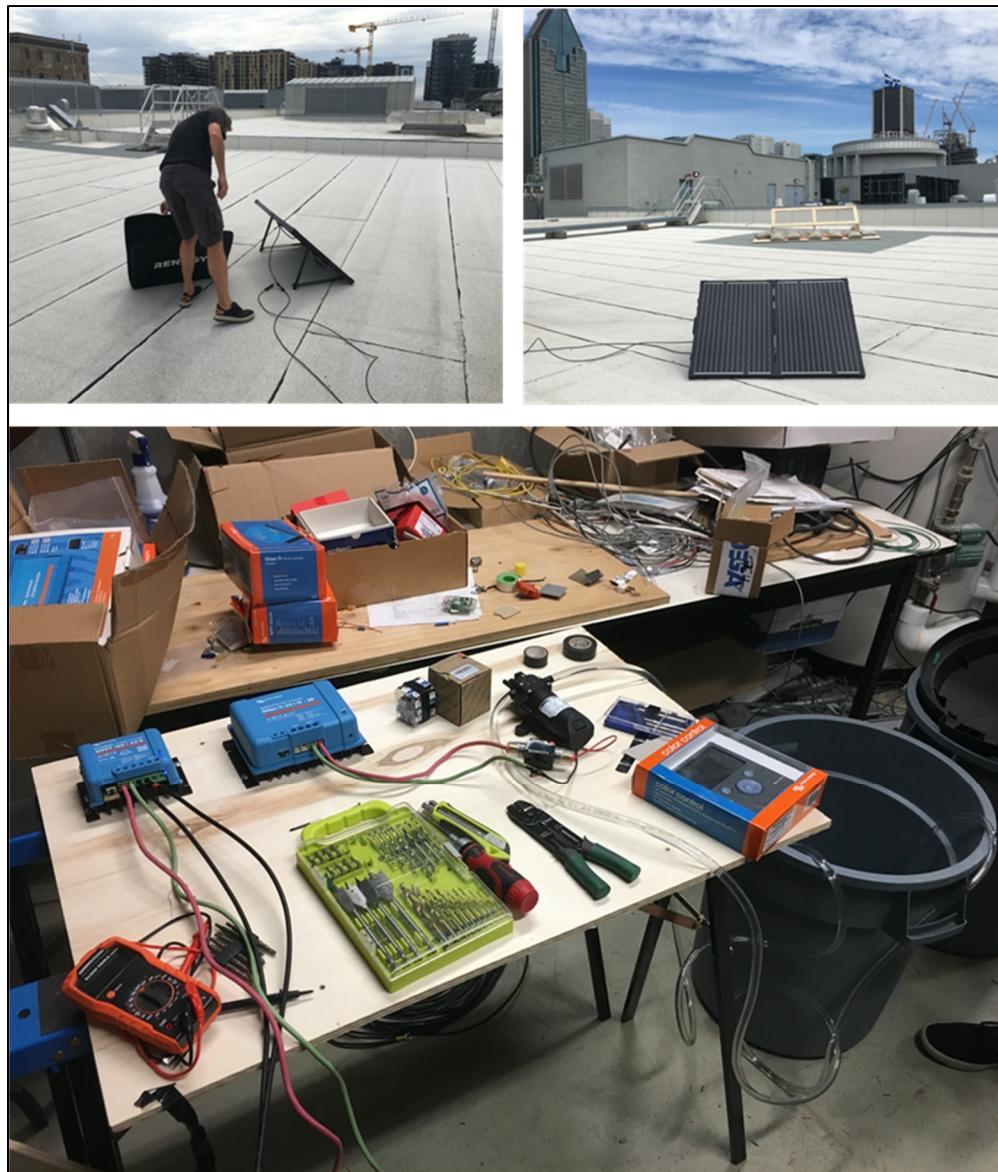


Figure 2.25 Control panel commissioning

2.4.3 Reservoir and piping commissioning

The piping system was verified for assembly, leaks, height, and operability of the pumps.

2.4.4 Data acquisition commissioning

Both data acquisition protocols were commissioned separately.

2.4.4.1 Data acquisition via Victron Energy cloud solution

A VRM account was set up and then verified thru the website and mobile app. All equipment connexions were verified: system controller, charge controller (MPPT), battery monitor and inverter.

2.4.4.2 Data acquisition via Arduino

Various errors were noted on the data treatment via Arduino, especially the measurement of the solar irradiance thru the pyranometer. Several iterations were necessary to tune up the Arduino data acquisition, including filtering and amplifying input signals and code updates. This was one of the more complex steps in the process.

2.4.5 System integration (configuration)

The selected MPPT model has an option to control the 12V load output which allows to cut off the pump at a defined point of the battery voltage and connect it again. For two reasons: first, to protect the battery from being fully discharged and damaged and secondly, to control the amount of energy used to pump, since the battery is oversized to the system's need.

The MPPT was configured to cut-off the load (pump) when the battery reached 12.20V and to power back on when it reached 13.30V. At the lower value the battery has a SOC of 87.3% approximately equivalent to 11.43Ah drown (See Figure 2.26).

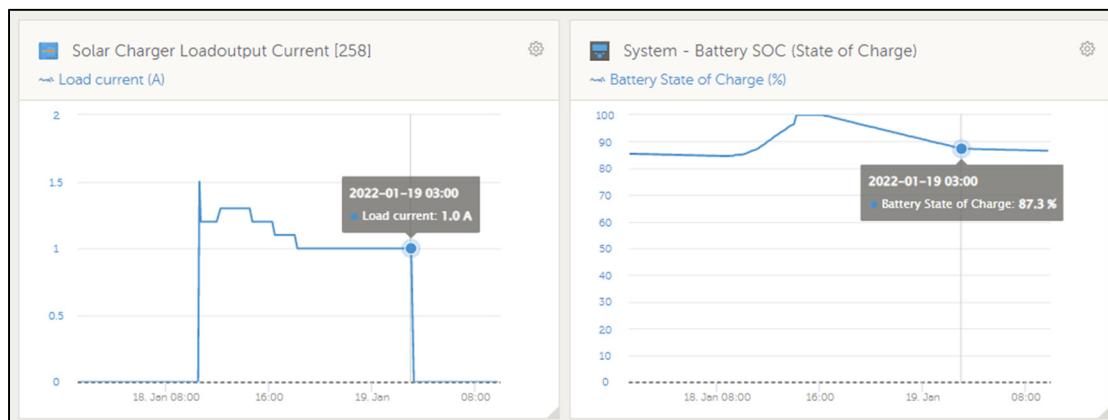


Figure 2.26 Load output cut-off

Figure 2.26 shows a point in which the pump in PVPS#2 is cut-off by the MPPT where the load current goes from 1 amp to 0, corresponding to a battery SOC of 87.3%.

2.4.6 Solar panel relocation

After the fall season the solar panels needed to be relocated to a permanent site. They were installed on the existing racking on top of the Heliolab, along with solar panels from other projects. PVPS panels were installed on the bottom row of the racking, see Figure 2.27.



Figure 2.27 Solar array relocation

2.5 Testing

To test both systems, it is required specific measurements such as the power produced by the solar panels, the power consumed by the pumps, the state of charge of the battery, the pumped water flow and total quantity, the solar irradiance, temperature, and the height of the water column.

2.5.1 General testing

The planned tests are:

- Solar module output for a given irradiance and temperature at a fixed orientation and tilt,
- Pump performance at a given height. Measurement of voltage, current and water flow.
Pump powered from a fully charged battery for steady performance,

- Maximum pumping in a day,
- Total pumping in 30 consecutive days,
- Minimum voltage to start the pump (minimum solar irradiance), particular to PVPS #1,
- Battery usage / available capacity, particular to PVPS #2.

2.5.2 Winter Testing

Testing went over the winter months thus it was possible to include additional testing particular to winter conditions.

CHAPTER 3

RESULTS AND DISCUSSION

This chapter allows to evaluate and compare the results of both PVPS, direct-driven and battery-coupled, gathered from testing. To do this, the following were analyzed:

- Performance of solar panels and each system,
- Amount of water pump in a single day / 10 consecutive days,
- Available energy stored for other usages,
- Use of a reservoir,
- Impact of solar and storage,
- Cost analysis,
- Winter conditions.

3.1 Total recorded data

Figure 3.1 shows the total data recorded during the testing campaign.

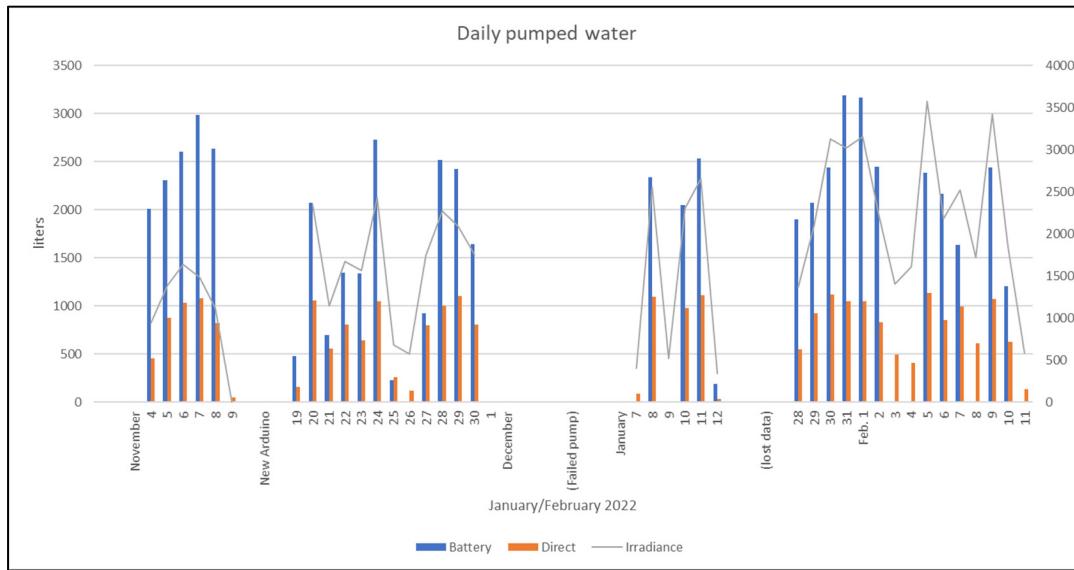


Figure 3.1 Total recorded data

The first section (Nov. 4-9) shows recordings from that period where Arduino errors were noticed, and the values are not precise. The second section (Nov. 19-30) shows proper data after Arduino was corrected. Pump #2 failed on Dec 2nd and it was replaced on Jan 7th. The third section (Jan 8-11) shows a small batch of data. Data between Jan 12th and 28th was lost during recording. The fourth section (Jan. 28-Feb. 11) has a set of data impacted by winter conditions where snow cumulation reduced the amount of power produced by the solar panels.

Section 2 was used for the analysis.

3.2 Testing panel and systems performance

To compare the expected solar power output to the real output the following measures were taken (see Table 3.1):

Table 3.1 Panel/system performance measurements

Date	Time				
Jan 28 th 2022	12:07				
Temperature, ambient	Solar irradiance (direct)	Solar irradiance (horizontal)	Solar power output	Water debit #1	Water debit #2
-12°C	1148W/m ²	500W/m ²	92W	2.345 lpm	2.897 lpm

Figure 3.2 shows the solar irradiance and external temperature measurement. On Jan. 28th at 12:07 the sun's position was at an azimuth of 179.94° and an altitude of 26.47°, and the sky was clear, see Figure 3.3.

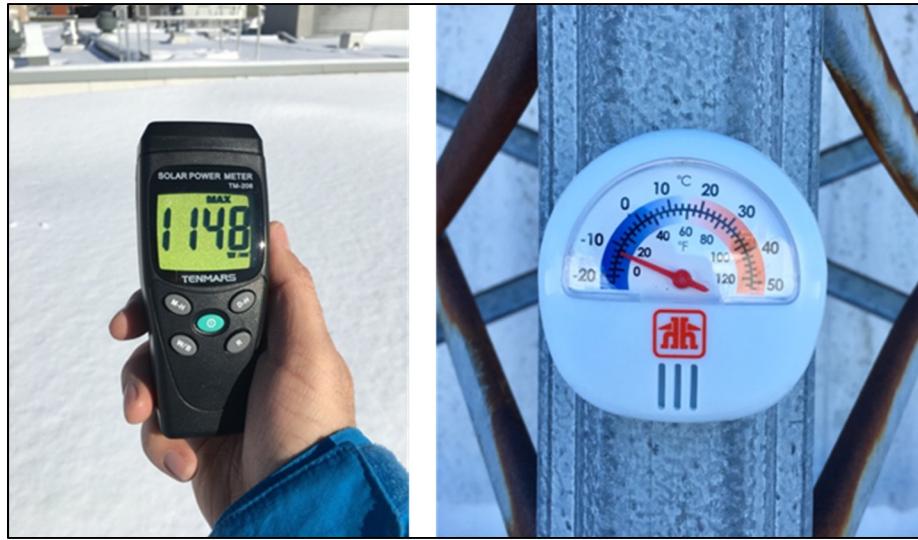


Figure 3.2 Solar irradiance and external temperature measurement

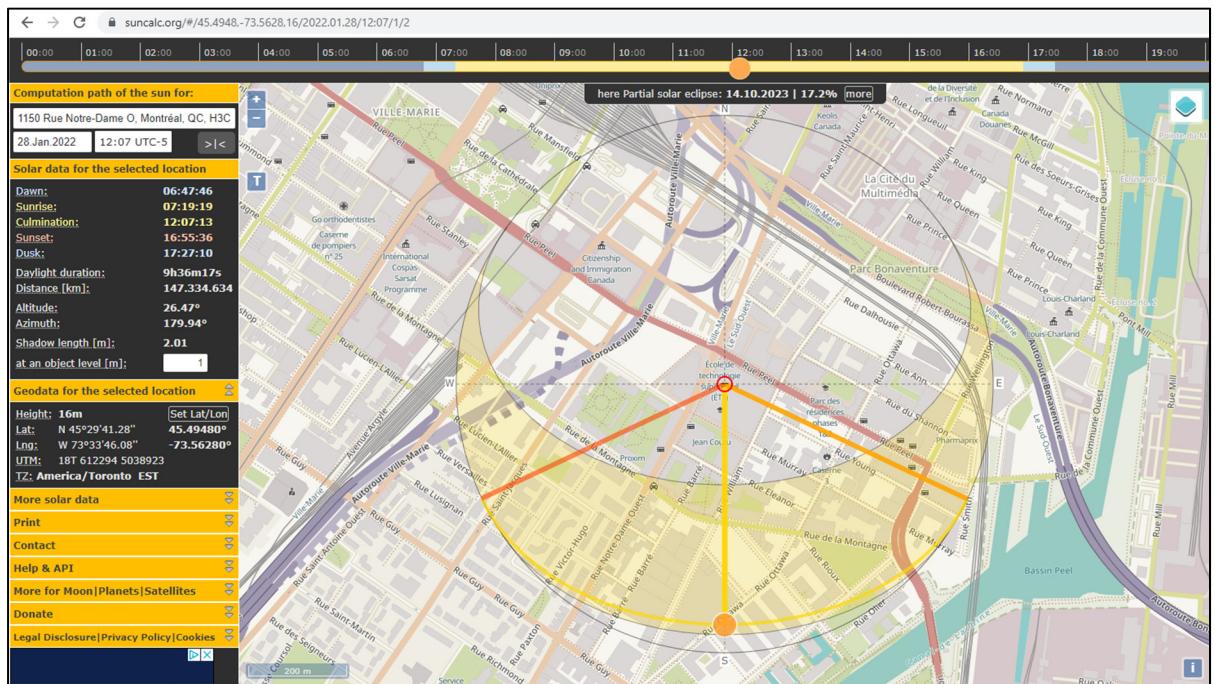


Figure 3.3 Solar position, source: Suncalc.org

Since the solar panels are installed at 45° tilt and 180° south, the azimuths are aligned, and the altitude difference is $45^\circ - 26.47^\circ = 18.53^\circ$.

To compare the measurement taken by a pyranometer at the horizontal plane with the measurement taken directly pointing at the sun with a manual solarimeter it can be calculated that the solar irradiance would be:

$$I = \frac{I_h}{\sin\beta} = \frac{500W/m^2}{\sin(26.47^\circ)} = 1120W/m^2 \quad (3.1)$$

This result is within 2.5% of the measurement pointed directly at the sun.

The perpendicular solar irradiance component equals:

$$Ip = \cos\alpha \times I = \cos(18.53^\circ) \times 1120W = 1088.5W/m^2 \quad (3.2)$$

The cells are receiving a different amount of the standard testing conditions of $1000W/m^2$ therefore the expected output value of the panel, at $25^\circ C$ would be

$$P' = 100W \times \frac{1088.5}{1000} = 108.9W \quad (3.3)$$

Considering the panel temperature equal to the ambient temperature, the expected power output for $-12^\circ C$ is:

$$108.9W (1 + (-12^\circ C - 25^\circ C) \times -0.37\%/^\circ C) = 123.8W \quad (3.4)$$

The measured power output is 92W, see Figure 3.4.



Figure 3.4 Solar power output

It was noted that the solar irradiance was above 1000W/m^2 which can be explained because the manual solarimeter used at an angle can capture the direct, diffuse and albedo solar radiation. The snow coverage tends to increase the albedo effect and the precision of the measurement tool is not considered.

The difference between the theoretical and real solar power output is about 27%, it is influenced by several factors: the ambient temperature measurement was used instead of the temperature of the rear sheet of the solar panel which is higher, the precision of the data treatment by Arduino, the precision of the measurement equipment (mppt, thermometer, pyranometer), the real efficiency of the solar panel, and the magnetic declination was not considered. Montreal has a magnetic declination of $13^\circ 60' \text{ W}$ (source: <https://www.ngdc.noaa.gov/>) which needs to be considered on the azimuth positioning of the solar array.

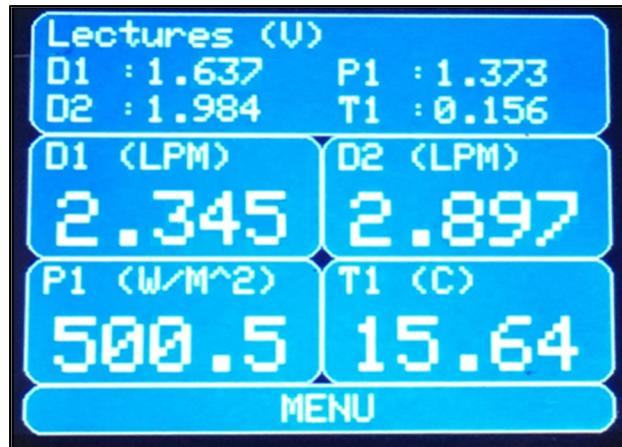


Figure 3.5 Water debit and solar irradiance

The water debit for system #1 (direct) is 2.345 lpm (see Figure 3.5), therefore the system performance can be calculated as:

$$Pf1 = \frac{\text{debit}}{Ip \times A_{\text{panel}}} = \frac{2.345 \text{ lpm}}{1088.5 \frac{W}{m^2} \times (1.062m \times 0.53m)} \quad (3.5)$$

$$= 0.00383 \text{ lmp/W or } 3.83 \text{lpm/kW}$$

System losses are the addition of solar panel efficiency, converter efficiency, pump efficiency, wiring and piping, etc.

The water debit for system #2 (battery) is 2.897 lpm (see Figure 3.5), therefore the system performance can be calculated as:

$$Pf2 = \frac{\text{debit}}{Ip \times A_{\text{panel}}} = \frac{2.897 \text{ lpm}}{1088.5 \frac{W}{m^2} \times (1.062m \times 0.53m)} \quad (3.6)$$

$$= 0.00473 \text{ lmp/W or } 4.73 \text{lpm/kW}$$

System losses are the addition of solar panel efficiency, mppt efficiency, battery efficiency, pump efficiency, wiring and piping, etc.

Under the same conditions, system #2 can deliver 23.5% more water than system #1, which translates into a flow of 4.73 and 3.83 liters per minute per kilowatt received by the solar panel respectively.

3.3 Total water pumped in 10 consecutive days

Total water pumped for the period between Nov 20th and Nov 30th is shown in Figure 3.6.

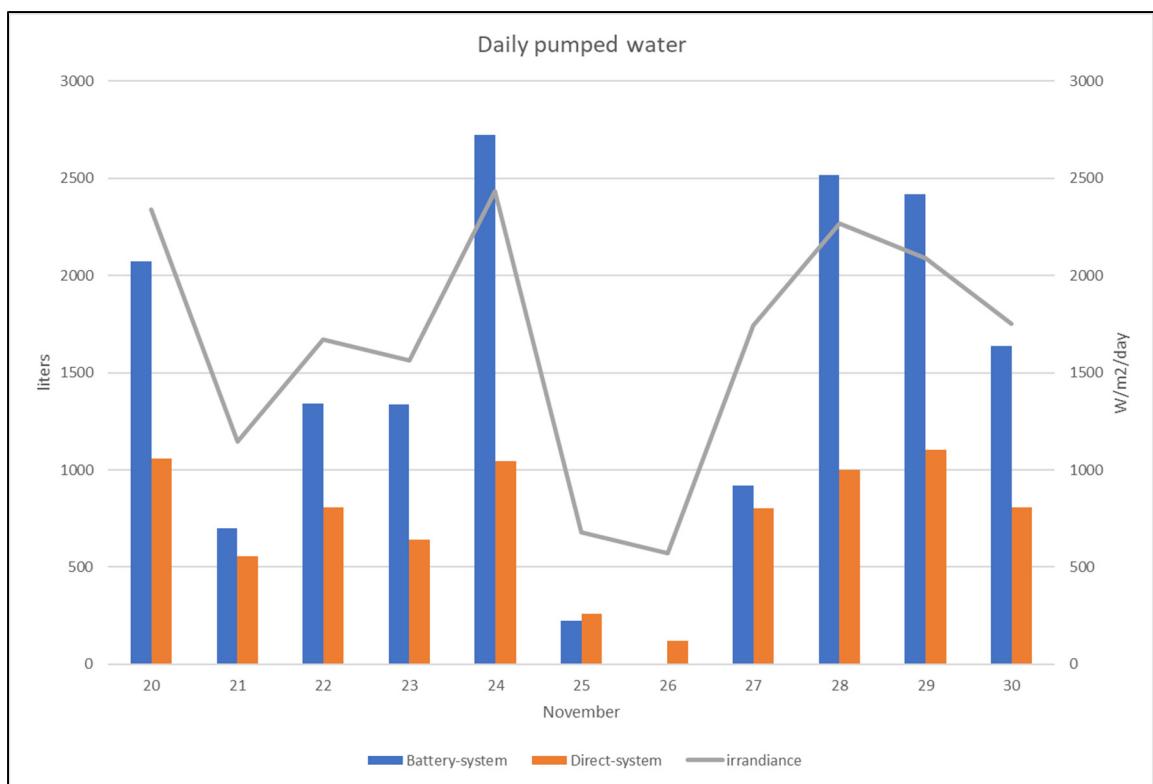


Figure 3.6 Daily water pumped

The amount of water pumped by both systems is directly related to the amount of solar irradiance in the day.

Table 3.2 Daily water pumped

Date	20	21	22	23	24	25	26	27	28	29	30	Total [L]	Avg [L]
PVPS#1	1060	555	805	639	1047	260	121	801	1000	1103	807	8198	745
PVPS#2	2072	698	1342	1335	2723	226	0	921	2517	2421	1640	15895	1445

As shown in Table 3.2, the total amount of water pumped by PVPS#1 is 8198 L and PVPS #2 is 15895 L, and their average is 745 and 1445 L/day.

The total amount of water pumped by PVPS #2 is twice as much as PVPS #1.

The average basic water consumption of a family of 4 is 400L/day, either system can provide on average at least twice that quantity. However, cloudy days like Nov 25th and 26th will not produce that minimal amount, for such cases it will be necessary to have a reservoir that can supply the water needs for cloudy days, or to have the consumer store water a few days before the weather forecasts cloudy periods.

3.4 Water pumped on an average day

November 24th was chosen as an average solar irradiance day since it received 1670Wh/m², while the average is 1660Wh/m².

Figure 3.7 shows the quantity of litres pumped per minute and Figure 3.8 shows the cumulative amount of water pumped during the day.

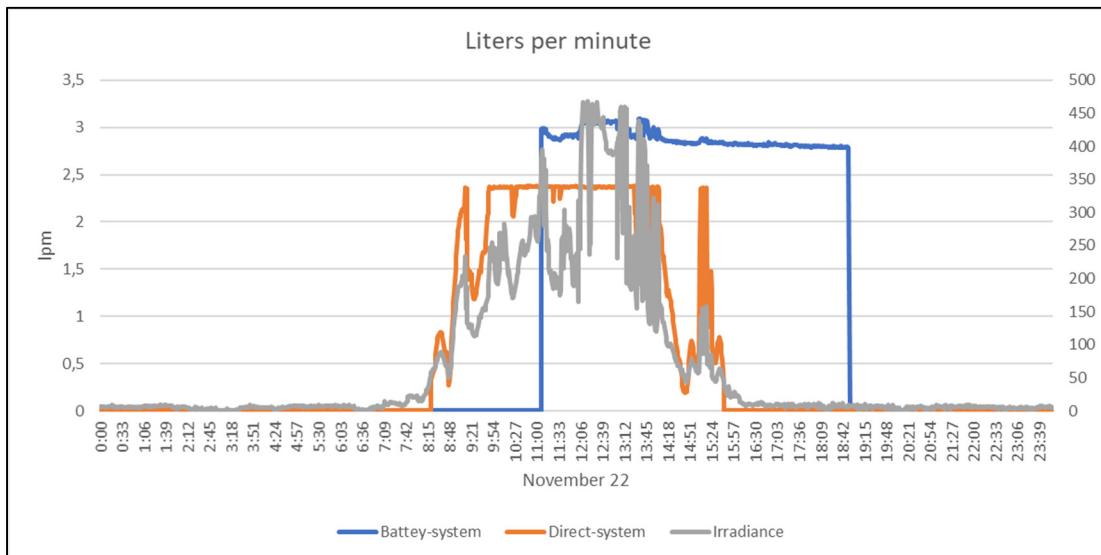


Figure 3.7 Litres per minute pumped on an average day

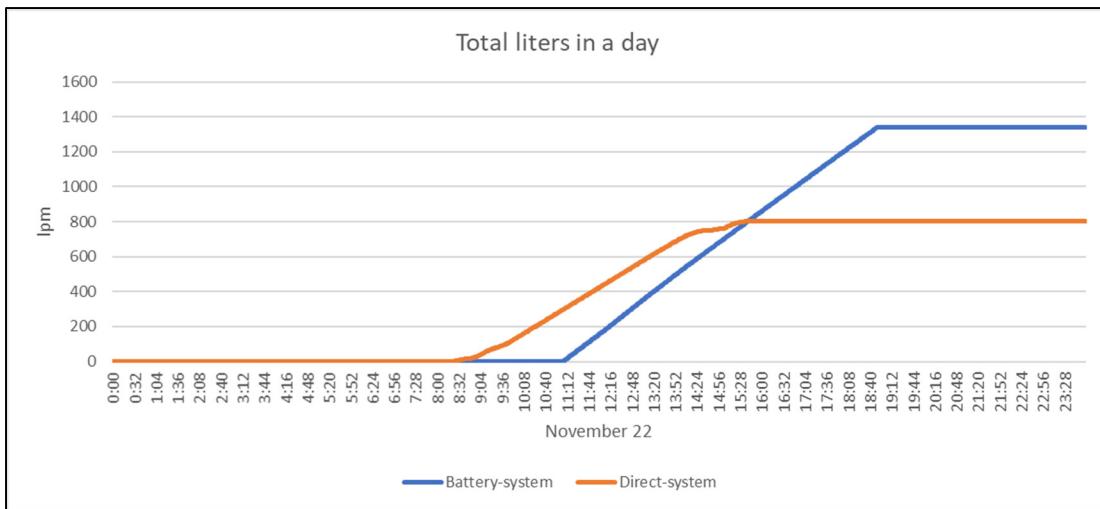


Figure 3.8 Cumulative litres pumped on an average day

Figure 3.7 demonstrates how the quantity of water pumped by the direct system is directly related to the amount of solar irradiance while a battery system pumps at a different schedule. When the sun comes up and shines strong enough the direct system starts pumping at a slow rate until it reaches full capacity; the battery system starts charging the battery until its voltage reaches a certain level and the pump starts at full capacity later in the day and stops pumping when the battery has discharged to a predetermined level.

The difference in the highest level of flow is explained by the fact the dc-dc converter is fixed to an output voltage of 12.5V with a variable amperage, while the MPPT in PVPS #2 modulates the output voltage to optimize the battery charge and can fluctuate between 13V and 14.4V and with a variable amperage as well.

Figure 3.8 shows a faster rate of pumping and for a longer period for PVPS #2.

3.5 Extra energy from the battery

PVPS #2 produces more energy than PVPS #1, that extra energy can be stored in a battery and used for applications other than pumping water, like illumination, cell phone charging, watching tv, radio, fans, etc.

3.5.1 Energy used per pumped litre

Figure 3.9 shows the DC consumption, in watts, for a single day on system #2.

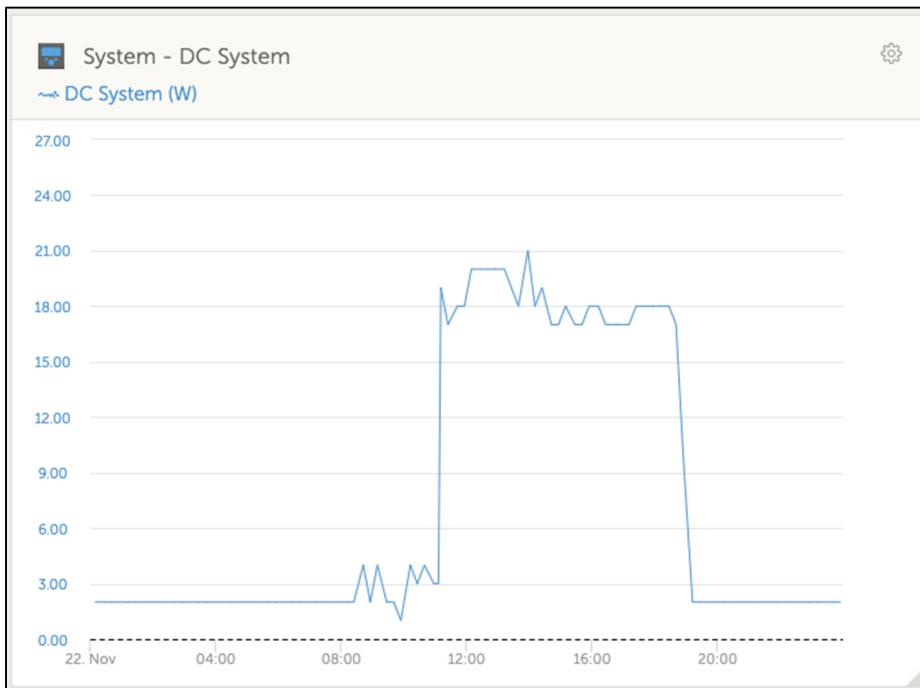


Figure 3.9 System #2 DC consumption – Nov 22nd

While the pump is running, the average energy discharge from the battery is 18.15 W, where 2 W equals the minimum control system consumption. On November 22nd, while the pump ran for 8.5 hrs it pumped 1342L of water.

$$1342L \div [(18.15W - 2W) \times 8.5hrs] = 9.78L/Wh \quad (3.7)$$

Compared to a direct system, Figure 3.10 shows the amount of energy that could be saved for other purposes.

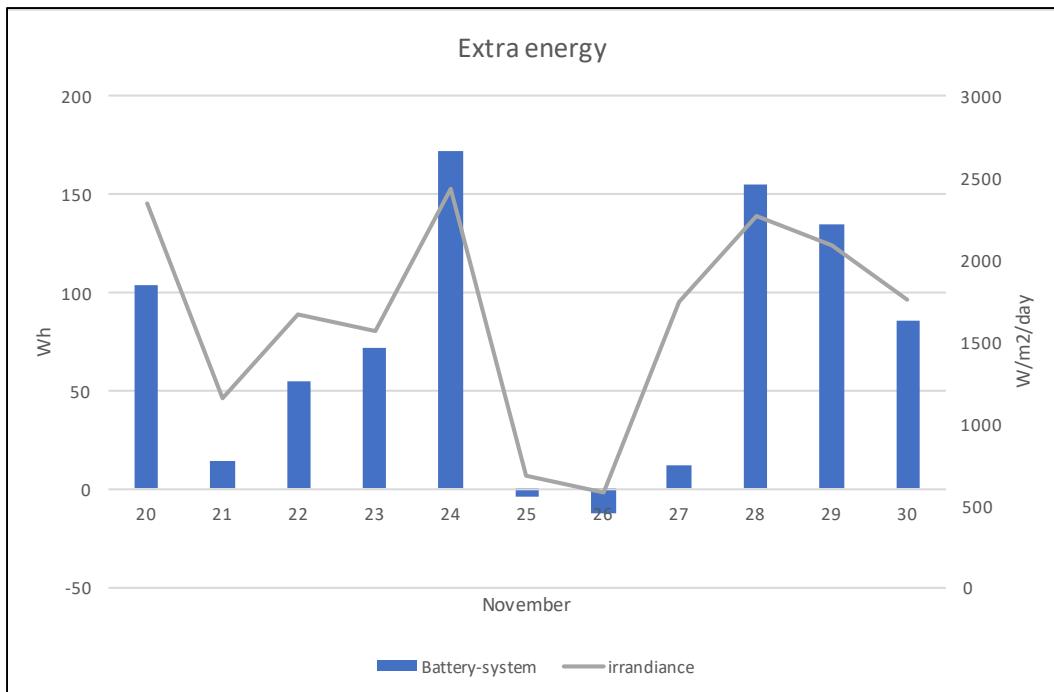


Figure 3.10 Energy saved

As an example, the average amount of extra energy, 71.6 Wh/day, would be enough to supply energy to:

- Light a low consumption bulb (10W) for 7 hours,
- Charge 13 cell phones (5.5W),
- Use a small fan (25W) for 3 hours,
- Watch a tv (70W) for 1 hr,

or the combination of any of the above.

3.6 Use of a reservoir

As previously discussed, the use of a reservoir will be beneficial for cloudy days. Figure 3.11 shows the reservoir level and represents different scenarios depending on its volume.

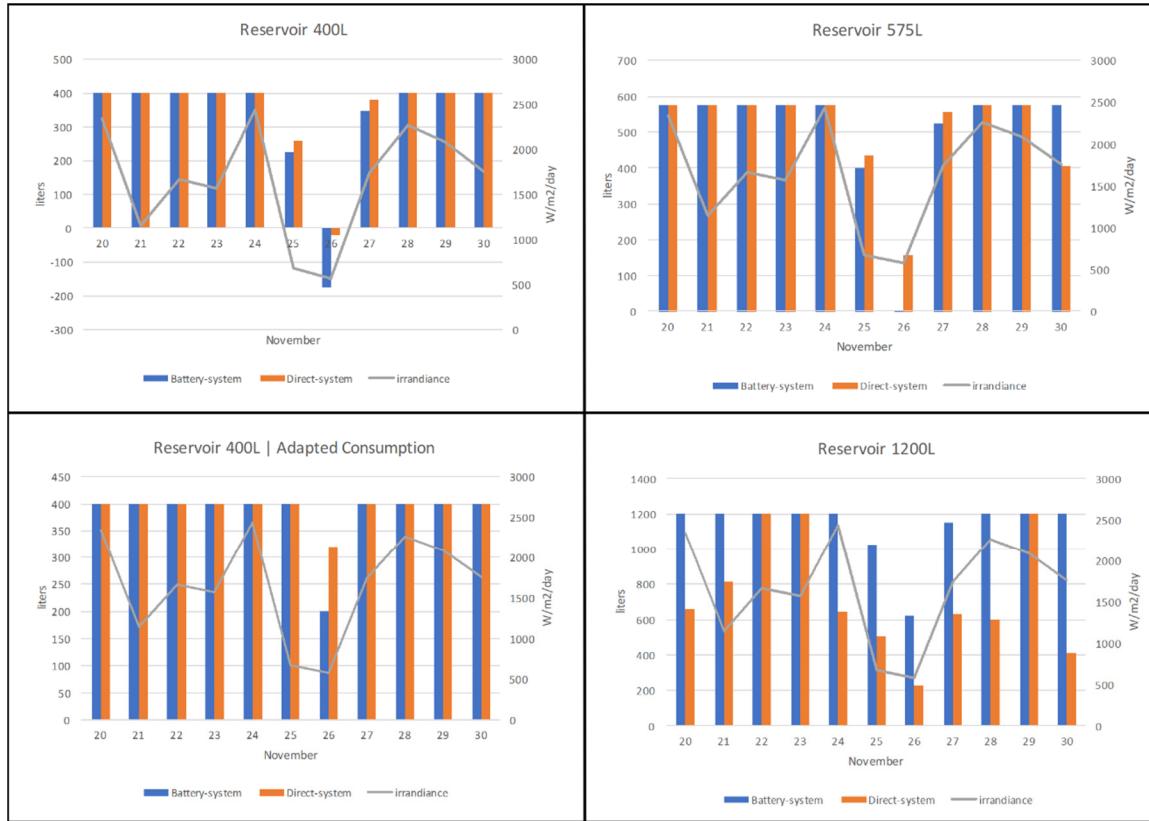


Figure 3.11 Variation of the reservoir level with time for selected water reservoirs and for the smallest reservoir with an adapted water consumption

Scenario 1 considers a reservoir of 400L, the minimal daily consumption, when exposed to continuous cloudy days, the requirement will not be met. Scenario 2, a reservoir of 575L, will have just a minimum amount of water to meet the requirement for both systems. Scenario 3 considers the human factor of an adapted consumption where the water usage will be limited during cloudy days, 200L/day in such case, then a 400L reservoir will be enough. Scenario 4, a reservoir of 1200L, would be ideal to secure 3 consecutive bad weather days.

Another option to be considered for PVPS #2 would be to stop the pump when the reservoir is full and save energy on the battery for cloudy days.

3.7 Impact of additional solar power

In the case study, it was shown that the power provided by a 100W solar panel will rapidly reach the pump's full capacity, at around a solar irradiance of 250W/m^2 , see Figure 3.12. Extending the size of the solar array will not have a significant impact on the water output. In such a case, a larger pump will be necessary to take advantage of the additional energy.

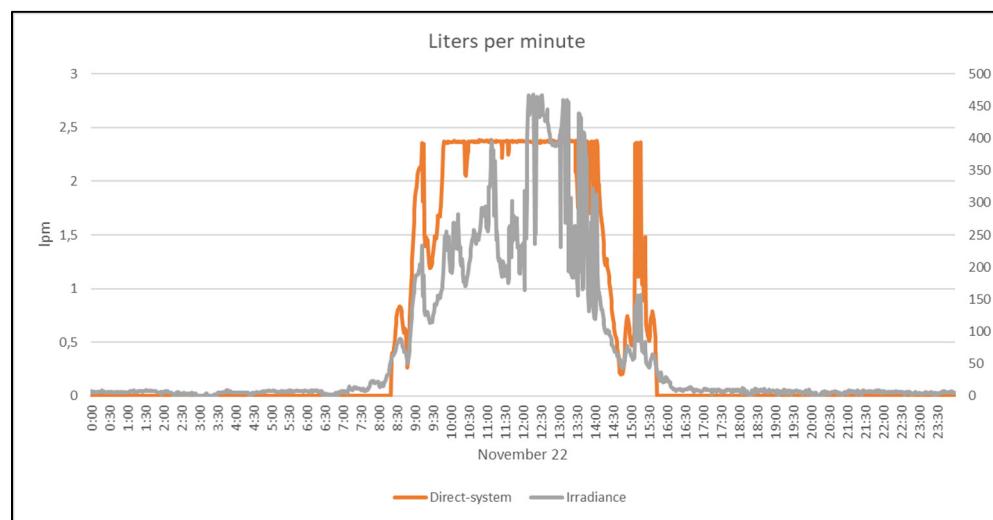


Figure 3.12 Daily water flow for a direct system

3.8 Cost analysis

An important aspect for targeted communities is the cost of the system. Table 3.3 shows the basic cost of each system, excluding the monitoring and measurement components.

Table 3.3 System cost

Component	System #1	System #2
Solar panel, 100W	115	115
Pump, 1GPM, 12V	146	146
DC-DC converter	72	
MPPT		264
Battery		295
Piping accessories (tubing)	34	34
Wiring	33	33
Support brackets	17	17
Breakers	32	32
Total (CAD)	449	936

A battery system could cost as much as double the cost of a direct system. Not considering the life span of the components, replacement parts and inflation costs, and as shown in section 3.3 that a battery system can pump twice as much water it can be deduced that the cost per litre is equivalent.

For a real-life application, the size of the components should be optimized, especially those of the mppt, the battery and the dc-dc converter which could significantly reduce the cost. In such a case, a battery system will be more advantageous in terms of cost per litter and flexibility. On the other hand, in the case where pumping water widely beyond the consumption is avoided and limiting the operation costs (ex. battery replacement every 5 years), a direct system will be more advantageous.

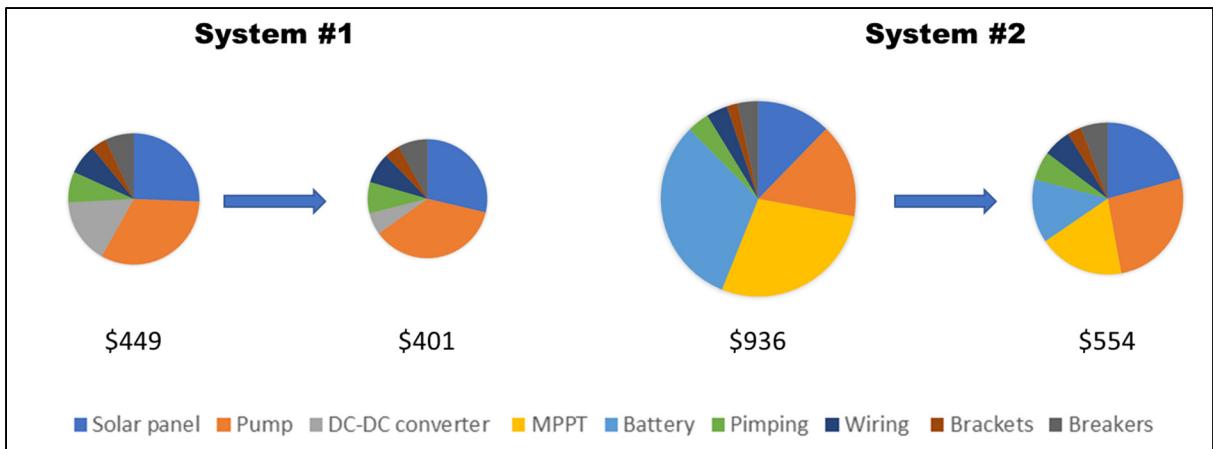


Figure 3.13 System cost after size optimisation

Figure 3.13 shows how the cost of each system can be reduced by optimizing its size.

3.9 Winter conditions

While having winter conditions, solar panels are regularly covered with snow preventing any energy production, see Figure 3.14. When the sun shines and heats up a water film will form between the panel and the snow layer, and the snow will slide down by gravity clearing the panel. The higher the tilt the faster the process will occur.



Figure 3.14 Solar array under winter conditions

However, as shown in Figure 3.15 such a process can take up to 11 days. In this test the system was in idle mode, no pump was working, and the only consumption was the minimum system's consumption.

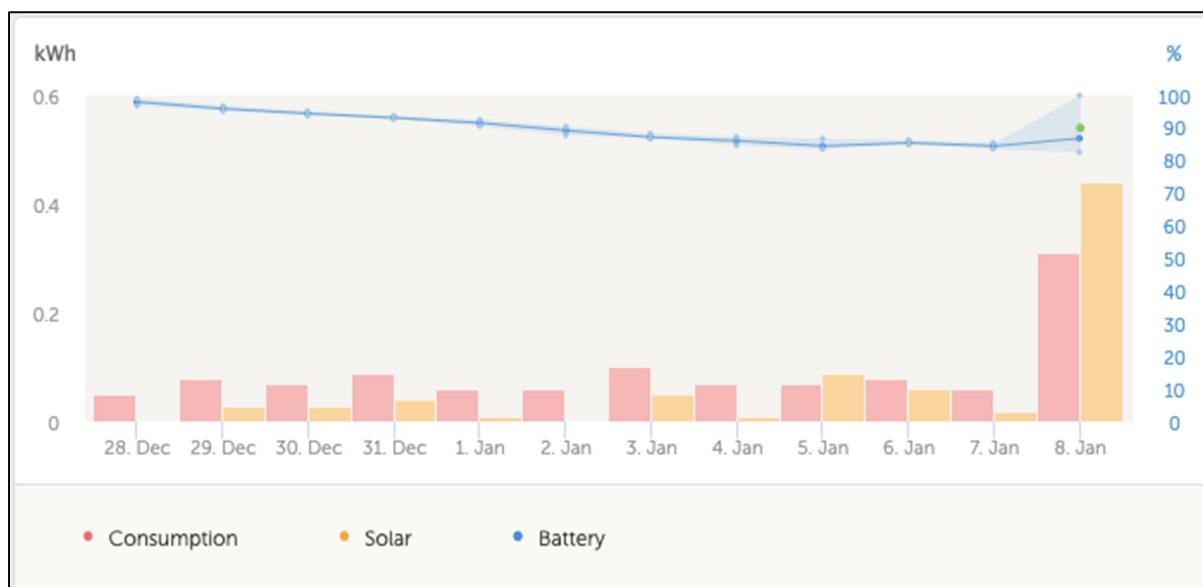


Figure 3.15 System overview under snow conditions

The battery was discharged daily until enough sunlight cleared the snow layer and started charging again (Jan 8th).

Manual snow clearing is helpful as the system restarts energy production earlier. It was also noted that even on a very cloudy day, after the snow removal the solar panels were able to produce 9W which was enough for the direct pump to restart with a slow debit.

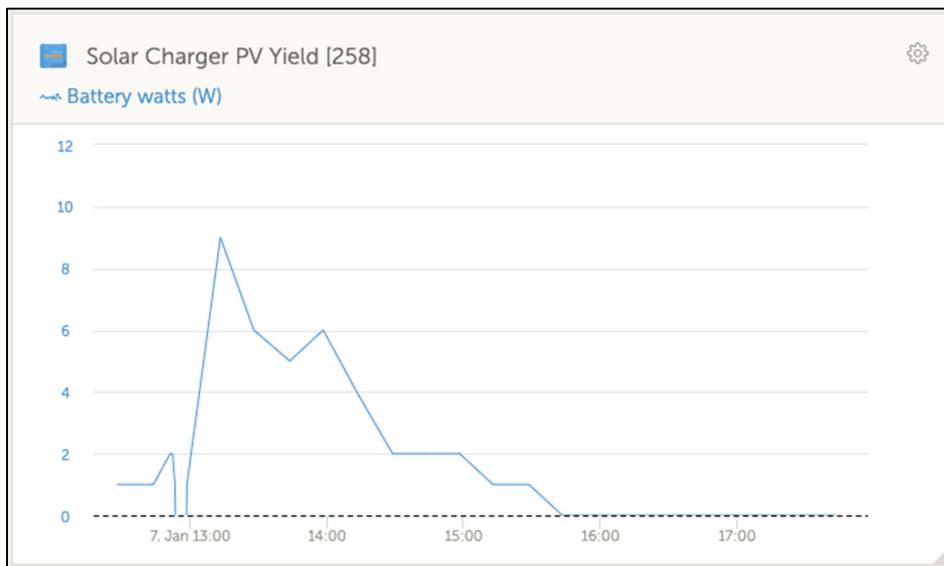


Figure 3.16 Solar charger PV yield (MPPT)

Figure 3.16 shows the pic in PV yield right after the snow was manually cleared from the panels.

CHAPTER 4

FULL-SIZE SYSTEM

4.1 Optimized system for a rural location

For a real-life application, a similar approach is taken to pre-design an optimal system to be installed in Diapaga, Burkina Faso (12°04'N, 1°47'E).



Figure 4.1 Diapaga, Burkina Faso location

Based on its location, a solar panel should be installed with 10° tilt and 180° azimuth.

The average solar radiation under these conditions is 5.22 kWh/m²/day and the worst-case scenario is the month of July with 4.45 kWh/m²/day. See Figure 4.2 (source PVWatts Calculator)

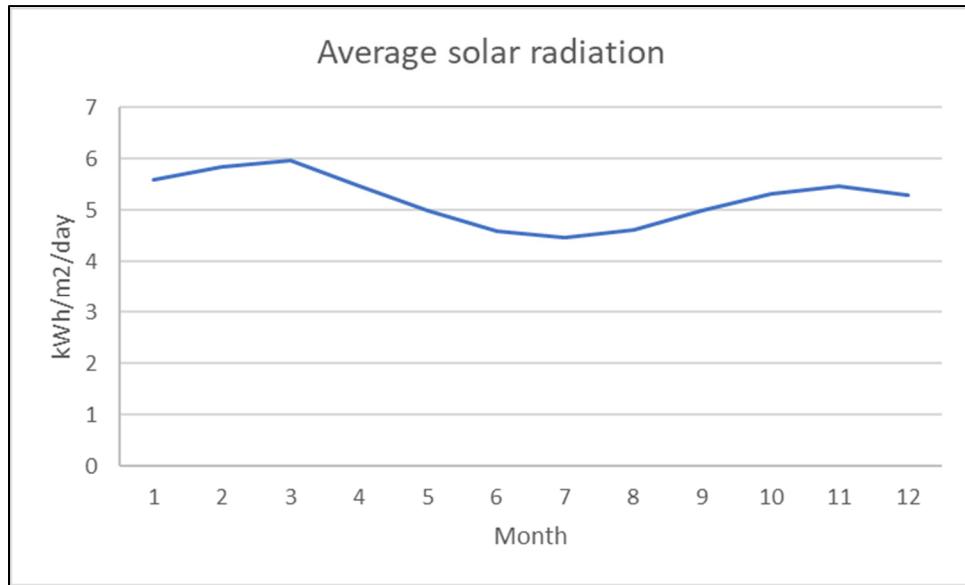


Figure 4.2 Average solar radiation for Diapaga, Burkina Faso

The average household size in Burkina Faso is 7 people (source <https://globaldatalab.org/>), therefore the target water consumption is $7 \times 100\text{L} = 700\text{L/day}$. This size is among the average in sub-Saharan Africa.

Using a similar pump to the one used in this study, the pump running time is:

$$700 \text{ L/day} / 3.7854 \text{ L/min} = 185 \text{ min/day} \quad (4.1)$$

The pump's energy consumption:

$$E_p = 12 \text{ V} \times 1.7 \text{ A} \times 185/60 \text{ h} = 63 \text{ Wh} \quad (4.2)$$

Solar array size is calculated as follows:

$$\begin{aligned}
 Avg \frac{Wh}{day} &\times \text{system derate factor} \\
 &\times \text{charge controller efficiency} \\
 &\times \text{battery efficiency} \times \text{peak sun h per day} \\
 &= \text{total array watts}
 \end{aligned} \tag{4.3}$$

$$63Wh \div 0.8 \div 0.98 \div 0.8 \div 4.45h = 22.6 W \tag{4.4}$$

The minimal requirement for the system is 22.6 Wp of a solar array, a commonly available panel of 30W could be used.

With a year average temperature above 25°C, no temperature coefficient needs to be considered when selecting dc-dc converter.

To minimize the cost of acquisition and operation, a direct type of system is recommended. The output current should be estimated to:

$$30 W \div 12V = 2.5 A \tag{4.5}$$

A 24|12 5A dc-dc converter could be used. The system uses small amounts of current (<3A) therefore the necessary wire gauge should be small and affordable.

Table 4.1 lists the estimated cost of such PVPS.

Table 4.1 System estimated cost

Component	Cost (CAD)
Solar panel, 30W	60
Pump, 1GPM, 12V	146
DC-DC converter	24
Accessories (tubing), wiring, breakers	50
Support structure	20
Total (CAD)	300

A PVPS with a total cost of 300CAD would be sufficient to provide pumped water to a rural average household of 7 in Burkina Faso. A cheaper pump should also be considered.

CONCLUSION

Water scarcity is a basic problem for about 1 billion people worldwide. One potential solution to alleviate this issue is the use of solar-powered water pumping systems. The main objective of this study was to design, install and test two types of PVPS: one direct-driven, and another battery-coupled. While both systems had the same solar panel and water pump the intermediate control differed in that the first system used the energy produced by the panel to power to pump whereas the second system stored the energy from the panel on a battery and then used it to operate the pump. The systems were installed and operated at the ETS's Heliolab Michel-Trottier t3e.

After analyzing the results, it was observed that a battery-coupled system is more efficient: it can pump more water, up to twice as much. The extra energy stored on the battery could also be used for other applications like lighting, charging small devices such as phones, ventilation, entertainment (tv, radio), etc.

A direct-driven system has a lower acquisition cost, about 48% compared to a battery-coupled system in the present study case. Optimizing the size of each system and considering the amount of water they can pump, a battery-coupled is the most advantageous of the two in terms of cost per litre and flexibility.

Since a PVPS is directly linked to solar irradiance, it is ideal to combine the PVPS with a reservoir to have available water on bad weather days. Adjusting the consumption to the weather will also be beneficial.

It can be argued that a larger solar array for a direct-driven PVPS could match the larger amount of water pumped by a battery PVPS at an equal or lesser cost. In the current set-up, with the combination of solar panel size and pump size, a larger solar array will not have a significant impact because the pump is already at full capacity for most of the daylight period.

Winter conditions can cause an important impact on the solar energy production especially when high latitudes are considered. A solar panel tilted at 45° has difficulty clearing the snow accumulation. It is recommended a higher tilt and/or manually remove the snow.

A real case application was pre-designed for an average household of 7 people located in Diapaga, Burkina Faso. The system required a 30W solar panel, 1gpm pump, dc-dc 24/12V converter and accessories. The cost was estimated to 300CAD. This demonstrates the feasibility of cheap systems.

For certain stand-alone applications, remote monitoring is convenient, in this case study, it allowed to quickly identify a faulty water pump, snow accumulation and an empty water tank among other things.

In this study, a 12V CC water pump typical of the RV market was used. Each pump could be operational on average 8 hours non-stop a day while their typical use in only a few minutes at a time per day. The battery-coupled pump, which operated longer, failed due to such stress. These types of pumps are not meant for such a regime.

The Arduino platform is an affordable and user-friendly means for data acquisition; however, it is very sensitive to electromagnetic noise. It was necessary to incorporate many electronic components to reduce such noise (ex. Capacitors, power source, etc.).

RECOMMENDATIONS

Several recommendations for future projects are noted in this chapter:

Control system

It is desirable to develop an improved control system that optimizes the cost-efficiency of the system: a more affordable dc-dc converter can be used and examine the possibility to use a pulse width modulation (PMV) solar charge controller instead of an MPPT, even if less performant. Additionally, it should be able to program the pump operation: ex. start/stop with the water level, battery voltage, and time of operation. While a more robust pump is recommended, an improved control system could limit the continuous usage of the pump to cool down.

Portable support

Another interesting project will be to design a portable type of support for the solar panels and their components. Such support should be modular for different size systems, diverse locations, affordable, and easy to transport and install.

Test in real conditions

Not all real application conditions were able to be tested in a lab environment. Installations such as a well, a river or a lake, should be tried out, including different pumping heights and distances, mechanical piping losses, etc. The use of a reservoir can be tested in parallel. The adaptation of the consumption to the weather predictions should be investigated.

ANNEX I

BILL OF MATERIALS

Table-A I-1 Bill of materials

No.	ITEM	QTY	SUPPLIER	UNIT COST	TOTAL COST
	Photovoltaic Array (exterior)				1994,93
	Solar panel 100W, (Renogy)	2	Solergy Systems	115	230
	Support brackets (Renogy)	2	Solergy Systems	17	34
	Wood planks, 2"x4",treated (m)	15	ETS	3,77	56,55
	Screws, deck, green, 10x3.5 (100pc)	1	ETS	20	20
	Plywood, 1/2", 215x42.2 (cm)	1	ETS	58,1	58,1
	Sand bags, 13kgs	12	Rona	5,19	62,28
	Pyrometer CMP3 (Kipp & Zonen)	1	ETS	1364	1364
	Montage pyrometer	1	ETS	100	100
	PV cable, AWG#12, 30ft	2	Solergy Systems	35	70
	Rubber support	4	Rona	15	60
	Attachment wire	1	ETS	10	10
	Control Panel (interior)				2553
	Charge controller, MPPT (+Bluetooth) (Victron)	1	Solergy Systems	264	264
	Battery monitor (+Bluetooth) (Victron Energy)	1	Solergy Systems	329	329
	Battery, AGM, 12V 90AH (Victron Energy)	1	Solergy Systems	295	295
	Inverter, 12V-120V 250W (Victron Energy)	1	Solergy Systems	150	150
	Cables kit (Pv cable , battery, pump, etc)	1	Solergy Systems	65	65
	Control/monitor panel (color) (Victron Energy Color)	1	Solergy Systems	800	800
	Wifi module, for color control (Victron Energy)	1	Solergy Systems	37	37
	Converter DC-DC 24V 12V (Victron Energy)	1	Solergy Systems	72	72
	Breaker 20A (pump)	2	Solergy Systems	32	64
	Cable set (battery, pump)	1	Solergy Systems	60	60
	Board, wood 80x60x1.3cms (4'x2'x1/2')	1	ETS	20	20
	Screws, mounting (+washers)	1	Home Depot	20	20
	Breaker 20A (PV)	2	Solergy Systems	32	64
	Bus bar, 4 studs, 100A	2	Solergy Systems	32	64
	Bus bar, 2 studs, 48A	2	Solergy Systems	14	28
	Ground cable	1	ETS	5	5
	screws + washers, mounting	1	ETS	20	20
	etherner cable	1	ETS	14	14
	wall mount bmv+CC (Victron Energy)	1	Solergy Systems	70	70
	VE.direct cables (Victron Energy)	2	Solergy Systems	21	42
	VE.direct to usb cable (Victron Energy)	1	Solergy Systems	39	39
	Cable tie (ty-wrap), 100pc	1	Home Depot	13	13
	Cable clamp, 18pc	1	ETS	18	18
	Reservoir				752,72
	Bin 77Litres (Rubbermade)	1	Solergy Systems	21	21
	Tubing, clear vinyl, 3/8', 10ft	2	Solergy Systems	34	68
	Water Pump 12V, 1Gpm (Shurflo)	2	Solergy Systems	146	292
	Flowmeter (0.13 to 7.9 GPM) (FTB2003)	2	Omega	175	350
	Fitting, 3/8" Tube ID x 1/4 NPSM Male (10pc)	1	McMaster	10,83	10,83
	Fitting, 3/8" Hose ID, 3/8 NPT Female Pipe (10pc)	1	McMaster	10,89	10,89
	Tools, others				400
	Solarimetre, hand held, 2000W/m2 +/- 10W/m2	1	Solergy Systems	152	152
	MC4 tool	1	Solergy Systems	13	13
	Portable solar panel 100W, w/ suitcase (Renogy)	1	Solergy Systems	235	235
	Data adquisition				184,9
	Arduino Mega 2560	1	Adafruit	39,95	39,95
	2.8" TFT Touch Shield for Arduino	1	Adafruit	34,95	34,95
	Converter, F/V (LM2907)	2	ETS	20	40
	Instrumentation amplifier (AD623)	1	ETS	20	20
	PCB	1	ETS	50	50
					5885,55

Note: unit prices in *italic* are estimates since items were already available at the ETS.

ANNEX II

WIND LOAD CALCULATION

Wind load calculation on the solar panels support structure considers an average wind speed below 22km/h for the last 10 years with a record speed of 117km/h gust.

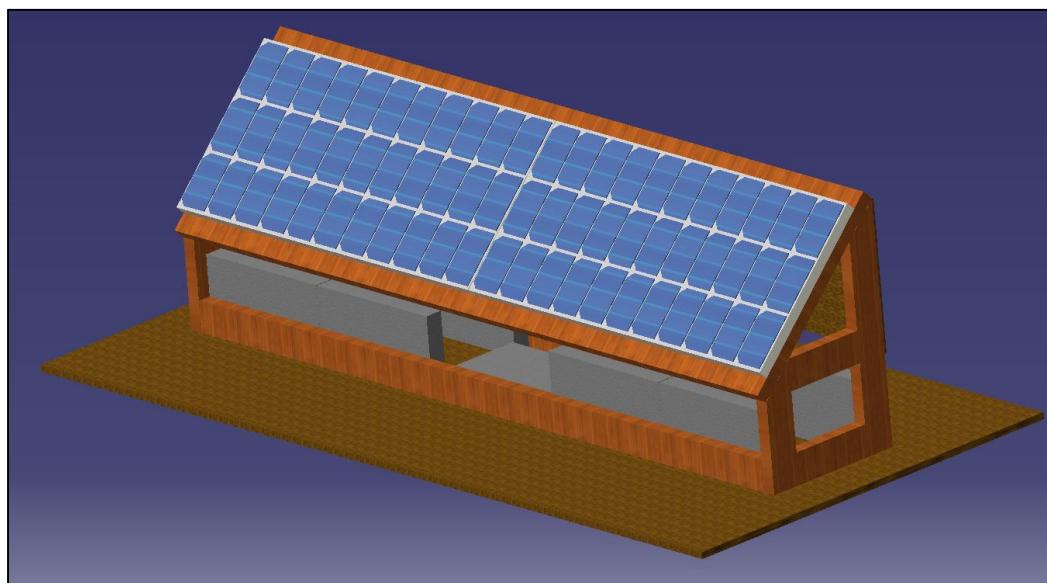


Figure-A II-1 Support structure for solar panels

The aerodynamic force applied to the structure is defined by:

$$F_A = \frac{1}{2} \rho V^2 C_D A \quad (\text{A II-1})$$

where,

ρ is the density of air, equals to 1.225kg/m³,

V is the speed of air, equals 117 $\frac{\text{km}}{\text{h}}$ considering the maximum recorded wind gust in Montreal,

C_D is the drag coefficient, which equals 1 for a conservative calculation,

A is the cross-sectional area.

To simplify the calculation the force applied to the solar panels is considered as a perpendicular flat surface. The area of such surface is:

$$A = \sin 45^\circ \times 1 \times w = \sin 45^\circ \times 2.15m \times 0.6m = 0.91m^2 \quad (\text{A II-2})$$

the forces applied to the structure are shown in the following diagram

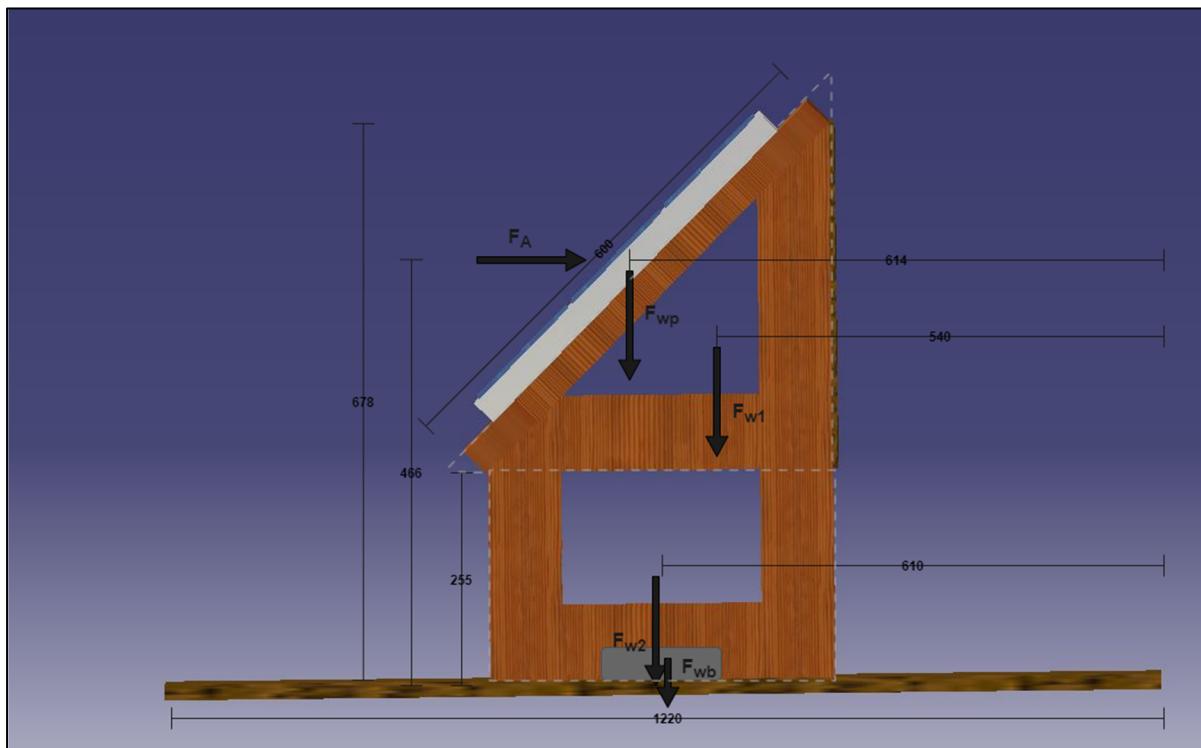


Figure-A II-2 Forces applied on the support structure

where,

$$\text{Aerodynamic force, } F_A = \frac{1}{2} \times 1.225 \times \left(\frac{117}{3.6}\right)^2 \times 1 \times 0.91 = 590N$$

The linear weight of the wooden planks is 1.7 kg/m, therefore by adding the total length of the planks:

$$\text{Weight force of the upper structure, } F_{w1} = (6.5m \times 1.7\text{kg/m}) \times 9.81\text{m/s}^2 = 108.4N$$

$$\text{Weight force of the lower structure } F_{w2} = (5.65m \times 1.7\text{kg/m}) \times 9.81\text{m/s}^2 = 94.2N$$

$$\text{Weight force of the solar panels, } F_{wp} = 2 \times 6.5\text{kg} \times 9.81\text{m/s}^2 = 127.5N$$

Weight force of the ballast, F_{wb} = unknown

Other forces were considered negligible.

Since there is a 90° board on the rear side of the structure with a cross-sectional area similar to the front side, the aerodynamic forces on the front face and rear face are considered equivalent.

In the case of a front wind gust, the sum of the momentums is

$$F_A \times d_1 = F_{w1} \times d_2 + F_{w2} \times d_3 + F_{wp} \times d_4 + F_{wb} \times d_5 \quad (\text{A II-3})$$

$$\begin{aligned} 590 \times 466 &= 108.4 \times 540 + 94.2 \times 610 + 127.5 \times 614 \\ &\quad + F_{wb} \times 610 \end{aligned} \quad (\text{A II-4})$$

The force created by the ballast equals, $F_{wb} = 132.2 \text{ N}$

The minimum weight required to prevent the structure from flipping is

$$132.2 \text{ N} \div 9.81 \text{ m/s}^2 = 13.5 \text{ kg} \quad (\text{A II-5})$$

The result from a rear aerodynamic force is slightly lower.

For safety factors, 120kg of ballast will be applied.

ANNEX III

SOLAR ARRAY MECHANICAL SUPPORT

Detailed dimensions

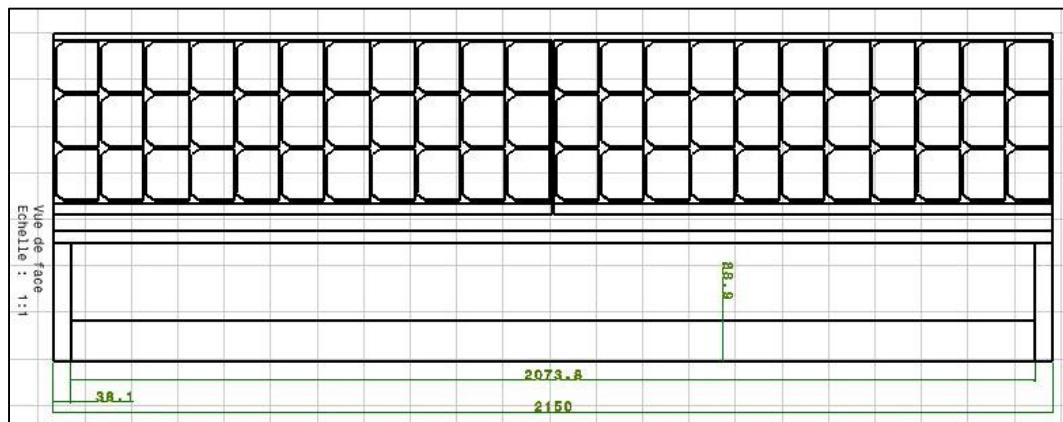


Figure-A III-1 Mechanical support – front view

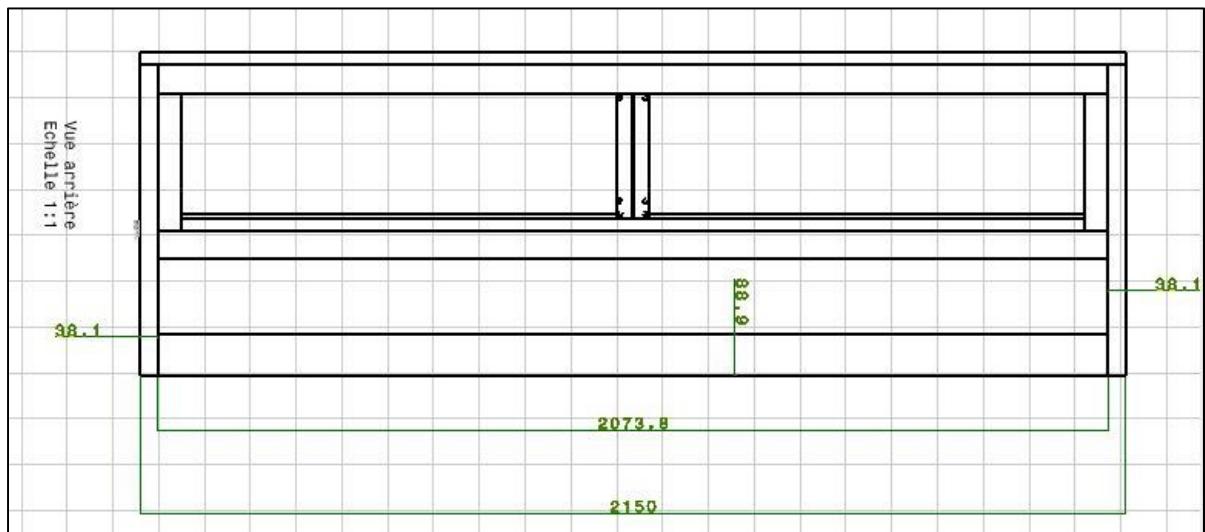


Figure-A III-2 Mechanical support – rear view

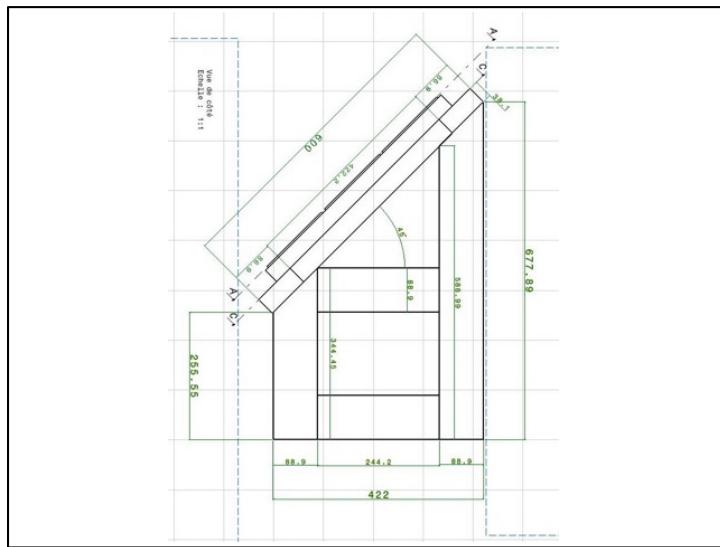


Figure-A III-3 Mechanical support – side view

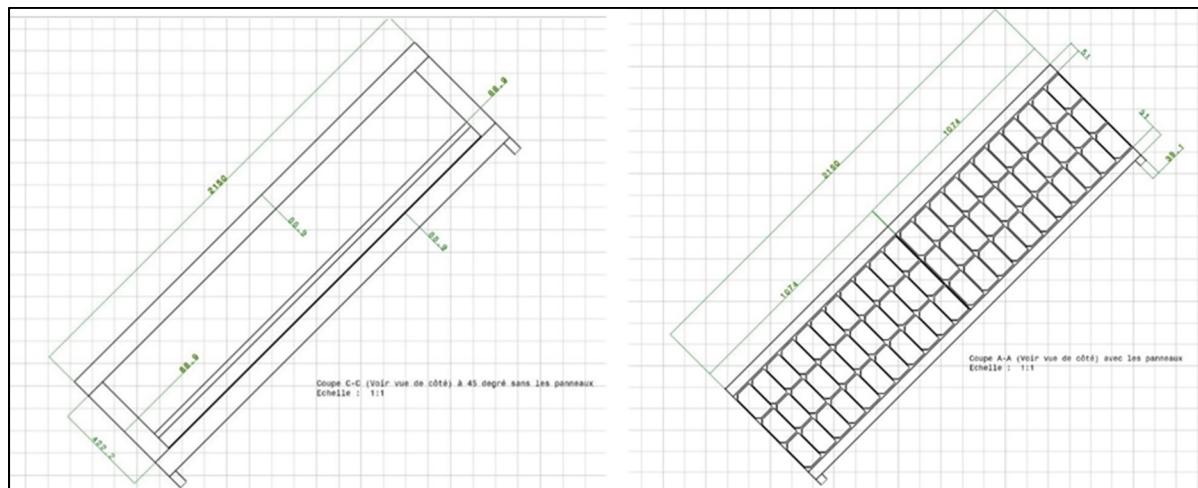


Figure-A III-4 Mechanical support – top view

ANNEX IV

ARDUINO PROGRAMMING

Arduino Algorithm

Algorithm-A IV-1 Flow_Pyro_Reader_V4.ino

```
// Programme "Flow_Pyro Reader V4" par M.Drouin 30-11-2021

#include <TimeLib.h>
#include <TimerOne.h>
#include <Adafruit_GFX.h>
#include <SPI.h>
#include <Wire.h>
#include <Adafruit_ILI9341.h>
#include <Adafruit_STMPE610.h>
#include <SD.h>

// Valeurs de calibrations pour l'écran
#define TS_MINX 150
#define TS_MINY 150
#define TS_MAXX 3800
#define TS_MAXY 3900

#define STMPE_CS 8
Adafruit_STMPE610 ts = Adafruit_STMPE610(STMPE_CS);

#define TFT_CS 10
#define TFT_DC 9
Adafruit_ILI9341 tft = Adafruit_ILI9341(TFT_CS, TFT_DC);

// Variables globales
int x, y;           // Coordonnées Touch!
int pilote=1000;     // Début a 1000
int _heure=0;
int _minute=0;
int _seconde=0;
int _annee=0;
int _mois=0;
int _jour=0;
int set_heure=0;
int set_minute=0;
int set_seconde=0;
int set_annee=0;
int set_mois=0;
int set_jour=0;
int compte_touch=0;
int bug_SD=1;
int SD_on=0;
int SD_entete=0;      // 0 => pas d'entete de créée : 1 => Entete déjà créée
int _fileno=0;
int set_fileno=0;
int _dt=1;            // en seconde
int _dt_scaler=1;     // dt appliqué en seconde
int set_dt=1;
int go_save=0;
int digit=3;

long compte_save=0;
```

```

float Ai0=0;
float Ai1=0;
float Ai2=0;
float Ai3=0;
float D1=0;
float D2=0;
float P1=0;
float D1_moy[50]={0};
float D2_moy[50]={0};
float P1_moy[50]={0};
float T1=0;
float Sens_D1=1.465; // Sensibilite Debitmetre 1 (lpm/V)
float Sens_D2=1.436; // Sensibilite Debitmetre 2 (lpm/V)
float Sens_P1=363; // Sensibilite Pyro 1 ((W/m2)/V) 90 744 (W/m2)/V ou 11.02 uV/(W/m2) Avec un gain 260
float offset_P1=0.0; // offset (V)
int compte_moy=0;

double _lecture_D1=0;
double _lecture_D2=0;
double _lecture_P1=0;
double _lecture_T1=0;

String dataString = "";
String fileString = "";
String init_string = "";

char c="";
char d1="";
char d2="";
char d3="";
char d4="";
char d5="";
char d6="";

File myFile;

// SD
Sd2Card card;
SdVolume volume;
SdFile root;

// Constantes
const int chipSelect = 4;

//-----
// Sous-programmes
void del_off()
{
    analogWrite(44, 0); // R
    analogWrite(45, 0); // B
    analogWrite(46, 0); // G
}

void del_green()
{
    analogWrite(44, 0); // R
    analogWrite(45, 0); // B
    analogWrite(46, 0); // G
}

void read_data()
{
    Ai0 = 0;
    Ai1 = 0;
    Ai2 = 0;
    Ai3 = 0;
}

```

```

/* for(int i = 0; i <= 99; i++)
{*/
  Ai0 = Ai0 + analogRead(0);
  Ai1 = Ai1 + analogRead(1);
  Ai2 = Ai2 + analogRead(2);
  Ai3 = Ai3 + analogRead(3);
// }
Ai0 = Ai0 / 1023 * 5;
Ai1 = Ai1 / 1023 * 5;
Ai2 = Ai2 / 1023 * 5;
Ai3 = Ai3 / 1023 * 5;
}

void SD_tester()
{
  bug_SD = 0;

  if (!SD.begin(chipSelect))
  {
    tft.setCursor(10, 50);
    tft.println("Demarrage SD Echec");
    bug_SD = 1;
  }
  else
  {
    tft.setCursor(10, 50);
    tft.println("Demarrage SD Ok");
  }

  if (!card.init(SPI_HALF_SPEED, chipSelect))
  {
    tft.setCursor(10, 75);
    tft.println("Init. SD Echec");
    bug_SD = 1;
  }
  else
  {
    tft.setCursor(10, 75);
    tft.println("Init. SD Ok");
  }

  tft.setCursor(10, 100);
  switch (card.type()) {
    case SD_CARD_TYPE_SD1:
      tft.println("Type SD1");
      break;
    case SD_CARD_TYPE_SD2:
      tft.println("Type SD2");
      break;
    case SD_CARD_TYPE_SDHC:
      tft.println("Type SDHC");
      break;
    default:
      tft.println("Type inconnu");
  }

  myFile = SD.open("TEST1.TXT", FILE_WRITE);

  if (myFile)
  {
    myFile.println("Testing 1...2...3");
    myFile.close();
  }

  if (SD.exists("TEST1.TXT"))
  {
    tft.setCursor(10, 125);
    tft.println("SD Accessible");
  }
}

```

```

}

else
{
    tft.setCursor(10, 125);
    tft.println("SD Non Accessible");

    bug_SD = 1;
}

delay(1500);
SD.remove("TEST1.TXT");
}

void maj_date()
{
    _annee = year() - 2000;
    _mois = month();
    _jour = day();
    _heure = hour();
    _minute = minute();
    _seconde = second();
}

// Interrupts
void callback()
{
    compte_save++;
    go_save = 1;
}

//-----
// programme_Setup
void setup()
{
    tft.begin();
    if (!ts.begin()) {
        tft.println("Unable to start touchscreen.");
    }

    tft.fillScreen(ILI9341_BLACK);
    tft.setTextSize(2);
    tft.setTextColor(ILI9341_WHITE, ILI9341_BLACK);
    tft.setRotation(1);

    Timer1.initialize(1000000); // initialise le timer1 a 1 secondes
    Timer1.attachInterrupt(callback); // attache callback() a timer1 overflow interrupt

    setTime(0,0,0,1,1,2021); // (hr,min,sec,day,mnth,yr)

}

//-----
// programme_Main
void loop()
{
    while (true)
    {
        read_data();

        _lecture_D1 = Ai0;
        _lecture_D2 = Ai1;
        _lecture_P1 = Ai2;
        _lecture_T1 = Ai3;

        // Sens_P1 = 0 - 66.0810463196*pow(_lecture_P1,5) + 611.8898805158*pow(_lecture_P1,4) - 2153.2154966177*pow(_lecture_P1,3)
        + 3593.1718947072*pow(_lecture_P1,2) - 2887.3017832012*_lecture_P1 + 1380.0707388886;

        D1_moy[compte_moy] = lecture_D1 * Sens_D1;
    }
}

```

```

if(D1_moy[compte_moy]<0.1) D1_moy[compte_moy]=0;
D2_moy[compte_moy] = _lecture_D2 * Sens_D2;
if(D2_moy[compte_moy]<0.1) D2_moy[compte_moy]=0;
P1_moy[compte_moy] = (_lecture_P1 - offset_P1) * Sens_P1;
if(P1_moy[compte_moy]<5) P1_moy[compte_moy]=0;
T1 = _lecture_T1 * 100; // LM35 10 mV/C

if(compte_moy >= 49)
{
    compte_moy=0;
}
else
{
    compte_moy++;
}

D1 = 0;
D2 = 0;
P1 = 0;

for (int i = 0; i <= 49; i++)
{
    D1 = (D1 + D1_moy[i]);
    D2 = (D2 + D2_moy[i]);
    P1 = (P1 + P1_moy[i]);
}

D1 = D1 / 50;
D2 = D2 / 50;
P1 = P1 / 50;

maj_date();

tft.setTextSize(2);
tft.setTextColor(ILI9341_WHITE,ILI9341_BLACK);

if(_heure < 10) // Afficher heure
{
    tft.setCursor(10, 0);
    tft.println("0");
    tft.setCursor(22, 0);
    tft.println(_heure, DEC);
}
else
{
    tft.setCursor(10, 0);
    tft.println(_heure, DEC);
}
tft.setCursor(34, 0);
tft.println(":");

if(_minute < 10) // Afficher minute
{
    tft.setCursor(46, 0);
    tft.println("0");
    tft.setCursor(58, 0);
    tft.println(_minute, DEC);
}
else
{
    tft.setCursor(46, 0);
    tft.println(_minute, DEC);
}
tft.setCursor(70, 0);
tft.println(":");

if(_seconde < 10) // Afficher seconde
{
}

```

```

tft.setCursor(82, 0);
tft.println("0");
tft.setCursor(94, 0);
tft.println(_seconde, DEC);
}
else
{
tft.setCursor(82, 0);
tft.println(_seconde, DEC);
}

if(_jour < 10) // Afficher jour
{
tft.setCursor(115, 0);
tft.println("0");
tft.setCursor(127, 0);
tft.println(_jour, DEC);
}
else
{
tft.setCursor(115, 0);
tft.println(_jour, DEC);
}
tft.setCursor(139, 0);
tft.println("/");

if(_mois < 10) // Afficher mois
{
tft.setCursor(151, 0);
tft.println("0");
tft.setCursor(163, 0);
tft.println(_mois, DEC);
}
else
{
tft.setCursor(151, 0);
tft.println(_mois, DEC);
}
tft.setCursor(175, 0);
tft.println("/");

if(_annee < 10) // Afficher annee
{
tft.setCursor(187, 0);
tft.println("0");
tft.setCursor(199, 0);
tft.println(_annee, DEC);
}
else
{
tft.setCursor(187, 0);
tft.println(_annee, DEC);
}

tft.setCursor(218, 0);
if(SD_on) // Afficher SD on/off
{
tft.println("Save ON ");
}
else
{
tft.println("Save OFF");
}

//----- Save to SD
if(_dt == 0)
{
dt_scaler = 1; // timer est a 0.1 s
}

```

```

        }

    else
    {
        _dt_scaler = _dt; // timer est a 1 s
    }

    if(SD_on && (compte_save >= _dt_scaler) && go_save)
    {
        compte_save=0;

        if(!SD_entete)      // Creer l'entete si pas fait
        {
            fileString = "DATA_";
            fileString += String(_fileno, DEC);
            fileString += String(".txt");

            myFile = SD.open(fileString, FILE_WRITE);

            if(myFile)
            {
                myFile.println("r");

                myFile.println("tick  (ms)\tDate  AA:MM:JJ\tTemps  HH:MM:SS\tAi0  (V)\tAi1  (V)\tAi2  (V)\tAi3  (V)\tD1  (LPM)\tD2
(LPM)\tP1(W/m^2)\tT1 (C)");

                myFile.close();
            }
        }

        SD_entete = 1;
    }

    dataString = "";
    dataString += String(millis(), DEC);
    dataString += String("\t");
    if(_annee < 10) dataString += String("0");
    dataString += String(_annee, DEC);
    dataString += String(":");
    if(_mois < 10) dataString += String("0");
    dataString += String(_mois, DEC);
    dataString += String(":");
    if(_jour < 10) dataString += String("0");
    dataString += String(_jour, DEC);
    dataString += String("\t");
    if(_heure < 10) dataString += String("0");
    dataString += String(_heure, DEC);
    dataString += String(":");
    if(_minute < 10) dataString += String("0");
    dataString += String(_minute, DEC);
    dataString += String(":");
    if(_seconde < 10) dataString += String("0");
    dataString += String(_seconde, DEC);
    dataString += String("\t");
    dataString += String(Ai0, 6);
    dataString += String("\t");
    dataString += String(Ai1, 6);
    dataString += String("\t");
    dataString += String(Ai2, 6);
    dataString += String("\t");
    dataString += String(Ai3, 6);
    dataString += String("\t");
    dataString += String(D1, 3);
    dataString += String("\t");
    dataString += String(D2, 3);
    dataString += String("\t");
    dataString += String(P1, 2);
    dataString += String("\t");
    dataString += String(T1, 3);
}

```

```

myFile = SD.open(fileString, FILE_WRITE);

if (myFile)
{
    myFile.println(dataString);
    myFile.close();
}

go_save = 0;
}

//-----
if(pilote == 0) // Creation 1er menu
{
    del_off();

    tft.fillScreen(ILI9341_BLACK);
    tft.setTextColor(ILI9341_WHITE,ILI9341_BLUE);

    tft.fillRoundRect (10, 20, 148, 70, 10, ILI9341_BLUE);
    tft.fillRoundRect (162, 20, 148, 70, 10, ILI9341_BLUE);
    tft.fillRoundRect (10, 170, 300, 70, 10, ILI9341_BLUE);

    tft.drawRoundRect (10, 20, 148, 70, 10, ILI9341_WHITE);
    tft.drawRoundRect (162, 20, 148, 70, 10, ILI9341_WHITE);
    tft.drawRoundRect (10, 170, 300, 70, 10, ILI9341_WHITE);

    tft.setCursor(42, 48);
    tft.println("Horloge");
    tft.setCursor(176, 48);
    tft.println("Sauvegarde");
    tft.setCursor(110, 198);
    tft.println("Affichage");

    pilote = 1;

    ts.getPoint();
}

//-----
if(pilote == 1 ) // Check reponse 1er menu
{
    del_green();

    if(!ts.bufferEmpty())
    {
        TS_Point p = ts.getPoint();
        p.x = map(p.x, TS_MINY, TS_MAXY, 0, tft.height());
        p.y = map(p.y, TS_MINX, TS_MAXX, 0, tft.width());
        y = tft.height() - p.x;
        x = p.y;

        if((y >= 20) && (y <= 90)) // Bouton : Ajuster Horloge et Sauvegarde
        {
            if(x < 150) pilote = 2;
            if(x >= 150) pilote = 50;
        }

        if((y >= 95) && (y <= 240)) // Bouton : Affichage
        {
            pilote = 6;
        }
    }
}

//-----
if(pilote == 2 ) // Ceation Ajuster Horloge
{
}

```

```
del_off();

set_annee = _annee;
set_mois = _mois;
set_jour = _jour;
set_heure = _heure;
set_minute = _minute;
set_seconde = _seconde;

tft.fillScreen(ILI9341_BLACK);
tft.setTextColor(ILI9341_WHITE, ILI9341_BLUE);

tft.fillRoundRect (10, 21, 100, 60, 10, ILI9341_BLUE);
tft.fillRoundRect (110, 21, 100, 60, 10, ILI9341_BLUE);
tft.fillRoundRect (210, 21, 100, 60, 10, ILI9341_BLUE);
tft.fillRoundRect (10, 117, 100, 60, 10, ILI9341_BLUE);
tft.fillRoundRect (110, 117, 100, 60, 10, ILI9341_BLUE);
tft.fillRoundRect (210, 117, 100, 60, 10, ILI9341_BLUE);
tft.fillRoundRect (10, 86, 50, 26, 10, ILI9341_BLUE);
tft.fillRoundRect (60, 86, 50, 26, 10, ILI9341_BLUE);
tft.fillRoundRect (110, 86, 50, 26, 10, ILI9341_BLUE);
tft.fillRoundRect (160, 86, 50, 26, 10, ILI9341_BLUE);
tft.fillRoundRect (210, 86, 50, 26, 10, ILI9341_BLUE);
tft.fillRoundRect (260, 86, 50, 26, 10, ILI9341_BLUE);
tft.fillRoundRect (10, 182, 50, 26, 10, ILI9341_BLUE);
tft.fillRoundRect (60, 182, 50, 26, 10, ILI9341_BLUE);
tft.fillRoundRect (110, 182, 50, 26, 10, ILI9341_BLUE);
tft.fillRoundRect (160, 182, 50, 26, 10, ILI9341_BLUE);
tft.fillRoundRect (210, 182, 50, 26, 10, ILI9341_BLUE);
tft.fillRoundRect (260, 182, 50, 26, 10, ILI9341_BLUE);
tft.fillRoundRect (10, 213, 150, 26, 10, ILI9341_BLUE);
tft.fillRoundRect (160, 213, 150, 26, 10, ILI9341_BLUE);

tft.drawRoundRect (10, 21, 100, 60, 10, ILI9341_WHITE);
tft.drawRoundRect (110, 21, 100, 60, 10, ILI9341_WHITE);
tft.drawRoundRect (210, 21, 100, 60, 10, ILI9341_WHITE);
tft.drawRoundRect (10, 117, 100, 60, 10, ILI9341_WHITE);
tft.drawRoundRect (110, 117, 100, 60, 10, ILI9341_WHITE);
tft.drawRoundRect (210, 117, 100, 60, 10, ILI9341_WHITE);
tft.drawRoundRect (10, 86, 50, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (60, 86, 50, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (110, 86, 50, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (160, 86, 50, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (210, 86, 50, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (260, 86, 50, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (10, 182, 50, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (60, 182, 50, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (110, 182, 50, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (160, 182, 50, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (210, 182, 50, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (260, 182, 50, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (10, 213, 150, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (160, 213, 150, 26, 10, ILI9341_WHITE);

tft.setCursor(84, 60);
tft.println("J");
tft.setCursor(184, 60);
tft.println("M");
tft.setCursor(284, 60);
tft.println("A");
tft.setCursor(84, 156);
tft.println("H");
tft.setCursor(184, 156);
tft.println("M");
tft.setCursor(284, 156);
tft.println("S");
tft.setCursor(31, 92);
tft.println("-");
```

```

tft.setCursor(81, 92);
tft.println("+");
tft.setCursor(131, 92);
tft.println("-");
tft.setCursor(181, 92);
tft.println("+");
tft.setCursor(231, 92);
tft.println("-");
tft.setCursor(281, 92);
tft.println("+");
tft.setCursor(31, 188);
tft.println("-");
tft.setCursor(81, 188);
tft.println("+");
tft.setCursor(131, 188);
tft.println("-");
tft.setCursor(181, 188);
tft.println("+");
tft.setCursor(231, 188);
tft.println("-");
tft.setCursor(281, 188);
tft.println("+");
tft.setCursor(75, 219);
tft.println("OK");
tft.setCursor(196, 219);
tft.println("ANNULER");

pilote=3;

ts.getPoint();
}

//-----
if(pilote == 3 ) // Ajuster Horloge
{
    del_green();

    tft.setTextColor(ILI9341_WHITE,ILI9341_BLUE);
    tft.setTextSize(4);

    if(set_jour < 10 ) // Ajout 0
    {
        tft.setCursor(30, 36);
        tft.println("0");
        tft.setCursor(54, 36);
        tft.println(set_jour, DEC);
    }
    else
    {
        tft.setCursor(30, 36);
        tft.println(set_jour, DEC);
    }

    if(set_mois < 10 ) // Ajout 0
    {
        tft.setCursor(130, 36);
        tft.println("0");
        tft.setCursor(154, 36);
        tft.println(set_mois, DEC);
    }
    else
    {
        tft.setCursor(130, 36);
        tft.println(set_mois, DEC);
    }

    if(set_annee < 10 ) // Ajout 0
    {

```



```

        set_jour = set_jour - 1;
    }

}

if((x >= 60) && (x <= 110))
{
    if(set_jour >= 31)
    {
        set_jour = 1;
    }
    else
    {
        set_jour = set_jour + 1;
    }
}

if((x >= 110) && (x <= 160))
{
    if(set_mois <= 1)
    {
        set_mois = 12;
    }
    else
    {
        set_mois = set_mois - 1;
    }
}

if((x >= 160) && (x <= 210))
{
    if(set_mois >= 12)
    {
        set_mois = 1;
    }
    else
    {
        set_mois = set_mois + 1;
    }
}

if((x >= 210) && (x <= 260))
{
    if(set_annee <= 0)
    {
        set_annee = 99;
    }
    else
    {
        set_annee = set_annee - 1;
    }
}

if((x >= 260) && (x <= 310))
{
    if(set_annee >= 99)
    {
        set_annee = 0;
    }
    else
    {
        set_annee = set_annee + 1;
    }
}

if((y >= 182) && (y <= 208))
{
    if((x >= 10) && (x <= 60))

```

```

{
    if(set_heure <= 0)
    {
        set_heure = 23;
    }
    else
    {
        set_heure = set_heure - 1;
    }
}

if((x >= 60) && (x <= 110))
{
    if(set_heure >= 23)
    {
        set_heure = 0;
    }
    else
    {
        set_heure = set_heure + 1;
    }
}

if((x >= 110) && (x <= 160))
{
    if(set_minute <= 0)
    {
        set_minute = 59;
    }
    else
    {
        set_minute = set_minute - 1;
    }
}

if((x >= 160) && (x <= 210))
{
    if(set_minute >= 59)
    {
        set_minute = 0;
    }
    else
    {
        set_minute = set_minute + 1;
    }
}

if((x >= 210) && (x <= 260))
{
    if(set_seconde <= 0)
    {
        set_seconde = 59;
    }
    else
    {
        set_seconde = set_seconde - 1;
    }
}

if((x >= 260) && (x <= 310))
{
    if(set_seconde >= 59)
    {
        set_seconde = 0;
    }
    else
    {
        set_seconde = set_seconde + 1;
    }
}

```

```

        }

    }

if((y >= 213) && (y <= 240))
{
    if((x >= 10) && (x <= 160))
    {
        setTime(set_heure,set_minute,set_seconde,set_jour,set_mois,set_annee); // (hr,min,sec,day,mnth,yr)
        pilote=0;
        maj_date();
    }

    if((x >= 160) && (x <= 310))
    {
        pilote=0;
        delay(300);
    }
}

//-----
if(pilote== 6 ) // Creation Affichage
{
    del_off();

tft.fillScreen(ILI9341_BLACK);
tft.setTextColor(ILI9341_WHITE,ILI9341_BLUE);

tft.fillRoundRect (10, 20, 300, 65, 10, ILI9341_BLUE); // Lectures V
tft.fillRoundRect (10, 85, 150, 65, 10, ILI9341_BLUE); // Lecture A1 V
tft.fillRoundRect (160, 85, 150, 65, 10, ILI9341_BLUE); // Lecture D2 LPM
tft.fillRoundRect (10, 150, 150, 65, 10, ILI9341_BLUE); // Lecture A2 V
tft.fillRoundRect (160, 150, 150, 65, 10, ILI9341_BLUE); // Lecture P1 W/M2
tft.fillRoundRect (10, 215, 300, 25, 10, ILI9341_BLUE); // Menu

tft.drawRoundRect (10, 20, 300, 65, 10, ILI9341_WHITE); // Lecture A0 V
tft.drawRoundRect (10, 85, 150, 65, 10, ILI9341_WHITE); // Lecture A1 V
tft.drawRoundRect (160, 85, 150, 65, 10, ILI9341_WHITE); // Lecture D2 LPM
tft.drawRoundRect (10, 150, 150, 65, 10, ILI9341_WHITE); // Lecture A2 V
tft.drawRoundRect (160, 150, 150, 65, 10, ILI9341_WHITE); // Lecture P1 W/M2
tft.drawRoundRect (10, 215, 300, 25, 10, ILI9341_WHITE); // Menu

tft.setTextSize(2);
tft.setCursor(19, 24);
tft.println("Lectures (V)");
tft.setCursor(19, 44);
tft.println("D1 :");
tft.setCursor(19, 64);
tft.println("D2 :");
tft.setCursor(169, 44);
tft.println("P1 :");
tft.setCursor(169, 64);
tft.println("T1 :");
tft.setCursor(19, 89);
tft.println("D1 (LPM)");
tft.setCursor(169, 89);
tft.println("D2 (LPM)");
tft.setCursor(19, 154);
tft.println("P1 (W/M^2)");
tft.setCursor(169, 154);
tft.println("T1 (C)");
tft.setCursor(140, 220);
tft.println("MENU");

pilote=7;

```

```

        ts.getPoint();
    }

//-----
    if(pilote== 7 ) // Affichage
    {
        del_green();

        tft.setTextColor(ILI9341_WHITE,ILI9341_BLUE);

        tft.setTextSize(2);

        tft.setCursor(69, 44);
        tft.println(_lecture_D1, 3);
        tft.setCursor(69, 64);
        tft.println(_lecture_D2, 3);
        tft.setCursor(219, 44);
        tft.println(_lecture_P1, 3);
        tft.setCursor(219, 64);
        tft.println(_lecture_T1, 3);

        tft.setTextSize(4);

        if(D1 < 9.95) digit=3;
        if(D1 < 99.95 && D1 >= 9.95) digit=2;
        if(D1 >= 99.95) digit=1;
        tft.setCursor(25, 115);
        tft.println(D1, digit);

        if(D2 < 9.95) digit=3;
        if(D2 < 99.95 && D2 >= 9.95) digit=2;
        if(D2 >= 99.95) digit=1;
        tft.setCursor(175, 115);
        tft.println(D2, digit);

        if(P1 < 9.95) digit=3;
        if(P1 < 99.95 && P1 >= 9.95) digit=2;
        if(P1 < 999.95 && P1 >= 99.95) digit=1;
        if(P1 >= 999.95) digit=0;
        tft.setCursor(25, 180);
        tft.println(P1, digit);
        tft.setCursor(121, 180);
        if(digit == 0) tft.println(" ");

        if(T1 < 9.95) digit=3;
        if(T1 < 99.95 && T1 >= 9.95) digit=2;
        if(T1 >= 99.95) digit=1;
        tft.setCursor(175, 180);
        tft.println(T1, digit);

        if(!ts.bufferEmpty()) // Touch!
        {
            TS_Point p = ts.getPoint();
            p.x = map(p.x, TS_MINY, TS_MAXY, 0, tft.height());
            p.y = map(p.y, TS_MINX, TS_MAXX, 0, tft.width());
            y = tft.height() - p.x;
            x = p.y;

            if((y >= 210) && (y <= 240))
            {
                if((x >= 160) && (x <= 310)) // Menu
                {
                    pilote=0;
                }
            }
        }
    }
}

```

```

        }

    else // No touch
    {

    }

//-----
if(pilote == 50) // Creation menu Sauvegarde
{
    del_off();

tft.fillScreen(ILI9341_BLACK);
tft.setTextColor(ILI9341_WHITE,ILI9341_BLUE);

tft.fillRoundRect (10, 20, 300, 50, 10, ILI9341_BLUE);
tft.fillRoundRect (10, 75, 300, 50, 10, ILI9341_BLUE);
if(bug_SD) tft.fillRoundRect (10, 130, 300, 50, 10, ILI9341_BLACK);
if(!bug_SD) tft.fillRoundRect (10, 130, 300, 50, 10, ILI9341_BLUE);
tft.fillRoundRect (10, 185, 300, 50, 10, ILI9341_BLUE);

tft.drawRoundRect (10, 20, 300, 50, 10, ILI9341_WHITE);
tft.drawRoundRect (10, 75, 300, 50, 10, ILI9341_WHITE);
tft.drawRoundRect (10, 130, 300, 50, 10, ILI9341_WHITE);
tft.drawRoundRect (10, 185, 300, 50, 10, ILI9341_WHITE);

tft.setCursor(100, 38);
tft.println("Tester uSD");
tft.setCursor(100, 93);
tft.println("Parametres");
tft.setCursor(52, 148);
if(!bug_SD) tft.setTextColor(ILI9341_WHITE,ILI9341_BLUE);
if(bug_SD) tft.setTextColor(ILI9341_WHITE,ILI9341_BLACK);
tft.println("Activer/Desactiver");
tft.setTextColor(ILI9341_WHITE,ILI9341_BLUE);
tft.setCursor(136, 204);
tft.println("Menu");

pilote = 51;

ts.getPoint();
}

//-----
if(pilote == 51 ) // Check reponse menu uSD
{
    del_green();

    if (!ts.bufferEmpty())
    {
        TS_Point p = ts.getPoint();
        p.x = map(p.x, TS_MINY, TS_MAXY, 0, tft.height());
        p.y = map(p.y, TS_MINX, TS_MAXX, 0, tft.width());
        y = tft.height() - p.x;
        x = p.y;

        if((y >= 20) && (y < 75)) // Bouton : Tester uSD
        {
            pilote = 52;
        }

        if((y >= 75) && (y < 130)) // Bouton : Parametres uSD
        {
            pilote = 54;
        }

        if (!bug_SD && (y >= 130) && (y < 185)) // Bouton : Activer/Desactiver
        {
    }
}

```

```

if(SD_on)
{
    SD_on=0;
    SD_entete=0;
    delay(200);
    ts.getPoint();
}
else
{
    SD_on=1;
    SD_entete=0;
    compte_save=0;
    go_save=1;
    delay(200);
    ts.getPoint();
}
}

if ((y >= 185) && (y <240)) // Bouton : Menu
{
    pilote = 0;
}
}

//-----
if(pilote== 52 ) // Cr ation Tester uSD
{
    del_off();

    tft.fillScreen(ILI9341_BLACK);
    tft.setTextColor(ILI9341_WHITE,ILI9341_BLACK);
    tft.setTextSize(2);

    pilote = 53;
}

//-----
if(pilote== 53 ) // Tester uSD
{
    SD_tester();
    pilote = 50;
}

//-----
if(pilote== 54 ) // Cr ation Parametres uSD
{
    del_off();

    set_fileno = _fileno;
    set_dt = _dt;

    tft.fillScreen(ILI9341_BLACK);
    tft.setTextColor(ILI9341_WHITE,ILI9341_BLUE);

    tft.fillRoundRect (10, 21, 300, 65, 10, ILI9341_BLUE);
    tft.fillRoundRect (10, 117, 300, 65, 10, ILI9341_BLUE);
    tft.fillRoundRect (10, 86, 150, 26, 10, ILI9341_BLUE);
    tft.fillRoundRect (160, 86, 150, 26, 10, ILI9341_BLUE);
    tft.fillRoundRect (10, 182, 150, 26, 10, ILI9341_BLUE);
    tft.fillRoundRect (160, 182, 150, 26, 10, ILI9341_BLUE);
    tft.fillRoundRect (10, 213, 150, 26, 10, ILI9341_BLUE);
    tft.fillRoundRect (160, 213, 150, 26, 10, ILI9341_BLUE);

    tft.drawRoundRect (10, 21, 300, 65, 10, ILI9341_WHITE);
    tft.drawRoundRect (10, 117, 300, 65, 10, ILI9341_WHITE);
    tft.drawRoundRect (10, 86, 150, 26, 10, ILI9341_WHITE);
}

```

```

tft.drawRoundRect (160, 86, 150, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (10, 182, 150, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (160, 182, 150, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (10, 213, 150, 26, 10, ILI9341_WHITE);
tft.drawRoundRect (160, 213, 150, 26, 10, ILI9341_WHITE);

tft.setCursor(20, 25);
tft.println("Fichier (#)");
tft.setCursor(20, 121);
tft.println("Intervalle (s)");

tft.setCursor(79, 92);
tft.println("-");
tft.setCursor(229, 92);
tft.println("+");
tft.setCursor(79, 188);
tft.println("-");
tft.setCursor(229, 188);
tft.println("+");

tft.setCursor(75, 219);
tft.println("OK");
tft.setCursor(196, 219);
tft.println("ANNULER");

tft.setTextSize(4);

tft.setCursor(30, 47);
tft.println("DATA_.txt");
tft.setCursor(30, 143);
tft.println("dt = s");

tft.setTextSize(3);

pilote=55;

ts.getPoint();
}

//-----
if(pilote== 55 ) // Affichage Parametres uSD
{
  del_green();

tft.setTextColor(ILI9341_WHITE,ILI9341_BLUE);
tft.setTextSize(4);

if (set_fileno < 9.95 ) // Ajout 0
{
  tft.setCursor(150, 47);
  tft.println("0");
  tft.setCursor(174, 47);
  tft.println(set_fileno, DEC);
}
else
{
  tft.setCursor(150, 47);
  tft.println(set_fileno, DEC);
}

if (set_dt == 0 ) // dt = 0.1 s
{
  tft.setCursor(150, 143);
  tft.println(".");
}

else if (set_dt > 0 && set_dt< 9.95 ) // Ajout 0
{
  tft.setCursor(150, 143);
}

```

```

        tft.println("0");
        tft.setCursor(174, 143);
        tft.println(set_dt, DEC);
    }
    else
    {
        tft.setCursor(150, 143);
        tft.println(set_dt, DEC);
    }

    tft.setTextSize(3);

    if(!ts.bufferEmpty()) // Touch!
    {
        TS_Point p = ts.getPoint();
        p.x = map(p.x, TS_MINY, TS_MAXY, 0, tft.height());
        p.y = map(p.y, TS_MINX, TS_MAXX, 0, tft.width());
        y = tft.height() - p.x;
        x = p.y;

        if((y >= 86) && (y <= 112))
        {
            if((x >= 10) && (x <= 160))
            {
                set_fileno--;
            }

            if((x > 160) && (x <= 310))
            {
                set_fileno++;
            }
        }

        if((y >= 182) && (y <= 208))
        {
            if((x >= 10) && (x <= 160))
            {
                set_dt--;
            }

            if((x > 160) && (x <= 310))
            {
                set_dt++;
            }
        }

        if((y >= 213) && (y <= 240))
        {
            if((x >= 10) && (x <= 160))
            {
                _fileno = set_fileno;
                _dt = set_dt;

                if(_dt < 1)
                {
                    Timer1.initialize(100000);      // initialise le timer1 a 0.1 seconde
                    _dt=0;
                }
                else
                {
                    Timer1.initialize(1000000);    // initialise le timer1 a 1 seconde
                }
            }

            SD_entete = 0;
            pilote=50;
        }
    }

    if((x > 160) && (x <= 310))
}

```

```

{
    pilote=50;
}
}

if(_fileno > 99) _fileno=99;
if(_fileno < 0) _fileno=0;
if(set_fileno > 99) set_fileno=99;
if(set_fileno < 0) set_fileno=0;
if(_dt > 90) _dt=90;
if(set_dt > 90) set_dt=90;
if(set_dt < 0) set_dt=0;
}

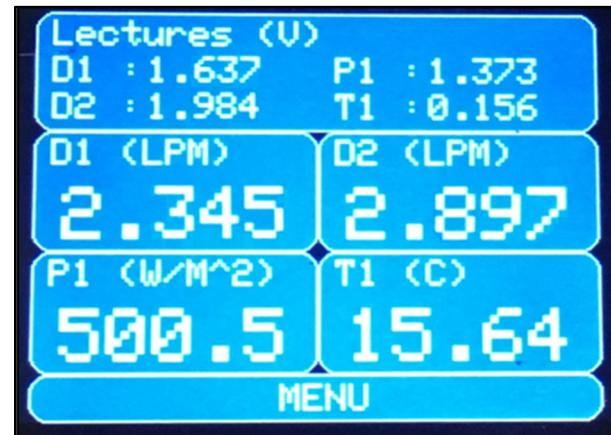
//-----
if(pilote == 1000) // Init
{
    del_off();
    SD_tester();
    pilote = 0;
}
}

```

Arduino interface



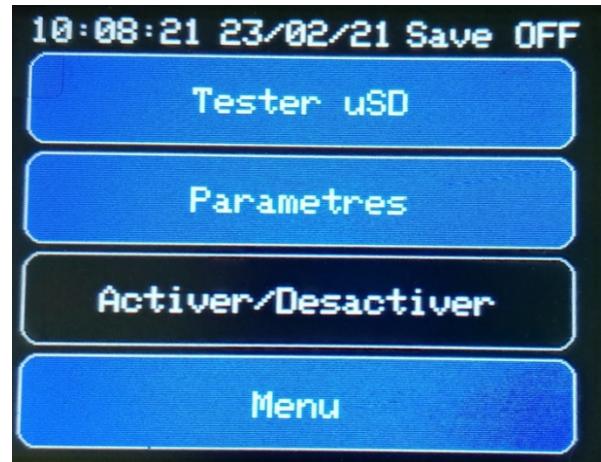
Main Menu



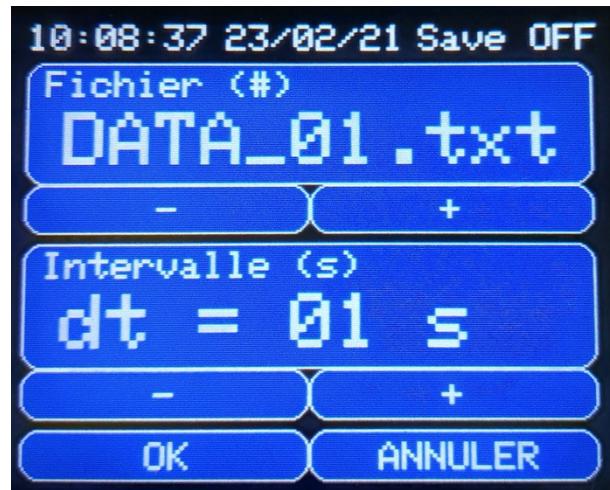
Main Display



Clock screen



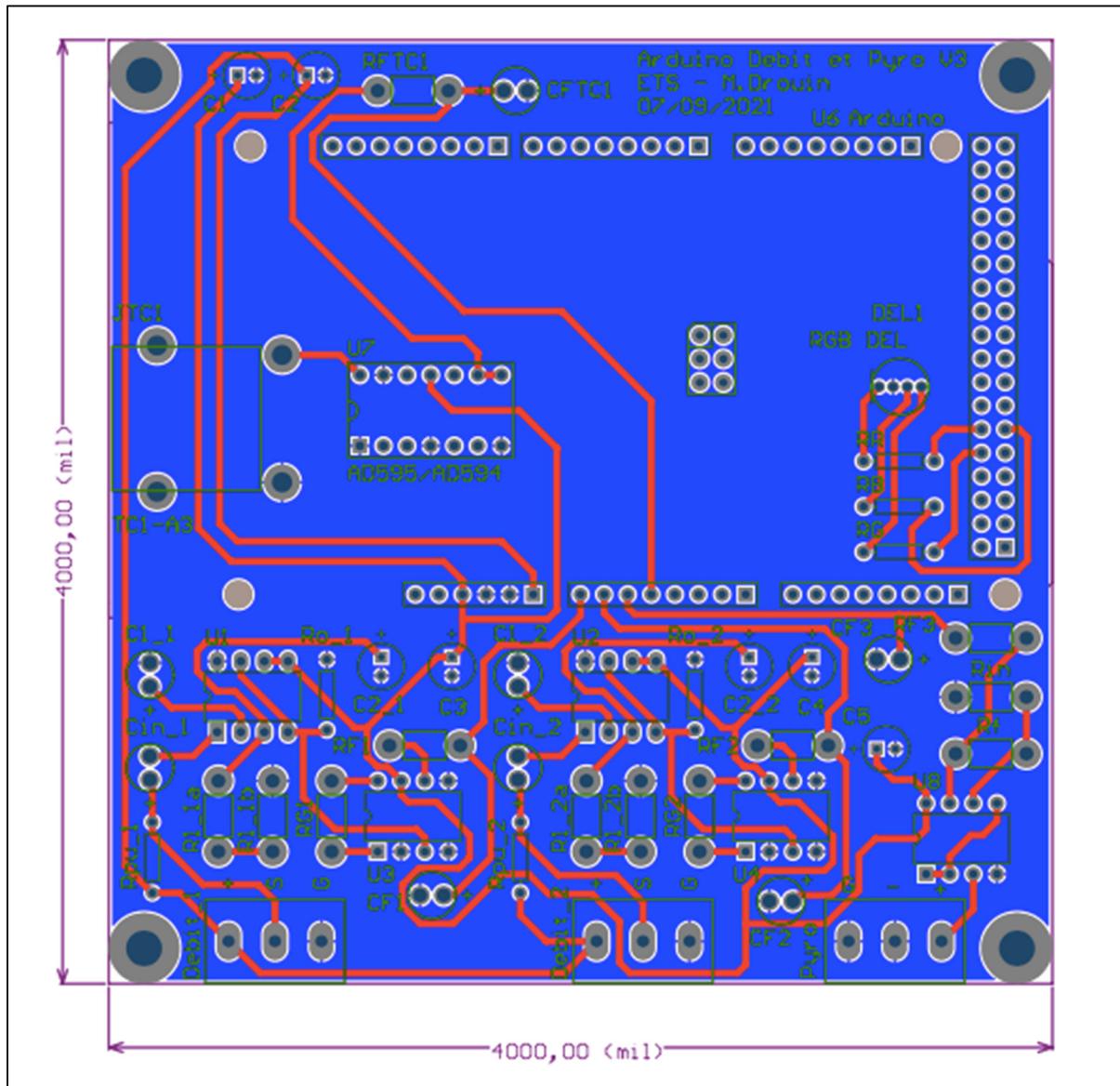
Save menu



Parameter screen

ANNEX V

ARDUINO CIRCUIT BOARD



ANNEX VI

ARDUINO ELECTRICAL PLAN

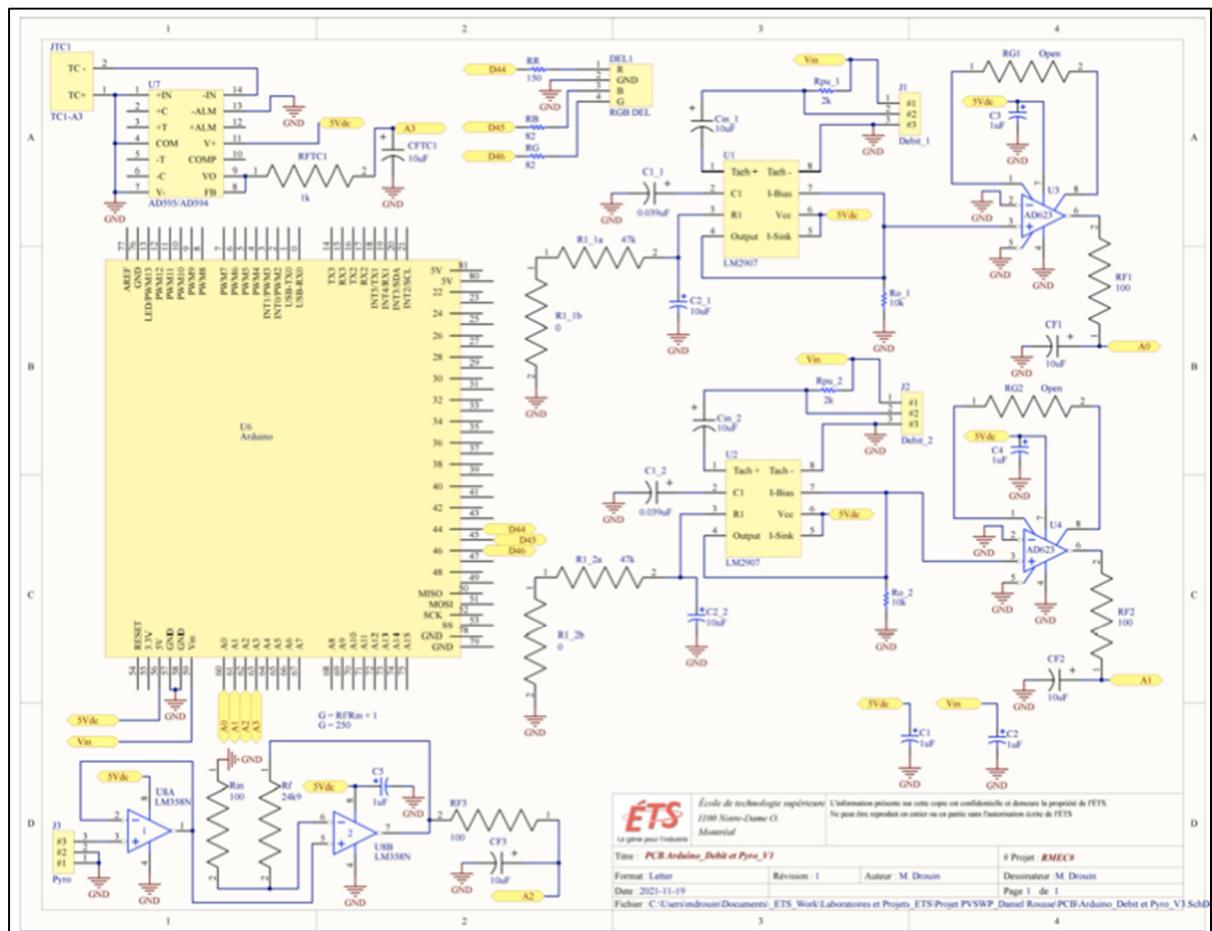


Figure-A VI-1 Arduino electrical plan

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