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ESCUELA DE INGENIERÍAS INDUSTRIALES

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Grado en Ingeniería Mecánica

Diseño e implementación de un sistema fotovoltaico en "The Moving Lab"

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Valladolid, mes y año.

TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO:	Design and implementation of a solar power system in The Moving Lab
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FECHA:	21 de Junio de 2018
CENTRO:	University Colleges of Leuven – Limburg
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Resumen

Este documento describe el diseño e implementación de un sistema de energía solar en un laboratorio móvil conocido como "The moving lab". El objetivo consistía en satisfacer cualquier necesidad energética de dicho laboratorio con el fin de hacerlo autosuficiente. La potencia se deriva de seis paneles solares de 300 W cada uno colocados en el remolque, a su vez el despliegue de los mismo se realiza de forma automática. Mi objetivo en el proyecto del sistema de energía solar se centró en el diseño mecánico. Debido a las dimensiones del remolque, de más de 2 metros de altura, uno de los principales problemas fue alcanzar el techo para colocar tantos paneles solares como fuera posible y encontrar una manera de desplegarlos sin intervención humana. Se ha utilizado el software Inventor para resolver estos problemas antes de comenzar a construir. Finalmente, después del diseño por ordenador, participé en la construcción del conjunto.

Keywords: Laboratorio móvil, Actuador lineal, Panel solar, Autosuficiente, Autodesk Inventor

Management and Technology Group

Design and implementacion of a solar power system in The Moving Lab and design of an air quality device

University Colleges of Leuven-Limburg
Final Degree Project of Electromechanics

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Acknowledgements

Dear reader,

My name is Pablo Posadas, author of this project and exchange student from the University of Valladolid (Spain). This is my senior year of Mechanical Engineering and I decided to do my final project abroad.

My European Erasmus+ exchange program has given me a base to broaden my horizons, learn in a different way and challenge myself daily as well as be part of an unforgettable experience. That is why there are many people whom I would like to express my gratitude to.

First of all, in the UCLL I have taken part of the Energy Department, in which I have been able to design and build a project that otherwise would not have been possible to do. I would like to thank the whole department for their help during these months, especially to Thomas Vanhove for leading and guiding me, Jan Elsen for his assistance and help in the design and while building and Eric Dirkx for his lessons and tips in the workshop. I also would like to show my gratitude to my fellows, Dennis Maes and Diedde Briers, who have made my stay in the Energy laboratory as pleasant and enjoyable as possible and helped me daily with my work.

Secondly, my regards to my Erasmus coordinator, Wim Claes, as well as my promoter in Spain, Fco. Javier García Ruiz for their willingness to answer all my questions and provide me with all the information I needed.

Last but not least, I want to say thank you to all the friends whom I have shared this experience with, Erasmus and Belgian. And with those who have supported me from Spain, family and friends.

Cordially,

Pablo

Abstract

This project has been developed at the UC Leuven Limburg, in the Energy Expertise Unit. This group focuses on research, study and transfer of research results to education regarding new energy technologies.

This paper describes the design and the implementation of a solar power system in “The moving lab”. The goal was to power the lab devices as well as any energetic necessity around it. The power is derived from six 300W solar panels placed on the roof of the trailer which are also extended automatically. A second assignment was the design of an air sensor device able to be attached to a drone or to a street post. Its purpose is to measure pollution and contamination to be studied in “The moving lab”.

My aim of the solar power system project was focused on the mechanical design. Due to the dimensions of the trailer, more than 2 meters high, one of the biggest problems was to reach the roof to place as many solar panels as possible and find a way to display them without manual intervention. Inventor software has been used to solve these problems before start building.

Concerning the air sensor device, the main task was to design a box that could hold the required sensors, pumps and devices but being as small as possible. Depending on where the box is going to be placed, the features of weight, dimensions, attachment system and sensors required, vary. The adopted solution is to have different designs for each box.

Finally, after designing on the computer I helped making parts at the work shop and put them together. Here I learned to solve daily problems that cannot be seen on the screen before. Regarding the box, the street post design has been 3D printed and finished as well.

Pablo Posadas

June 2018

Resumen

El desarrollo de este proyecto ha tenido lugar en la UC Leuven Limburg, en la Unidad de Energía Avanzada. Este grupo se centra en la investigación, el estudio y la transferencia de los resultados obtenidos a la educación en relación con las nuevas tecnologías energéticas.

Este documento describe el diseño e implementación de un sistema de energía solar en un laboratorio móvil conocido como "The moving lab". El objetivo consistía en satisfacer cualquier necesidad energética de dicho laboratorio con el fin de hacerlo autosuficiente. La potencia se deriva de seis paneles solares de 300 W cada uno colocados en el remolque, a su vez el despliegue de los mismo se realiza de forma automática. Una segunda tarea consistió en diseñar un dispositivo sensor de aire capaz de ser conectado a un dron o a un poste de la calle. Su finalidad es medir la polución y la contaminación de su entorno para posteriormente ser estudiado en " The moving lab ".

Mi objetivo en el proyecto del sistema de energía solar se centró en el diseño mecánico. Debido a las dimensiones del remolque, de más de 2 metros de altura, uno de los principales problemas fue alcanzar el techo para colocar tantos paneles solares como fuera posible y encontrar una manera de desplegarlos sin intervención humana. Se ha utilizado el software Inventor para resolver estos problemas antes de comenzar a construir.

Con respecto al dispositivo sensor de aire, la tarea principal fue diseñar una caja que pudiera contener los sensores, bombas y dispositivos requeridos pero que fuera lo más pequeña posible. Dependiendo de dónde se vaya a colocar la caja, las características de peso, dimensiones, sistema de fijación y sensores necesarios varían. La solución adoptada fue tener diferentes diseños para cada caja.

Finalmente, después del diseño por ordenador, participé en la construcción y montaje del conjunto. Aquí he aprendido a lidiar con los problemas del día a día que no se pueden ver en una pantalla. En cuanto a la caja, el diseño del poste de la calle se realizó con una impresora 3D y se finalizó con éxito.

Pablo Posadas

Junio 2018

This Final Degree Project has been structured in 8 chapters.

In Chapter 1, "Preliminary Study", the characteristics and main advantages of the construction of a mobile laboratory are presented, as well, the main objectives of the project are identified.

Next, in Chapter 2, "Photovoltaic System", the theoretical framework that determines the design of the solar panel system, is explained. It also includes an introduction to the electrical system.

Subsequently, Chapter 3, "Preliminary Design" describes the stages that the design has followed until the moment of construction, as well as the different problems that we have had to face. In addition, this chapter includes some of the already-done designs that have served as inspiration. The different models that have been developed with the software Autodesk Inventor Professional 2018 are also shown.

In Chapter 4, "Structural description and calculations", the description of each of the parts and components of the design is carried out, as well as a brief introduction to the structural calculations.

In Chapter 5, "Building Process", the stages of the construction process are analysed step by step. A description of the machines and the material used is also added.

In Chapter 6, "The Box", the device for measuring air quality and environmental pollution is presented. Its design is justified, and its characteristics are described.

Finally, in Chapter 7, "Conclusions and references," the conclusions reached after the development of the Thesis are included. In addition, possible lines of study are exposed to deepen the development of future work. The bibliography used is also included.

Chapter 8 are Annexes.

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CHAPTER l. Preliminary Study

1. Introduction

What are the possible technologies for producing off-grid electricity? Options include fossil fuel-based technologies such as diesel generators, or renewable sources such as photovoltaic or wind power.

And what if we could use one of them to power a mobile research station called The Moving Lab?

In this thesis, I describe the mechanical design and implementation of a 1800W photovoltaic (PV) electric power system in The Moving Lab.

In the following sections I will give a brief description of the technical elements of the project, as well as an overview of the work done during the project and its result.

1.1. The Moving Lab: definition

In the technological advances of the 21st century, science has covered many of the work areas where its usefulness is being of significant importance, appearing a new and revolutionary portable work equipment called **Mobile Laboratory,** this is a means for the realization of an infinity of projects highly necessary to be able to elaborate many tasks, being able to adapt to the needs of the user.

Mobile laboratories allow access to reliable laboratory services in locations that would otherwise not be able to support full laboratory facilities. It also reduces the time to obtain reliable analytical results, compared to conventional laboratory tests, helping to make quick decisions on the spot in case of an emergency.

Figure 1. Mobile Laboratory Unit

Another revolutionary advance is the **Mobile Energy Unit** which is available to provide energy from different kind of sources. This means it can supply energy without being connected to the general grid. As it is mobile, it can be brought to provide energy to the most isolated places, or also it can be used in connected places when a failure occurs in the general grid.

Figure 2. Mobile Energy Unit

Our goal in this project is to integrate the autonomous energy system of the Mobile Energy Unit into our Mobile Laboratory, giving it the ability to be self-sufficient. This would allow us to combine its applications resulting into a wide range of possibilities. That is how the idea of **The Moving Lab** was born.

1.2. The Moving Lab: applications

The mobile laboratory can be brought to the site, allowing site personnel to interface quickly and directly with laboratory staff. The laboratory offers real-time analytical results for both site investigation and remediation projects, thereby providing the analytical data necessary to make important decisions in the field, to meet project schedules, and to reduce mobilization and equipment costs.

The use of mobile units and laboratories nowadays is essential in situations in which it is required:

- Analysis and monitoring in situ.
- Agility and speed of action.
- Reduction of logistics costs.
- Optimization of implementation processes.

So, The Moving Lab has application in the following fields:

- Medical equipment
- Emergency Services
- Communications
- Military
- Wild live
- Events and Entertainment
- Educational use

Figure 3. Fields of application

1.3. The Moving Lab: Air Quality Device

Along with the development of The Moving Lab this project includes the design of an air quality measurement device. The purpose of this section of the project is to show some of the possible applications provided by The Moving Lab as well as to open a new alternative line of development with the aim of promoting future projects related to it.

The air quality device consists of a box in which different sensors and electronic devices will be introduced, such as wireless connection or vacuum pumps in order to take measurements of the air in unusual conditions.

Due to the elements that make up the device, the requirements of the box vary and there may be several types of different designs depending on what you want to measure with them and the form of measurement. In this project two possibilities have been studied:

- The first one consists on a box that has integrated sensors, vacuum pumps and measuring tubes. This device is placed on a drone with the objective of taking measurements in locations of difficult access for people.

- The second of them contains other different sensors and its purpose is to be placed on the street poles or similar. For example, the placement of several of these units around an area affected by a pollution catastrophe would allow us to determine its expansion range.

2. Background

Currently, the UCLL has already built the Mobile Renewable Energy Unit (MREU) based on solar energy, background of this project and inspirations as well.

We start from the premise that the first designs have been done without knowing how the real trailer dimensions, roof and structure were. That means that initially, this project has been developed with a trailer-to-structure approach. This means that the core design has been focused around the mechanical design of the solar system and integrated into the trailer.

3. Goals

The goals of this Final Degree Project are those that are represented below:

- Study and understanding of a Mobile Energy Unit with the final purpose of develop The Moving Lab.

- Learning the software tool Autodesk Inventor Professional 2018, which is widely used in today's industry.

- Realization of a simple, resistant and economically affordable structural design of The Moving Lab solar array in order to optimize and facilitate its construction.

- Final construction of The Moving Lab.

- Design of the air quality measurement device as an example of the application of The Moving Lab.

4. Scope of the project

The realization of this project has been carried out in the company and help of several people. In the initial design of the project, as well as the air measurement device, I had the participation of Dennis Maes. The construction of the laboratory has been possible with the help of Jan Elsen and Diedde Bries. Due to this, during the presentation of this thesis I will speak in the plural since several of the decisions have been made with the help and advice of these colleagues.

This project only focuses on the design of the mechanical part of The Moving Lab, the study and analysis of the electrical components is detailed and deeply studied in the Thesis Work of Diedde Briers.

In this project, no calculations are required. The low weight of the aluminium structure and solar panels, and the low loads required to lift it, make the possible failures due to deformation of the structure, needless.

In addition, the small area covered by the solar panels allows us to disregard the calculations of wind and snow loads. This is also due to the fact that the structure is compact and with several points of support, not like solar installations of a single pole that are more susceptible to this type of loads.

The Moving Lab construction has been successfully completed on June 5, 2018.

CHAPTER ll. Photovoltaic System

In this chapter the photovoltaic system is briefly described. It is an introduction to solar systems design so that can it be explained how the PV array works and why the design was made like that. In this chapter I define the power capacity of The Moving Lab as well as a description of its devices and the requirements of the Photovoltaic System.

1. Solar energy

In the Solar Systems design there are two main factors of study. The correct orientation (azimuth angle) and the optimal inclination of the panels (tilt angle) depending on the energy requirement and the geometric location.

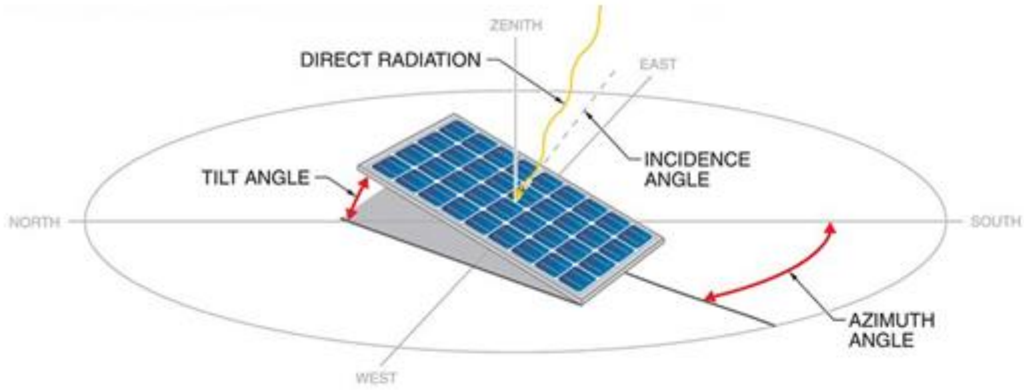


Figure 4. Solar Panel Orientation Factors

1.1. Orientation

When designing a photovoltaic system, it is crucial to choose the direction in which to mount the panels. For our laboratory it is the same. So, it is necessary to know on which side there is more solar radiation all day to get as much energy as possible. In northern latitudes, by conventional wisdom PV modules are ideally oriented towards south.

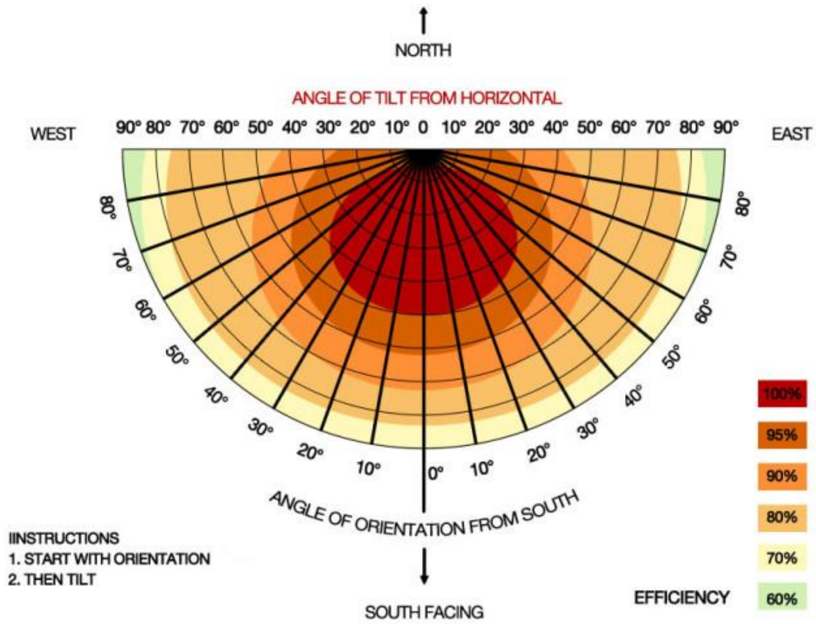


Figure 5. Angle of Orientation for Optimum Isolation in Solar Panels

Since solar panels are more productive when the sun's rays are more perpendicular, the best is the one that is directly to the south, but the tilt or orientation of the PV array does not need to be perfect. Solar modules produce 95% of their full power when within 20° of the sun's direction. Or even if the trailer's panels face east or west, it may also be acceptable. This can be seen in the Figure 5.

Also, optimum orientation can be influenced by typical local weather patterns as rain and fog. Thus, in Belgium the maximum power is generated with a southwest orientation.

1.2. Tilt

It depends on two factors:

- Latitude of the geographical location
- Season of the year

An increased tilt favours power output in the winter and a decreased tilt favours output in the summer. Nevertheless, tilts from 20° to 45° will result in approximately the same power production over the course of the year. This is because tilts that are less than the latitude of the site increase summer production when the solar resource is most available here but reduce winter production when it tends to be cloudy anyway.

Generally, the optimum tilt of a PV array in the Pacific Northwest equals the geographic latitude minus about 15° to achieve yearly maximum output of power.

Diepenbeek Campus	
Latitude	**Longitude**
50.926 North	5.392 East
50°55'31" North	5°23'32" East

Table 1. Diepenbeek Campus Location.

As shown in the Table 1, following the general rule the optimum would be:

50°55'31" - 15° = **35°55'31"**

1.3. Optimum

As can be appreciated in the IMAGE the optimum orientation and angle in fixed arrays is around 30° and 40°.

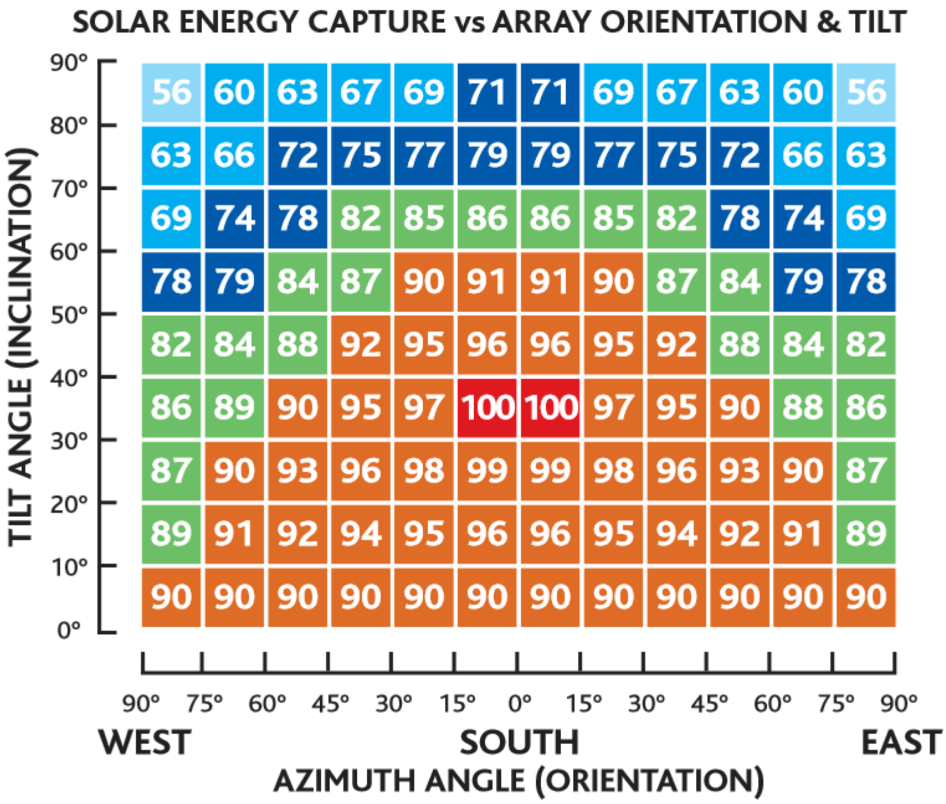


Figure 6. Orientation vs. Tilt Comparative Graphic

Combining the data obtained in the table with the optimum for the angle of inclination of the panels, we deduce that the optimum angle for our project would be around 35° to the horizontal axis. It can also be said that the inclination is 55° to the vertical axis.

35° is the angle which we are going to work with. The project has finally been designed and built with this angle.

2. Solar Trailer System

The solar PV generator consist of 6 solar panels from CSUN Solar of 300W each. Therefore, the system has a total power of 1,800W. The main electrical characteristics of the panels are shown in Table 2. The complete datasheet can be found in Annex.

CSUN-300-60M-BB					
Voltage (V)	**Nominal Power (P_{MPP}) [W]**	**Max-Power Voltage (V_{MPP}) [V]**	**Max-Power Current (I_{MPP}) [A]**	**Open-Circuit Voltage (V_{OC}) [V]**	**Short-Circuit Current (I_{SC}) [A]**
24	300	32.2	9.31	39.8	9.6

Table 2. Solar Panel Main Characteristics

2.1. Optimal Layout for the PV panels

To choose the best layout possible for the PV panels it is necessary to know the existing mean Solar Irradiance of the place where the system is located. In this case, since the project has been developed in the UCLL, the best choice was to consider Diepenbeek Campus as the geographic situation. The data has been obtained from The Joint Research Centre (JRC) of the European Commission website, using the Photovoltaic Geographical Information System (PVGIS). The parameters for obtaining the data are summarized in:

Diepenbeek Campus Average Solar Insulation (Measured in $\mathrm{Wh/m^2}$/ day)											
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1140	1840	3490	4870	5040	5340	5140	4690	3870	2680	1380	1020

Table 3.Monthly Solar Isolation in Diepenbeek Campus

2.2. Calculation of energy produced.

From this information, it is possible to calculate the average insolation per year:

$$Mean\ solar\ irradiance\ per\ year = \frac{\sum month\ data}{12} = 3370\ \frac{wh}{m^2 day}$$

If this value is divides by 1000 W/m^2 , which is the irradiance in Standard Test Conditions (STC), we obtain the Number of Peak Sun Hours (PSH). This is the number of hours of irradiation per day considering a constant irradiance of 1000 W/m^2.

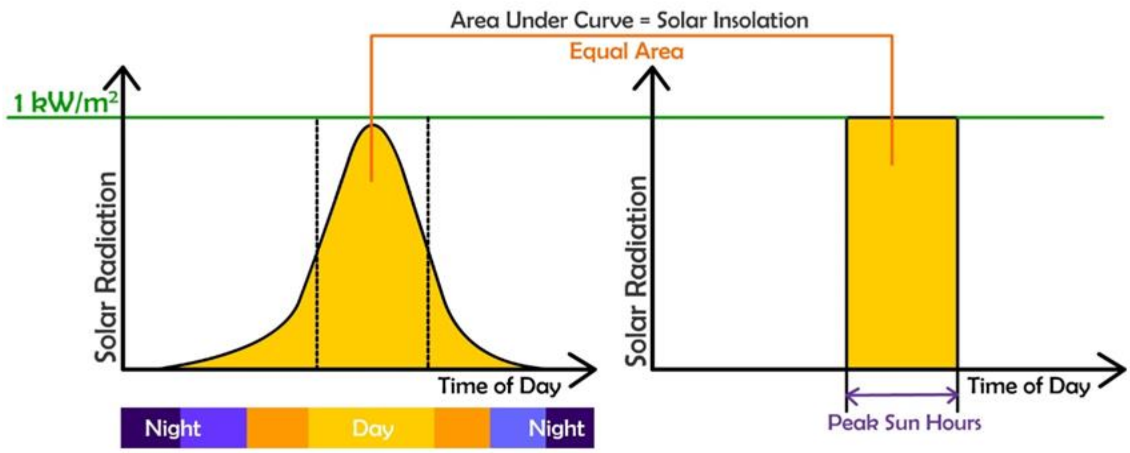


Figure 7. Calculation Solar Blog

Once we have the number of peak solar hours we can calculate the energy provided by the solar system:

$$E(Wh) = P(W) \cdot t(h) = 1800\ W \cdot 3.37\ h = 6066\ Wh$$

CHAPTER III. Preliminary Design

This chapter sums up the development and progress of the project itself, from the beginning and the first sketches to the final result. All the steps covered are explained until the final design is found.

Since the main objective of this project consists in the construction of the project, as we progressed in it, the design of this project has been modified and constantly improved to solve the problems that were arising, following the philosophy of design and redesign.

The Moving Lab requires certain characteristics such as toughness, mobility, easy to handle for the operator and, as it is mobile, it has also to be prepared to function in any kind of path or place. The unit must be able to unfold itself when needed and fold when it's not necessary anymore.

Following these specifications, first ideas were thought and afterwards drawn to evaluate them. Despite being only preliminary designs, they helped a lot to understand what we were able to do and what not. They showed with real dimensions and good accuracy how could the ideas respond in real life. For example, about the height of the deployed PV array, the number of solar panels that we were able to put, where and how to put them and showed also the potential problems we could face as which system could we use to tilt it up.

1. Design stages

It is important to note that at the beginning of this project the only known data were the challenge of the project and the dimensions of the trailer:

Length: 2570 mm

Width: 1570 mm

Height: 2100 mm

From here the beginning was to narrow the idea and the dimensions of the project and study all the possibilities of this.

First, other designs of mobile solar systems available in the market were studied to obtain ideas and serve as inspiration while designing.

Secondly, the idea was analysed to narrow the scope of the project. The main goal on this stage was to simplify the design as much as possible, we look for a simple and economical design to facilitate its construction. During this stage the idea of the project is specified, and the following questions are posed:

- Dimensions of the trailer and roof shape.
- Number of panels and layout.
- Elevation system
- Material and structure of the PV array.
- Solar tracker or fixed.

The third stage of the design consisted in the creation of the CAD model, using the Autodesk Inventor tool. In this stage the model that will be carried out is developed.

Finally, as a final phase the design is modified while it is being built to solve the possible errors that arise.

2. State-of-the-art

Currently, there are many kinds of Solar Trailers or Solar Powers Units that have been already built and that are available in the market. One of the goals of this project is to simplify the design as much as possible, so by taking refences and details from other similar project will help to enhance the design and to give solutions for potential problems.

To achieve these specifications, some mechanical and structural notions must be taken into consideration. Due to this fact, before creating The Moving Lab, I decided to study some bigger designs. In this way, I can compare them and draw some conclusions.

2.1. Solar Trailer

There are few solar trailer manufacturers, but the features and performance of these systems have increased significantly. The smaller single-axle units typically include PV arrays in the 1 to 2 kW range and can be towed behind an SUV. This are the examples we are going to take ideas of. However, the larger dual-axle units have much larger PV arrays with heavier battery banks and require a mid-sized truck to tow. Even though we are not going to make an array that big, the solutions they have taken for the size problems can be helpful as well.

In addition to large fold-out solar arrays, they often include a backup generator. The generator is used to recharge the battery bank or cover large power demands. The more sun-hours available, the fewer hours the generator is required to run to recharge the batteries. For example, our MREU unit but we are just focusing in the structural solutions they have used.

Example 1

3000 Series Part SLR-7505-12AH – Patriot Solar Group

The Patriot Solar Group product is a little trailer with a low power capacity which mission is to be deployed quickly and easy.

Figure 8. Example 1. Solar Trailer Folded

Figure 9. Example 1. Solar Trailer Unfolded

Mechanical / Technical Data	
Body	Injection Molded Polythylene
Dimensions	Box 1870mmL x 1500mmH x 1200mmW
Maximum Solar Power	720W
Maximum System Voltage	12VDC
Batteries	980AH - 1200AH
Maximum Power Output	5000W
Frame	Angle Iron All Welded Construction Black Powdered Coated Finish 1200 Kg. Spring axle (allows for 1500Kg carrying capacity)

	Wheels and Tires
Deploy System	Gas Springs

Table 4. Patriot Solar Group Trailer Mechanical Specifications

From this design we take the idea of possible gas springs, easy to be supplied and mounted. The laterals panels idea becomes an option and since we have problems with where to fix the frames because the trailer walls are not strong enough, the option of adding extra bars in one face is showed.

In this trailer we can see for the first time the sliding guides for deploying the panels. It is an idea that gives and easy-deployed-system. It would allow us to place more solar panels in less space.

Example 2

GT916 Trailer – GreenTow

GT916 is a towable power generation unit powered and charged by solar arrays. The size is increased so the power as well.

Figure 10. Example 2. GT916 Solar Trailer – GreenTow

Mechanical / Technical Data	
Body	Aluminium, Iron Welded Structure
Dimensions	Box 4400mmL x 1500mmH x 1350mmW
Maximum Solar Power	12000 W

Maximum System Voltage	12VDC
Batteries	120-240-VAC -12 VDC Output
Maximum Power Output	6.8 kw for 4 Hrs or 4.5 kw for 8 Hrs.
Frame	Angle Iron All Welded Construction 1900Kg. Dual Axle Trailer
Deploy System	Two Hydraulic Linear Actuators System.

Table 5- GreenTow Trailer Mechanical Specifications.

This energy unit is the first medium-big size unit we studied. The main point is that the roof is even less wide than ours from what we can get a view of the solar panels position. In this case they solve the problem of the space by using a slide guides to move the panels what helps them to save the lack of space.

In this model we first saw the linear actuator system for deployment. It is a hydraulic system powered by a generator system. In our case it would be electric due to the fact that we don't want our laboratory to be mix-powered.

Example 3

TMSPDC – Ok Solar

This line of portable solar units provides stand-alone photovoltaic power. These portable units supply AC power just about anywhere the sun shines. This systems is fully assembled for immediate use in the field. What is more, it has a self deployable automatic solar modules position, which can be vary and programed.

Mechanical / Technical Data	
Body	Iron Welded Structure
Dimensions	Box 3400mmL x 2000mmH x 1530mmW
Maximum Power Input	No imput
Maximum System Voltage	12VAC or DC
Batteries	24V, 800Ah
Maximum Power Output	6KW AC Power, !8 KW DC Power
Frame	All Welded Construction 2300Kg. Trial axle trailer
Deploy System	Two electric linear actuators system.

Table 6. Ok Solar Trailer Mechanical Specifications

Figure 11- Example 3. TMSPDC – Ok Solar

The idea of the slider guides is reinforced. The similarities in dimension gives us a straight road to design. After watching this example, we started with our second model which has a lot of similarities with this one.

We didn't take the idea of the electric linear actuator until we dismissed the lead screwed one due to its price.

Example 4

MREU – UCLL

The main source of inspiration for being the previous idea of our project. From here we took the main ideas of the structure, the actuator, the dimension of the panels, the system hinges.

Combining it with the previous things we began to give form to our model that will include the main concept of this Solar Trailer with added concepts of the other models studied like the sliding guides and the position of the solar panels.

Figure 12. Example 4. MREU – UCLL

2.2. Mobile laboratories

A mobile laboratory is a laboratory that is either fully housed within or transported by a vehicle such as a converted bus, or tractor-trailer. Such vehicles can serve a variety of functions, including: science education, science research, air, water, and soil analysis and monitoring as well as biosafety. Mobile laboratories, vehicles and trailers are designed to meet all possible requirements for rugged use in cold or tropical climates and all instruments are usually securely mounted on specially designed shock absorbers to avoid damage during driving.

For these reasons they are a good example of study because, to meet these specifications, it has special designs from which we can take several ideas.

Example 5

MS-225 SOLAR GENERATOR – Mobile Solar

The MS-225 is a compact design. The trailer frame is easy, just two pieces. It also offers considerable cargo space and comes with a side entry door.

Figure 13. Example 5. MS-225 SOLAR GENERATOR – Mobile Solar

This model is a good example of what we have done at the end. Simple and easy, one of our goals. The side frame has been inspired in this model.

Example 6

The SkyFire Energy Solar Energy Station

Figure 14. Example 6. The SkyFire Energy Solar Energy Station.

In this mobile unit we can appreciate again the sliding guides showed before. Again, the idea of using those is reinforced. In this case it is also manual deployed.

2.3. Conclusions

The main conclusions and ideas that we draw from these examples are the following:

- Solar panel deployment system with sliding guides (Examples 1,2,3,6)
- System of deployment of the set with lead screw actuator (Example 4)
- Colocation of 8 solar panels in longitudinal arrangement to the trailer to maximize solar uptake (Example 3)
- System of metal frames as structural support instead of directly attach everything to the trailer's roof. (Example 5)

As we know, not all these ideas have been possible to be implemented. Thus, some different solution from these examples were taken later:

- Solar panels deployment by hinges with a side frame and an upper frame like in example (Example 5)
- Gas springs use (Example 1)
- Electric linear actuator (Example 3)

3. Problems faced

During the development and construction of the project there have been many problems that had changed our designs. Some solutions were alternatives already studied while others had to be taken at the time. This has been one of the great challenges of the project and daily work. The most important ones are shown here.

3.1. Dimensions of the trailer

At the beginning the total height expected for the trailer was 2100 mm high including the wheels, which was enough to enable us to manipulate some parts of the PV array directly, like lock and unlock the panels frame or even move a sliding rail guide where we wanted to put some panels in.

After the trailer arrived we figured out that it was higher because the trailer's frame was not count. This supposes an increase of 115 mm more and the height of the frames to adapt the PV array to the structure of the trailer. We had to dismiss these ideas to make it simpler.

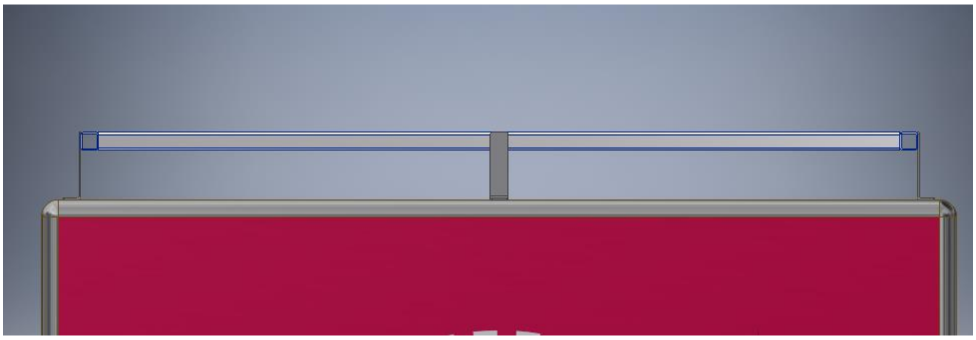


Figure 15. Trailer Frame Front view, Autodesk Inventor

The solution adopted was to design a simpler model of two different frames, a lateral one locked on one side of the trailer and an upper one, flatted and with just one level.

3.2. Trailer's frame

The trailer came with a frame on its roof (the dimensions of the roof rack are widely explained in Chapter IV) which meant we had to figured out how to mount our PV array on it. It also meant that our structure was going to be higher than we had supposed.

Another problem added was that the faces of the trailer where we wanted to fix our structure were very weak. This would not allow us to put the weight and forces of the PV array on it.

At the end the roof rack came in handy to be used as the attachment point on the trailer and to make an empty space between the trailer and the PV array. This space is needed to give the actuators enough angle to tilt the structure up.

3.3. Number of solar panels and layout

The designs came with the idea of holding as many solar panels as possible to maximize the output power.

First, the optimal dimensions of the panels had to be chosen. The best option was to work with some panels we were already familiar with and the MREU appeared to be the answer. The MREU panels are 1660 x 990 x 50 mm so that was the designing dimension to start with.

Due to the dimensions of the trailer's roof, a rectangle of 1570 x 2750 mm, a total of 4,375 m^2. The best option was to put the panels in their horizonal side so that the maximum distance on the width way were 990 + 990 = 1980 mm, not exceeded the towing dimensions law which is 200 mm more in each side of the trailer. On the length direction we had no problem.

The number of solar panels with the sliding guides idea were 8 solar panels. After the idea had to be dismissed we planned to place 6.

3.4. Unfold system angle

Derived from a problem related to the height of the trailer we have to design the lowest possible solar system structure. This is a problem for the actuators, regardless of the system used.

The little space available between the roof of the trailer and the solar panel´s frame makes the initial angle, with which the actuator pushes the frame, very low. This produces that the cosine of the forces is very high - or that the sine is very low - which means that our force is almost horizontal.

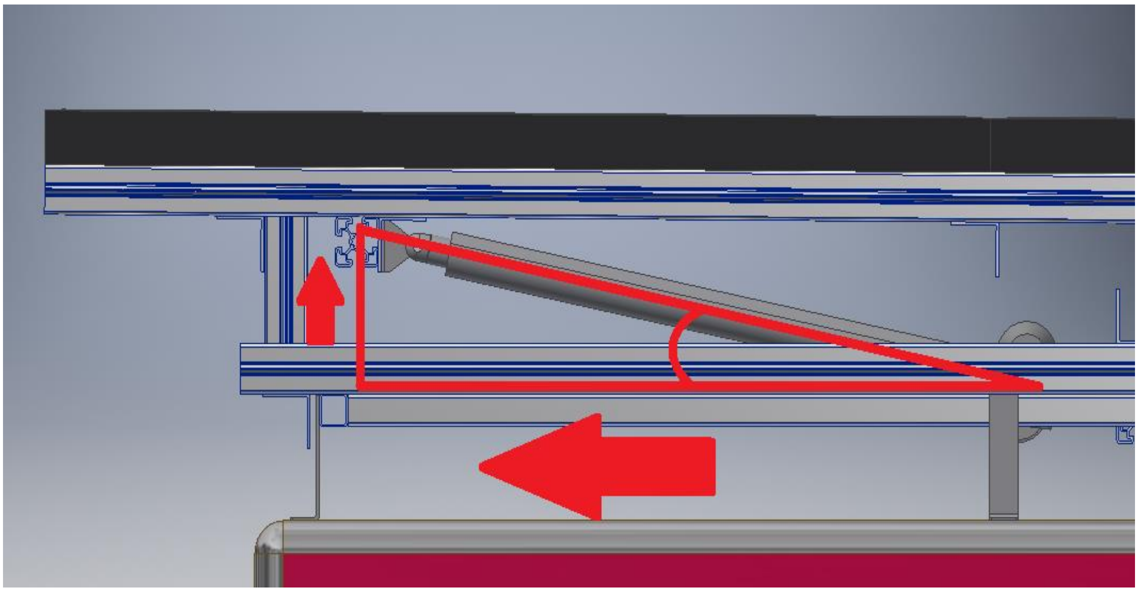


Figure 16. Actuator Forces Distribution with Low Angle, Autodesk Inventor

A too large horizontal force can damage our structure and involves a very high effort for the hinges, which are the ones that will receive the largest amount of load. This problem only appears in the first moments of the deployment of the PV array since as the angle increases, the force becomes more vertical and the effect disappears.

During the construction we realized that a space of at least 100 mm was necessary between the frame and its rest position. This left us three viable solutions:

- Leave the Upper Frame in a non-horizontal resting position. This would increase the initial angle. The problem is that it affects aesthetics.

- Reduce the position height of the actuator as much as possible. Being closer to the frame, the angle would be higher. The difficulty would be in holding it securely in such a low position, away from the support frame.

- Include some Gas Springs that help to give that extra impulse in the first moments of the deployment.

The solution adopted was a combination of the last two. Two Gas Springs are included in the design and it is tilted enough so that it is not perceived.

4. CAD model

4.1. Software

One of the project's goals is to create a 3D model of the design. To carry out this work, the software tool **Autodesk Inventor Professional 2018** has been used, a powerful 3D design tool that has served as a guide for the design of our project. With its help it has been possible to model and visualize the project in each stage of its realization. The primary objective has always been the learning of the software for the modeling of the design to obtain the plans and representations of our project.

More specifically, the **Frame Generator** function of Autodesk Inventor has been learned, which has been used to design the frame and PV array.

4.2. First Design

The first design is the simplest CAD model and its purpose is the preview of the real dimensions of the trailer with the PV array, as well as the study of possible lifting systems. This first design contains the first ideas and was designed in paper sketch with the most complex concepts. The idea is to simplify the project based on this design.

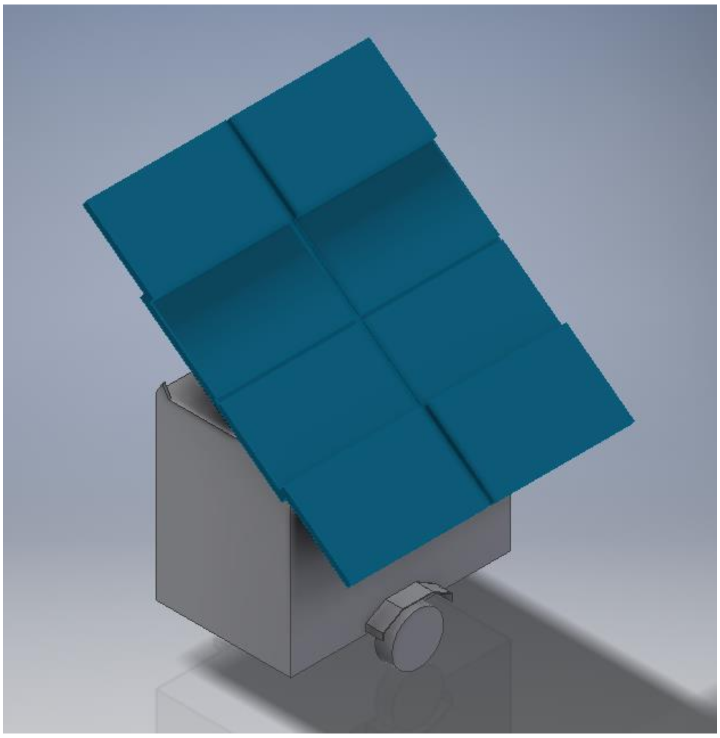


Figure 17. Solar Panels View of the First Design, Autodesk Inventor.

The initial intention of the project was a design of 8 solar panels placed in three different blocks, one of 4 panels under two others with 2 panels each that would be deployed on a sliding rail guide. Those would place the solar panels at the ends of the trailer before being tilt. As has been shown previously - 3.1. Dimensions of the trailer – the number of solar panels and the sliding guides idea had to be dismissed.

Figure 18. Sliding guides.

The lifting system is a linear axe with lead screw drive located on the roof of the trailer that would be connected to the PV array through a fixed length bar. This system is like the one used in the MREU.

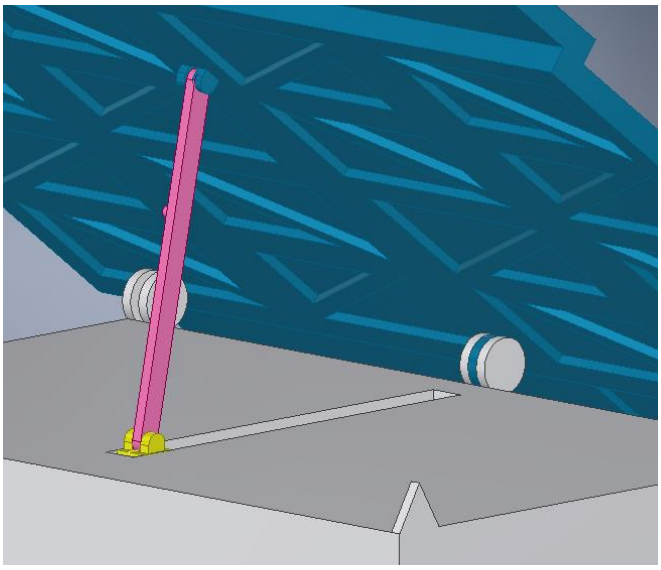


Figure 19. First actuator design, Autodesk Inventor.

Its key features are:

First Design			
Solar Panels Number	**Unfold System**	**Supporting Point**	**Difficulties**
8 solar panels in two levels (1660 x 990 x 50)	Linear axe with lead screw drive.	4 hinges for the whole PV array	Height, design and construction very complex

Table 7. First design features.

4.3. Second Design

The second CAD design is more elaborated. It has less solar power because we removed two solar panels which also means its design and construction are simpler. The main ideas that will later evolve to the final model are implanted.

It begins to design with the Frame Generator. It is designed in aluminium using two different types of profiles - A more detailed explanation of the profiles is given in the Chapter IV)

- L-shaped Profile: 50 x50 x3 mm.
- Square Profile: 45 x45 mm.

The system of the structure of three different metallic frames is designed: The Bottom Frame, attached to the Trailer Frame and that serves as support of the other structures and of the actuator. The Main Frame and the Lateral Frame are designed to support the panels.

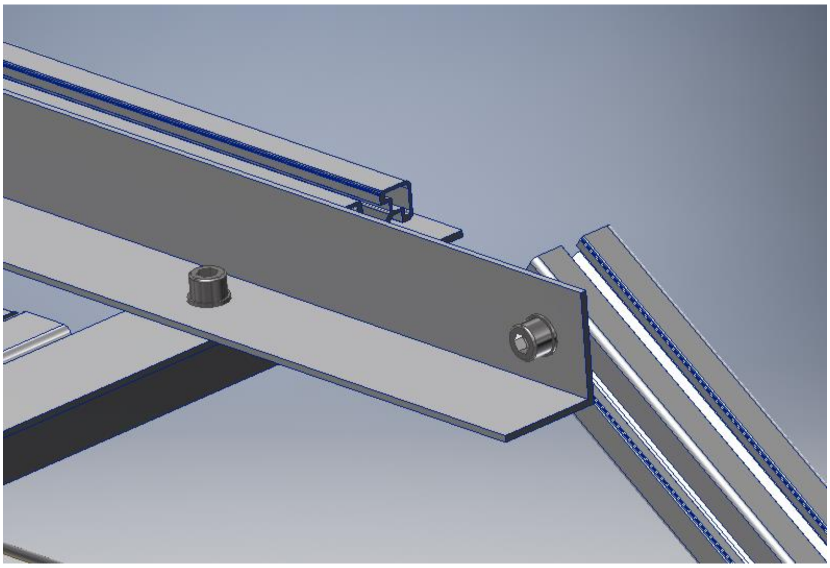


Figure 20. Previous hinge design in the second design, Autodesk Inventor.

The design of the hinges is simple and effective but requires more material and workshop work. Moreover, the systems with two different hinges implies an added difficulty for the panels to be aligned, which requires much more precision when working with the profiles and mounting them.

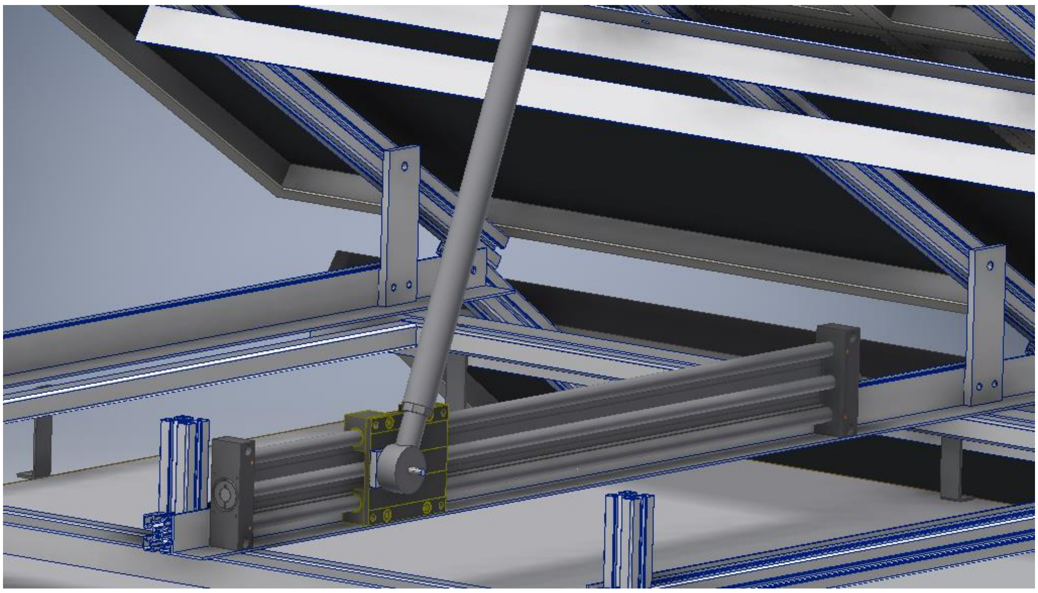


Figure 21. Previous actuator design in the second design, Autodesk Inventor.

Its key features are:

Second Design			
Solar Panels Number	**Unfold System**	**Supporting Point**	**Difficulties**
6 in two different frames (1660 x 990 x 50)	Linear axes with lead screw drive.	4 hinges for the main frame and 4 for the lateral frame integrated in the beams.	Complex and expensive lifting system. Two different supporting points.

Table 8. Second design features.

4.4. Final Design

The final design is the result of enhancing the second design, simplifying it and adding new components. This last model has been being redesigned during the construction stage which has allowed us to correct possible errors or problems of the second design and find alternative solutions to the most complex parts of that design.

This last model has the new dimensions of solar panels, the redesign of the hinges, much more simple and effective, a new linear actuator that modifies the unfold system, the introduction of new components such as gas springs, the design of the lock point and of the props when the PV array is folded

Its key features are:

First Design			
Solar Panels Number	**Unfold System**	**Supporting Point**	**Difficulties**
6 in two different frames (1640 x 990 x 35)	2 Linear Actuators and 2 Gas Springs.	4 hinges for the main frame and 4 for the lateral frame, made by pieces.	Small probems while build.

Table 9. final design features.

While the final design was being constructed I made the 3D model with all the final details. The purpose is to serve as guide or example in future projects.

Figure 22. Right view of the final design, Autodesk Inventor.

Figure 23. Left view of the final design, Autodesk Inventor.

CHAPTER IV. Structural description

This chapter is a description of the final structure of The Moving Lab completely finalized and operational. In it, the distinct parts that compose it will be studied with the help of images of the real model and the CAD model.

The purpose of this chapter is to show the final design in a simple, clear and detailed way.

1. Components.

1.1. Beams

First of all, the whole project has been built in **Aluminium**. Physically, chemically and mechanically aluminium is a metal with valuable properties. It can be melted, cast, formed and machined easily. These features make it the suitable material to be used in this project.

One of the most important points of aluminium for use in construction is its exceptional strength / weight ratio. Aluminium is a very light metal with a specific weight of 2.7 g/cm^3, about a third that of steel. By using it we make the design lighter so less force will be needed.

In the workshop, we had access to the following types of aluminium beams:

UNI EN 10056 – L 50 x 50 x 3

Used for the general structure. It is used for the vertical and horizontal beams, for the Side Frame support beams and to our own-made components like the lock points. The next figures show the beam profile with its measurements:

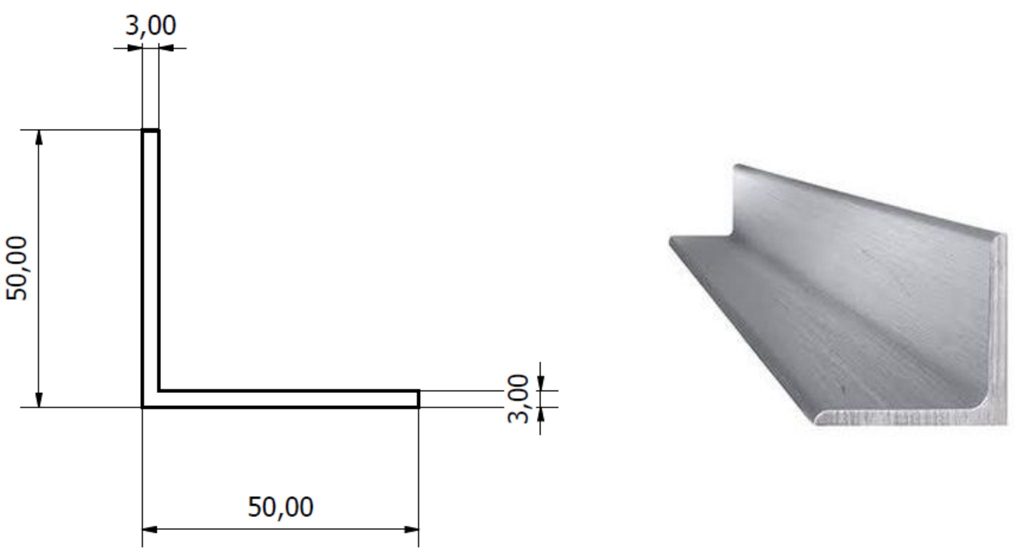


Figure 24. UNI EN 10056 – L 50 x 50 x 3

SOLAR PROFILE 45 x 45 2N180

Used to hold the PV panels in the leaning parts. Two beams of this type are necessary to hold one single panel. It is rough and very easy to be linked, that’s why we also use it to vertebrate the estrucuture and to link each part. This is the main beam of the strucutre.

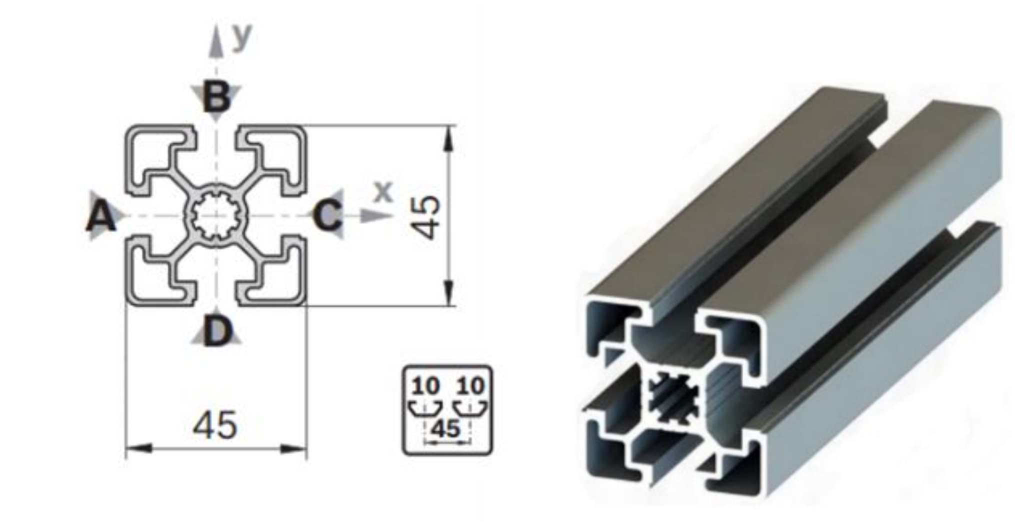


Figure 25. SOLAR PROFILE 45 x 45 2N180

1.2. Bolts and Nuts

The material used in this project is divided into two.

On the one hand the screws and nuts needed for the square profiles come from the same supplier. We have used the T-Nuts shown in the Figures and M8 x 30 screws with hexagonal head. The holes needed for this type of screws were of diameter 8.

Figure 26. T-Nuts used in the square profiles.

On the other hand, M10 and M12 screws of different lengths have been used for the other parts links. The M10 mainly for most of unions in between L profiles, and the M12 for the longitudinal holes with the square profiles. All of them are allen circular headed screws like the ones showed in the Figure:

Figure 27. Example of the screws used to build The Moving Lab.

2. The trailer

This boxed trailer has been chosen due to its suitable dimensions to hold a small laboratory inside. The trailer has a solid hot dip galvanised chassis that will hold and withstand erosion for years. The trailer has been equipped with a side door and a rack roof on top. It has 342 Kg weight and its dimensions are showed in the following images:

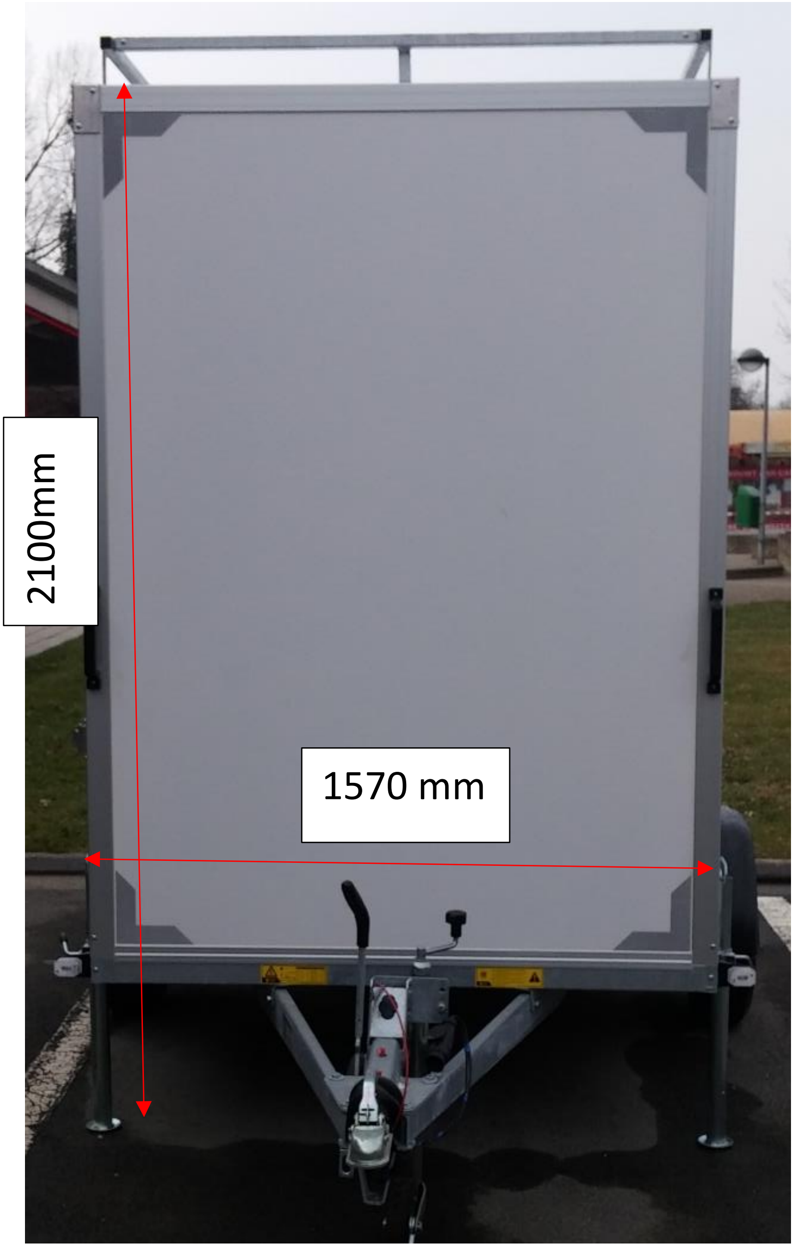


Figure 28. Front view of the trailer.

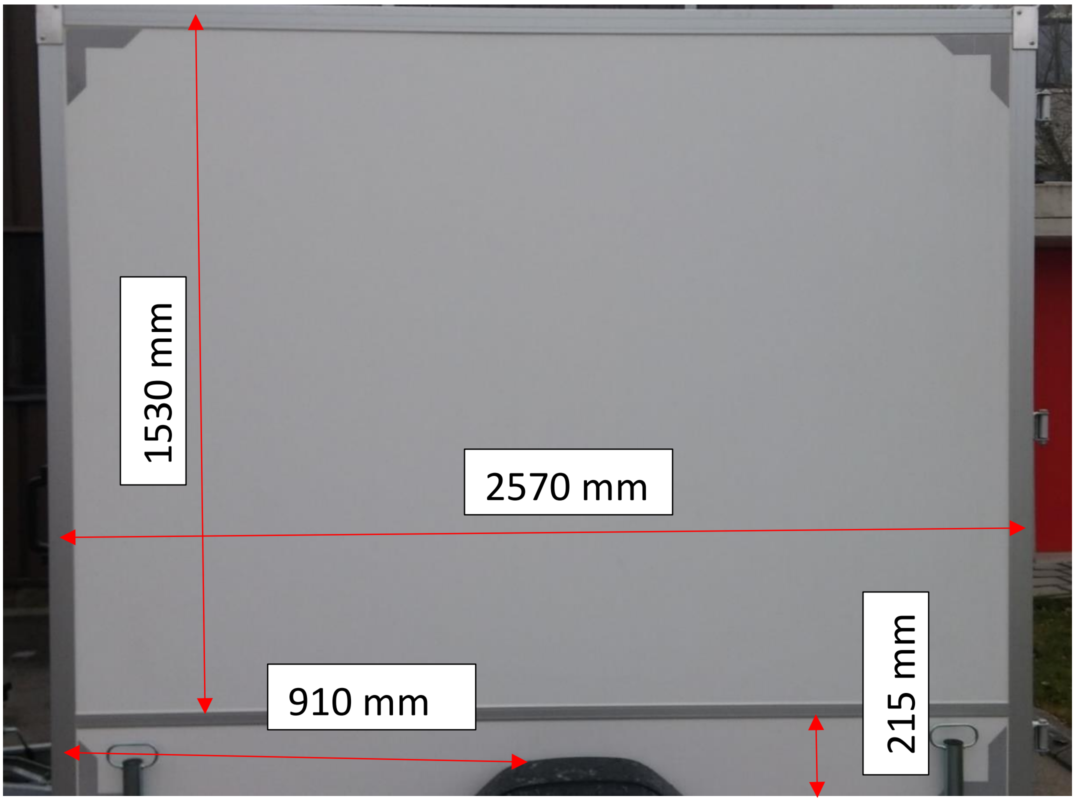


Figure 29. Left view of the trailer.

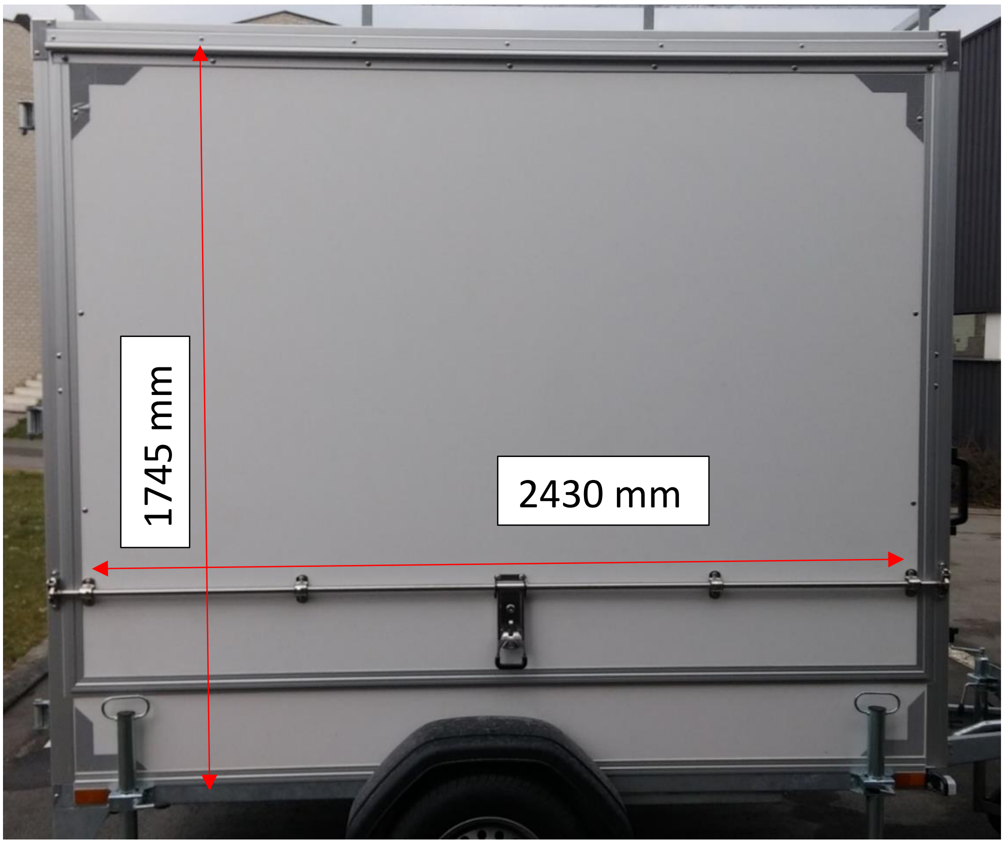


Figure 30. Right view of the trailer.

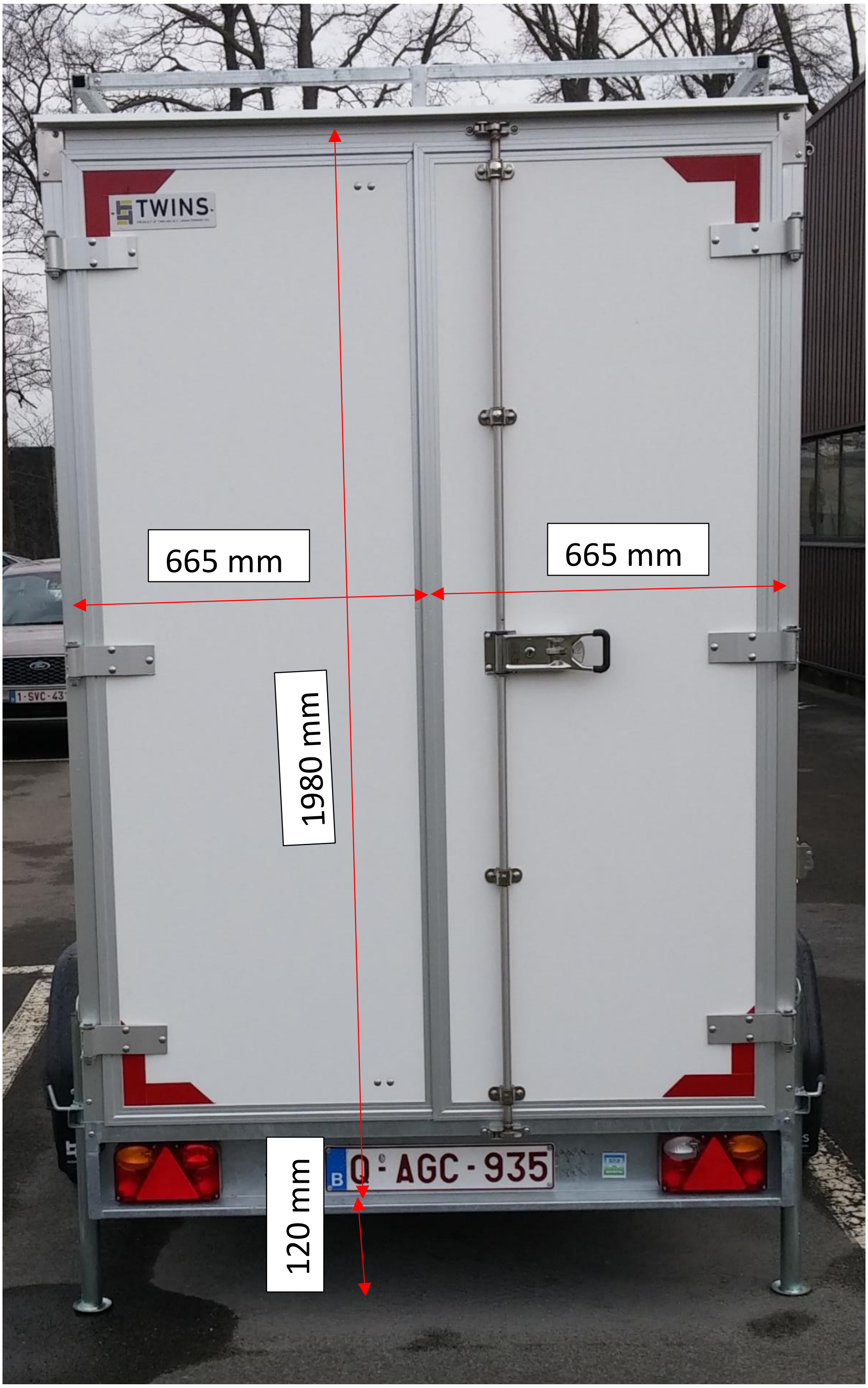


Figure 31. Back view of the trailer.

3. Frames

All the frames have been designed with the Frame Generator tool of Autodesk Inventor as it is mention in Chapter III.

The design of the structure is made up of three different frames, each with a purpose, plus one that comes attached to the trailer. They described below:

3.1. Trailer Frame

This frame comes standard with the trailer and is attached to it by metal plates that are welded to the roof of the trailer.

It is welded made in steel beams of 30 x 30 x 3 mm. It dimension is 2505 x 1430 mm in the exterior parts. Drawing are included in the Chapter VIII - Annexes.

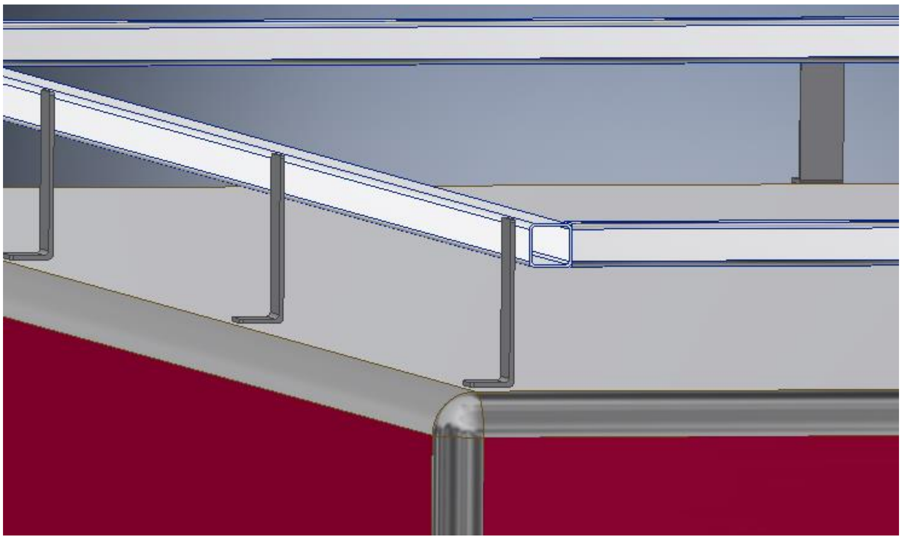


Figure 32. Trailer Frame detail, Autodesk Inventor.

This frame serves as a fastening and union of the solar panel system with the trailer. its rectangular shape also serves as support for our beams, making it responsible for the entire weight of the structure.

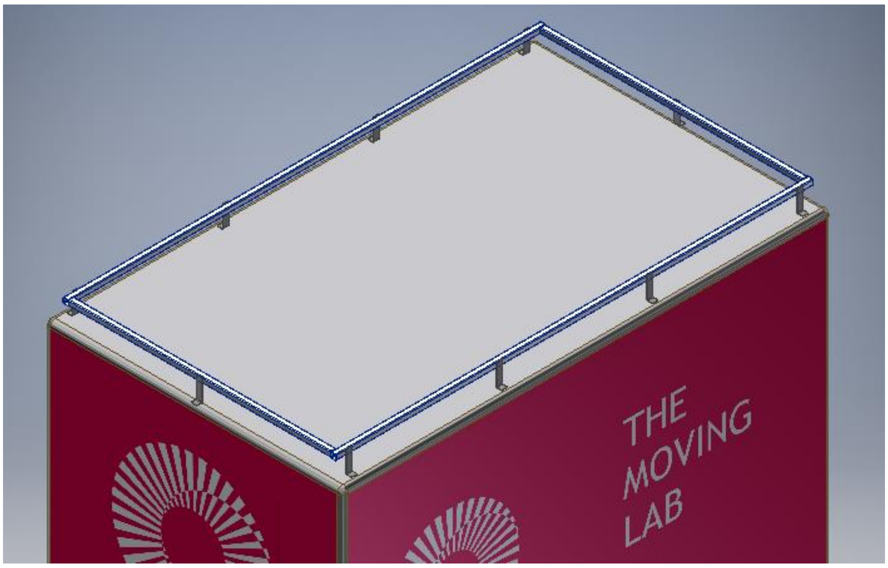


Figure 33. Trailer Frame top view detail, Autodesk Inventor.

It is in this frame where the supporting frame is bolted, which makes it very important at the structural level.

3.2. Support Frame

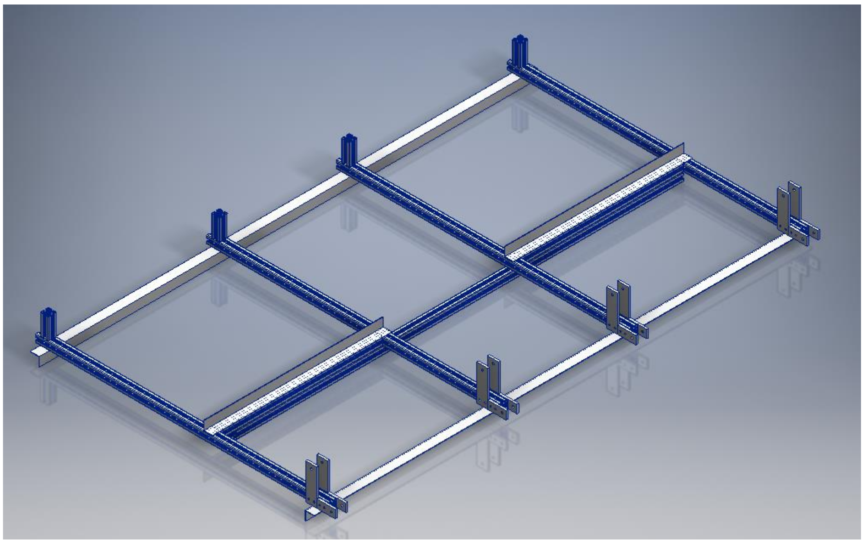


Figure 34. Support Frame top view detail, Autodesk Inventor.

It is the main component of the structure. On this frame, through the hinges placed on it, will be supported the two frames that holds the solar panels. What is more, it is the fulcrum point of linear actuators and gas springs.

It is the main structural component and will be the one that receives the loads produced by the actuator and by the weight of the other two frames. It serves in turn for the correct alignment of the panels since the hinges that serve as support will be placed on it.

Its design is meant to be easily placed on the Frame Trailer. Since this project has been built by students, it has always been a matter of designing easy-to-assemble components. It is composed by two longitudinal L profile 50x50x3 mm beams of length 2725 mm and other four transverse square profile 45x45 mm of 1600 mm each. It also has another set of longitudinal beams that serve as support for the actuators. For more details, drawing is included in the Chapter VIII - Annexes.

The L-shaped profiles are positioned so that they can be joined by bolts with the Trailer Frame and with the transverse beams. Its purpose is to join the structure with the trailer, the two profiles act as a "sandwich" closing on the rectangular structure. Between the L profiles and the Trailer Frame there is a 6 mm space that has been left to correct possible errors of assembly or construction. This space is filled with washers in the union bolts to facilitate correct and safe fixing.

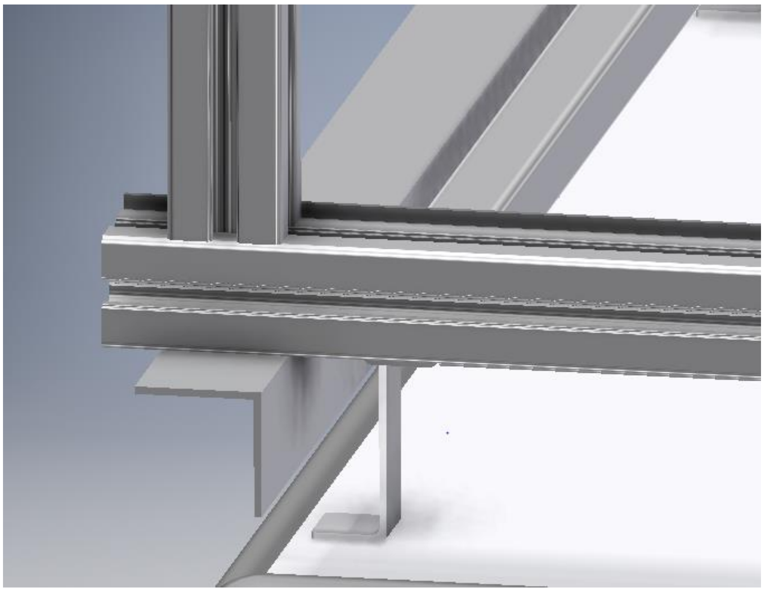


Figure 35. Detail of the join system to the trailer, Autodesk Inventor.

The square cross sections are the supports of the entire structure. Above them the hinges are placed. The hinges join the other frames and they are the rest points on which the Top Frame rests when it is not deployed. For a correct alignment of the solar panels these are also collinear with the four transversal profiles of the other two frames. The Gas Springs are also supported on the outermost profiles.

3.2.1. Actuators fulcrum

Attached to the transversal profiles by 12M bolts are the points of support of the linear actuators. This is a very reinforced structure, composed of three profiles on which the loads of the actuators are supported when deploying and closing the Top Frame.

In the upper part there is an L profile that serves as an extra grip for the main beams. This is screwed to the transverse beams from above. In the middle is the square profile screwed at its ends. This is the main component and the one that receives most of the load of the actuator. In the lower part there is a square profile that crosses underneath the entire support frame linking the two actuator fulcrum beams.

Figure 36. Actuator fulcrum in The Moving Lab.

The reinforcement of three profiles assures no torque problems in the beams and minimizes the effect of lateral deformation due to the loads.

3.2.2. Hinges

The hinges have been made in the workshop and are made of aluminum. They are a very important component of the project because all the PV array is linked in them. In addition to allowing the rotation its function is to align the frames so that the solar panels are in the same line. It also support the weight of the structure.

There are two types of hinges, one for each frame, and each frame carries eight which make a total of 16 hinges in the trailer.

The hinges for the Top Frame are 195 x 60 x 10 mm.

The hinges of the Lateral Frame are 100 x 45 x 10 mm.

Figure 37. Hinges in The Moving Lab

Both hinges are placed at the end of the square profiles of the Support Frame and their distance and position have been calculated so that the panels rotate at the correct point. They also keep a security distance between the two frames.

To be placed in the square profiles they have been designed with a parcitular shape with grooves that fit into the grooves of the profile. Then they are screwed with the screws for that type of profiles. For more details, drawing is included in the Chapter VIII - Annexes.

3.2.3. Rest points

The rest points are four square profile bars 115 mm length, placed vertically on the support beams. When the Top Frame is unfolded it rests on the rest points. They are designed to fit perfectly in the spaces of the beams of the Top Frame.

Figure 38. Rest points in The Moving Lab.

Its main function is to keep the structure safe when the trailer is towed. Avoiding bumps due to bumps and vibrations.

3.3. Top Frame

This metallic structure supports four solar panels and its main feature is that it is deployed automatically. Its design is made to be as simple as possible but still strong enough to withstand the load of the actuator.

It is composed by four beams of square profile on which the solar panels are fixed. They are placed transversely to the trailer. To maintain the rigidity of these four beams, there are four others, perpendicular to these of profile L. Its disposition is the optimum to allow the movements and placements of the actuators and Gas Springs.

Figure 39. Detail of the Top Frame, Autodesk Inventor.

In addition, another beam of profile has been placed along with one of the L profile in which the actuator is subject to reinforce its hardness. The length of the L profile is 2625 mm and that of the square profiles is 1980 mm.

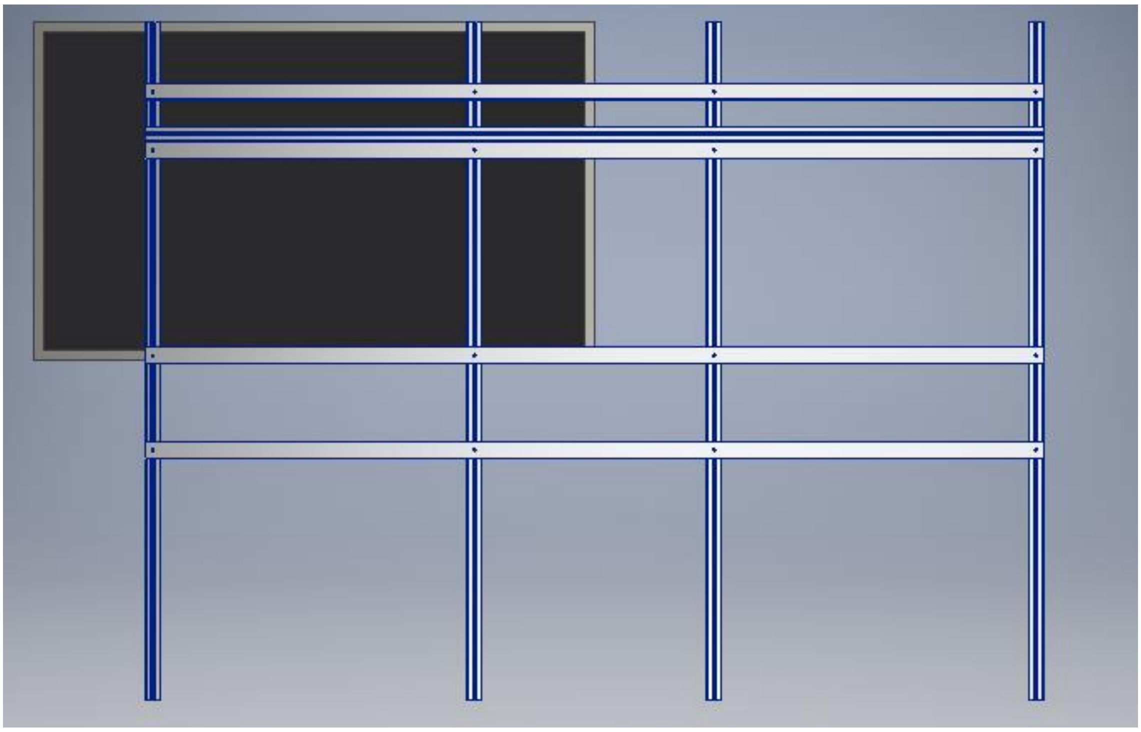


Figure 40. Structural system of the Top Frame, Autodesk Inventor.

This frame is linked to the rest of the structure through the hinges and the actuators. To connect them to the hinges, the square profiles have been made a transverse hole at 255 mm. This distance has been calculated so that the panels are perfectly placed in the centre of the trailer.

3.4. Lateral frame

The Lateral Frame or Side Frame is placed on one side of the trailer. Two solar panels are fixed on it. Its structure is the smallest of all and it also follows the same design pattern.

It consists of four square profile beams on which the solar panels are fixed. To join these profiles, other square profiles are bolted through its central hole and M12 screws to them. This design allows to have a less thick frame that project less from the side of the trailer.

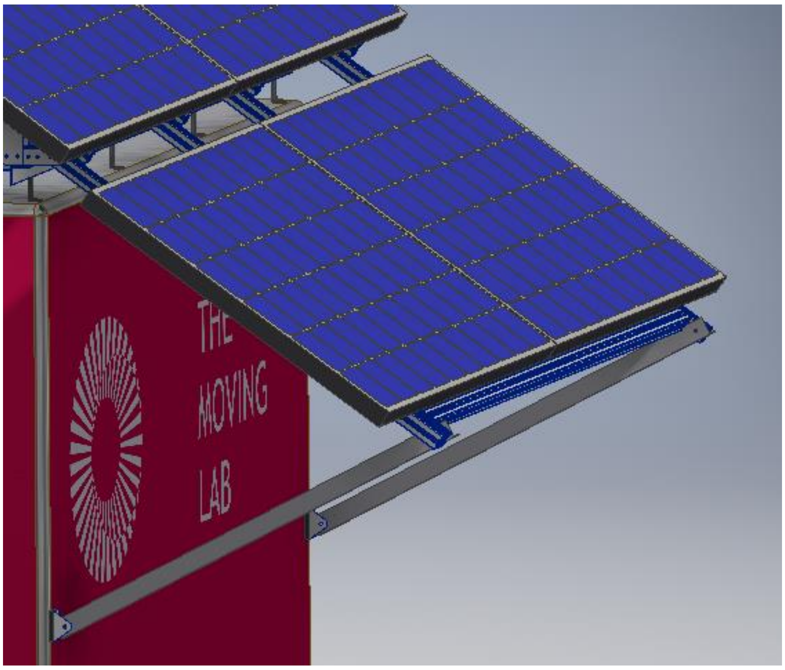


Figure 41. Detail of the Lateral Frame, Autodesk Inventor.

It is attached to the rest of the structure with the same system of hinges as the Top Frame. At the other end is fixed to the trailer through blocking points that allow two things.

On one hand, when the frame is folded, you can lock the frame on the trailer through these points. On the other hand, when the frame is unfolded these points serves to connect the support beams. Due to this fact, these lock points are at the same vertical distance as the frame.

Figure 42. detail of the lock points in The Moving Lab.

Unlike the Top Frame, this frame does not deploy automatically, and the intervention of at least one person it is necessary to lift and fix it through the support beams and lock points. The dimension of this support beam so that the angle to which the Lateral Frame is located is the optimum (35º) is 1210 mm. The calculation is simple because we know where the lock points are located, them the length only depends on the angle you want to give it.

Figure 43. Lock beams for the Lateral Frame in The Moving Lab.

3.5. Linear actuator

As a linear actuator we have used the Easyswing 200 door opener from HBopeners because the movement required by our frame is like a door. This actuator is suitable for a door of up to 2 meters and 200 KG per side providing enough power to ours which is around 100 KG and of similar dimensions.

The motors that work in 24 V are more powerful than most other gate openers that work with 12 V. It also has many adjustment options, including automatic closing after an adjustable wait time, which is used to block the frame while it’s towed.

Figure 44. View of the actuator placed in The Moving Lab.

Two actuators have been mounted so that they reach the necessary power to raise the frame without problems. In addition, as already mentioned in previous chapters, its placement has been carefully designed to optimize its movement to the maximum and not produce problems of high loads in the structure.

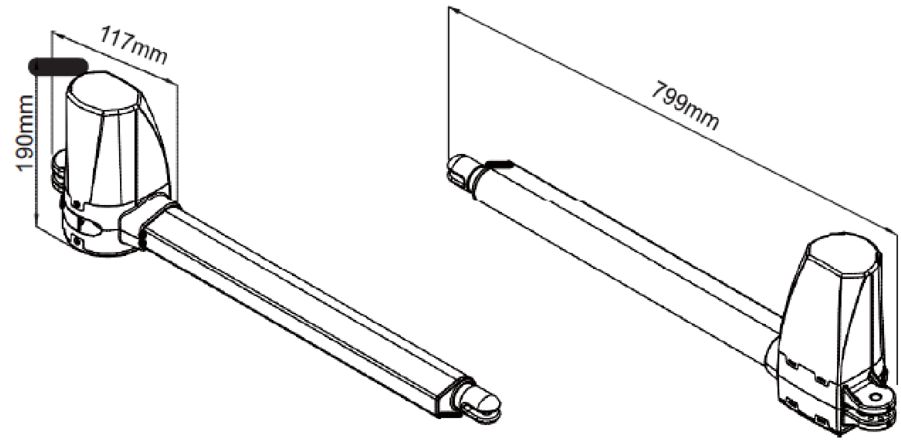


Figure 45. Detail of the actuator dimensions.

Specification Description	
Torque	1500 Newton
Weight	3,6 KG
Dimensions of retracted motor	65 x 9.8 x 19 cm
Dimensions of the extended motor	101 x 9.8 x 19 cm
Motor	24 V

Table 10. Specifications of the actuator Easy Wing 200.

It also comes with two remote controls to unfold or fold the PV array when it is required.

3.6. Gas springs

As already advanced in previous chapters, two Gas Springs has been used to help to lift the Top Frame in the initial moments.

Its size has been dimensioned through a web page that has given us the following values based on the weight, size and placement of the Top Frame:

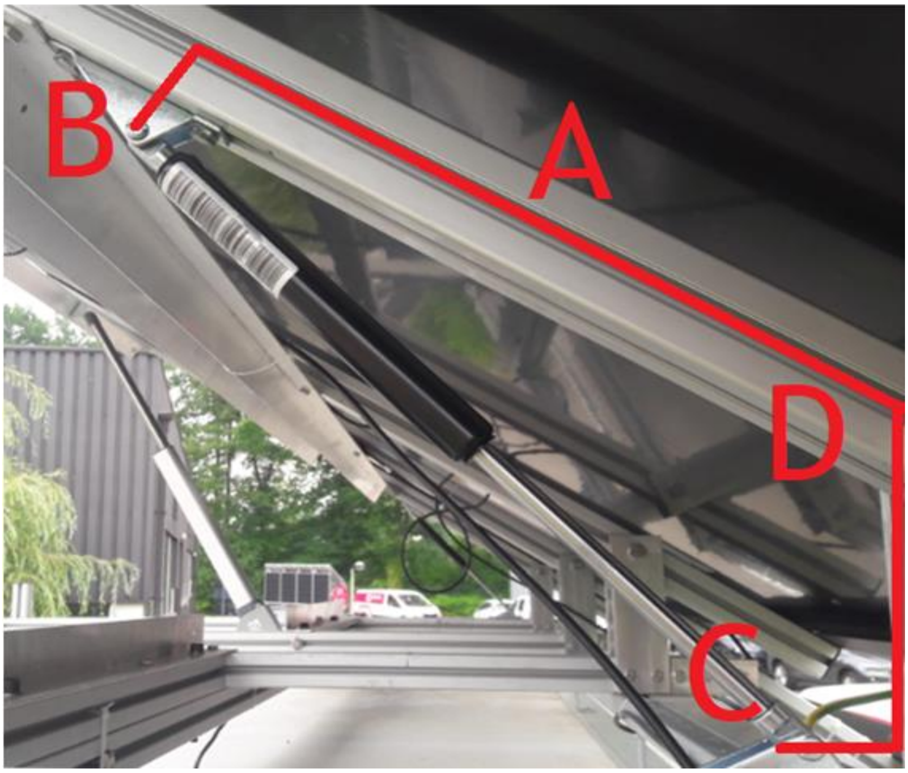


Figure 46. Dimensions of the gas spring location.

A = 380 mm; B = 20 mm; C = 176 mm; D = 152 mm

CHAPTER V. Building process

In the previous chapter the dimensions and features of the trailer are explained in detail. For the final design the trailer has been painted and stickers have been placed with the logos of the UCLL Hogeschool and the project's name. This has been done to decorate the trailer and make it more eye-catching for the public. The final trailer looks like this:

The building process has been developed mainly in the workshop. In this chapter some of the machines and tools used for the construction of this project are described, as well as some images that visually explain the construction process.

1. Tools and materials

For the beams we have used 6 meters profiles unities. To manipulate the beams, we have used the tools shown in the following images:

Figure 47. Drills used during the construction.

The drills used have been of Ø12, Ø10, Ø8 and a centre drill. In this order are shown in Figure 47.

The unions between beams have been done with screws. For the square profile we have used a special type of joints, T-Nuts. In the following Figure we can appreciate how it fits in the beam.

Figure 48. Detail of the T-Nuts in the beams.

To manipulate the beams, we have used the machines used in the two following images. The saw is from *VM services* (Figure 49). The drill is from *Malilla* (Figure 50). All these materials can be found in the workshop of the UCLL.

Figure 49. Automatic Saw, VM Service.

Figure 50. Drilling Machine, IMA Malilla.

2. Procedure

The procedure of building The Moving Lab was the following:

First, we sawed and drilled all the profiles with the drawings arisen in Inventor. In this stage we also cut slides from the billets (see Figure 51) for the hinges and the lock points in aluminium and plastic pieces.

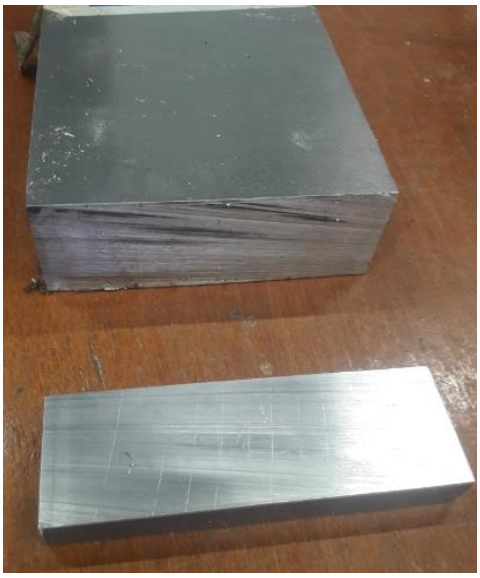


Figure 51. Aluminium billet for the hinges.

Once we had all the beams and the drawings, we started mounting and screwing all the parts. We built each part on the floor (see Figures 52 & 53) or directly to the trailer (see Figures 54 & 55) to finally attach them all together. The best solution for couple the pieces was a single girder cranes placed in the Technology Building as shown in Figure 54.

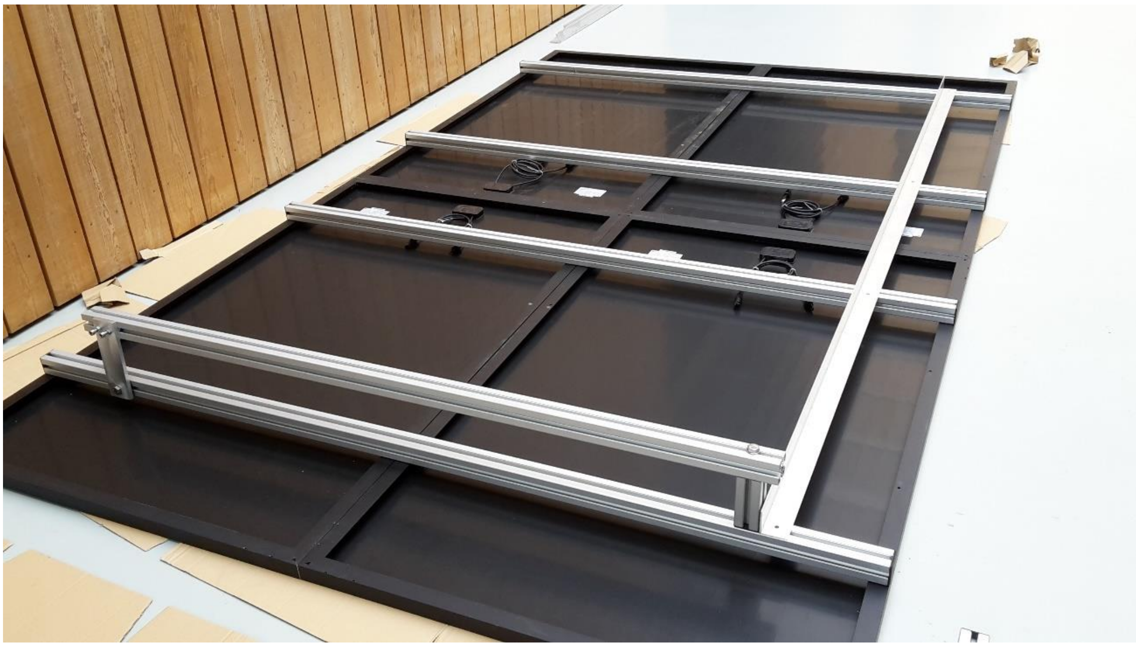


Figure 52. Construction of the Top Frame detail.

Figure 53. Construction of the Lateral Panels detail.

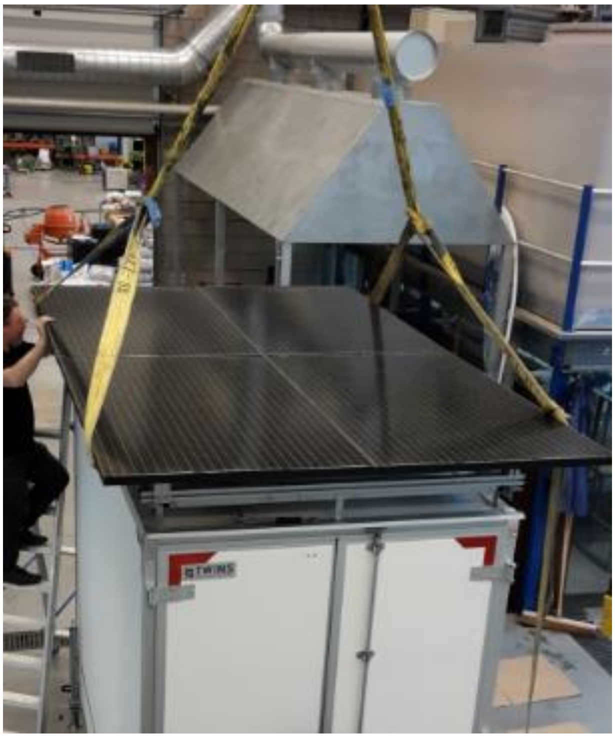


Figure 54. Mounting the Top Frame to the trailer.

Figure 55. View of the mounting place.

3. Electric assembly

During the construction of this project, as part of my work, I have also helped with the installation of the electrical components as well as to build the mechanical parts on which they are assembled.

During the realization of this project I have acquired knowledge about electrical design and the operation of the components that form a solar installation. That work and that knowledge have not been included in this thesis because they are part of the Study of the Electrical Design of The Moving Lab by Diedde Briers.

CHAPTER VI. The box

1. Introduction

Along with the development of The Moving Lab this project includes the design of an air quality measurement device as an application of The Moving Lab.

The air quality device consists of a box in which different sensors and electronic devices will be introduced such as wireless connection or vacuum pumps to take measurements of the air in unusual conditions. My work on this field has consisted in the design of the lay out and de shape of this device. The modelling work has been carried out by Dennis Maes.

Due to the elements that make up the device, the requirements of the box vary. To achieve this aim, we have divided the design in two different devices, each one satisfies different purposes. The wide mobility of The Moving Lab allows to place or use any of these boxes in the places where they are required.

The work in this project has not been completed to the end because the sensors that the University wanted to use have still to be specified. What has been achieved is to design two prototypes in 3D models with the Autodesk Inventor tool and finally built with a 3D printer one of them. The sensors used are standard.

The key idea of this project was to:

- Keep everything compact
- keep the installation process faster and reproducible

2. Description

The aim of this research was to establish the best mounting point for three Alphasense B4 series sensors (SO_2, NO_2 and OX) and a Particle Monitor (PM). For the computer-controlled system we have used a Raspberry Pi as an excellent choice for serious data harvesting. It's easy to manipulate and program.

Figure 56. Raspberry Pi.

This gives the device the capability of providing remote monitoring data from on-board sensors. This information is transmitted to The Moving Lab operator's tablet for to be viewed live and logged.

The enclosure is a weather proof electrical box. The Raspberry Pi board is easy to spot mounted to the bottom of the case. Along with it a battery is meant to be as it provides a USB port and enough current to operate the Pi and the sensors. On back is a 3G modem used to access the data remotely - although it can log to the SD card for collection later.

The sensors we have worked with are the followings:

2.1. Sensors

- **Digital universal particle concentration sensor – PMS5003**

Figure 57. Particle Monitor Sensor, PMS 5003

Description of the Datasheet: PMS5003 is a kind of digital and universal particle concentration sensor, which can be used to obtain the number of suspended particles in the air, the concentration of particles, and output them in the form of digital interface. This sensor can be inserted into variable instruments related to the concentration of suspended particles in the air or other environmental improvement equipment's to provide correct concentration data in time.

- **SO2-B4 Sulfur Dioxide Sensor**
- **NO2-B43F Nitrogen Dioxide Sensor**
- **OX-B431 Oxidising Gas Sensor**

Figure 58. Alphasense B4 serial sensors example.

3. Drone model – Flying Laboratory

Refineries, petrochemical plants, and many other processes have emissions that are difficult to sample using traditional methods. The use of drones opens a whole new dimension in air sampling by allowing the operator to take direct samples from odour plumes and other sources that are difficult and /or dangerous without exposure to physical or chemical hazards. Taking samples at various heights upwind and downwind of the plant allows for accurate measurement of all emissions generated by the plant without the need for source sampling.

Monitoring air quality using small sensors onboard a drone is very complicated, not only for constraints such as power consumption, weight and propeller effect, but also because the choice of sensors depends on the pollution source being measured. In this project we have used a M600 drone model property of the UCLL. This model provides a larger payload capacity (>5 kgs payload), a good in-flight stability and manoeuvrability, making it suitable for air quality studies where the capability to carry different sensors and maintain an in-flight fixed position are needed.

Figure 59. Drone M600, Djicdn.

The aim is to develop a drone system capable of measuring point source emissions. Due to the air speed behaviour a study of the location of the box is required. Some consulted sources show that the best mounting point for the sensors is to be alongside the drone. This position is less affected by the propeller downwash effect. Furthermore, the position of the tube inlet strongly affected the gas measurement results and wind resistance caused by the enlarged drone.

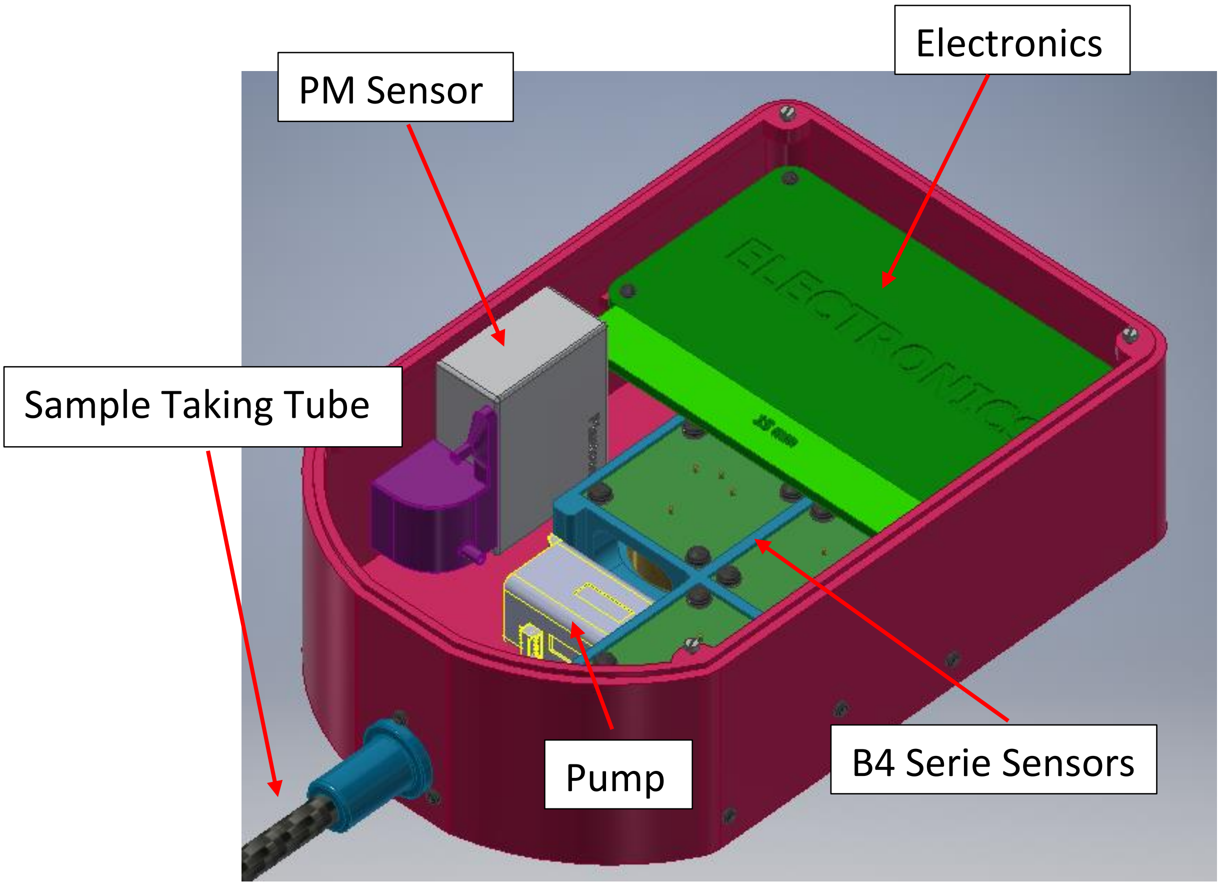


Figure 60. Inside details of the Flying Laboratory, Autodesk Inventor.

The Flying Laboratory has essentially three main parts:

- The B4 sensor (any analog or digital sensor can work). Left in the main box.
- Sample taking tube (entrance for the sensors). Front in the main box.
- Pump and tubes (for the B4 sensors). Middle in the main box.
- The PM sensor (particle concentration sensor). Right in the main box.
- Power and electronics (any electronic component required). Back in the main box.

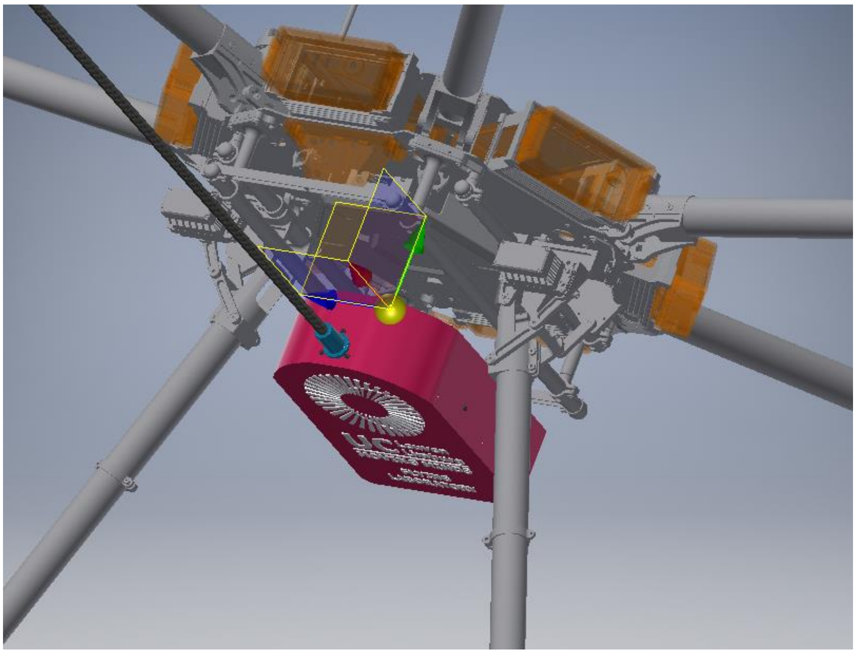


Figure 61. Detail of the box placed in the drone, Autodesk Inventor.

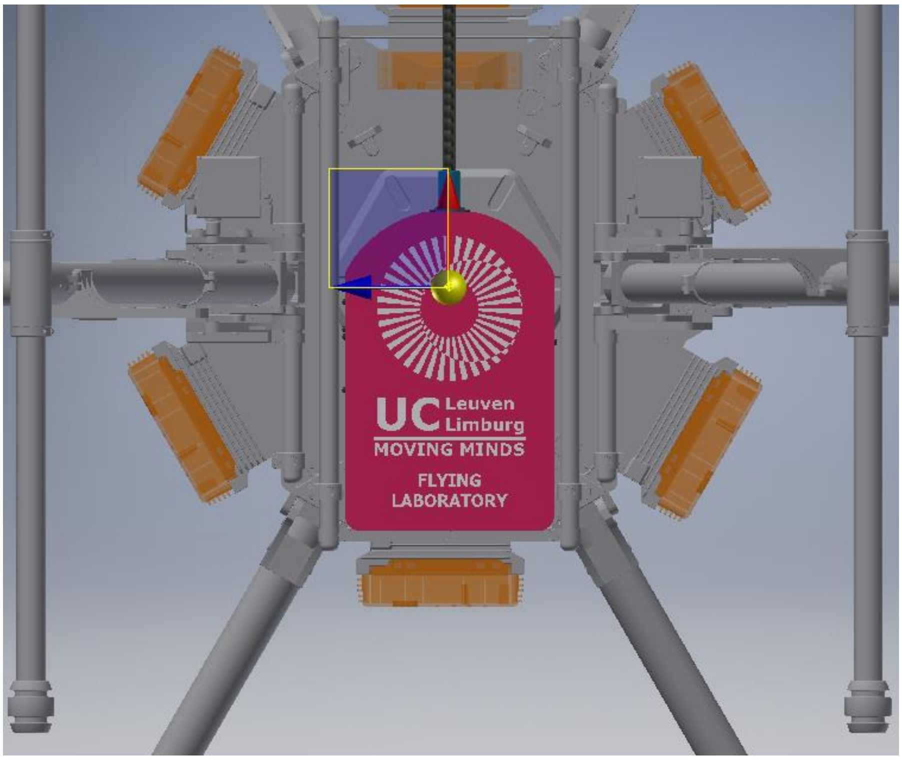


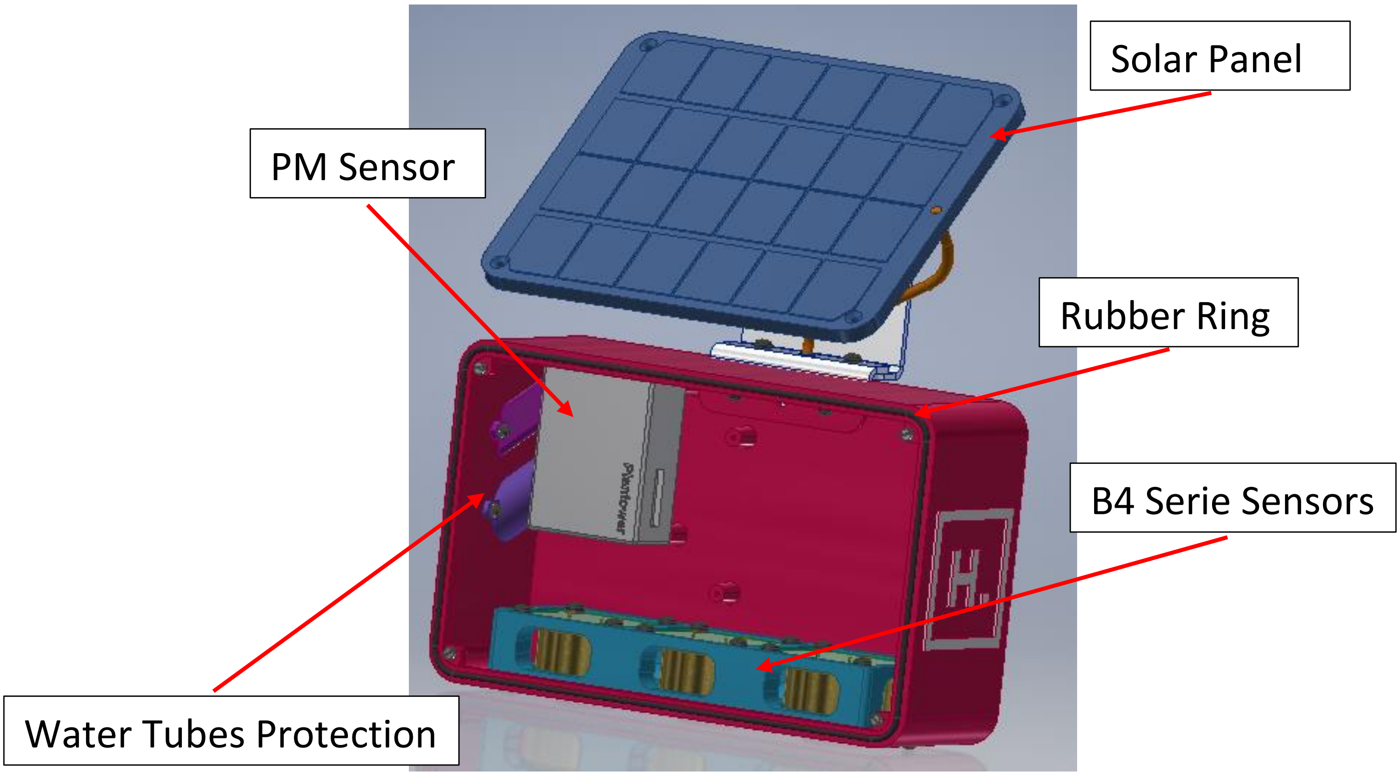
Figure 62. Detail of the cover face of the box in the drone, Autodesk Inventor.

4. Pole model – Air Quality Monitor

Since monitoring equipment is expensive, measurements of air pollutants are taken at relatively few locations, and while this is important, more individualized information is also necessary. The standalone package can be taped, screwed, bolted, or bungeed at the target location with a minimum of effort and will immediately start generating sample data.

The layout and sensors vary. This device is designed to be installed on a pole and as it is powered by solar energy, it requires a minimum of maintenance. Its design is waterproof: the cover is sealed with a rubber ring and the air inlets and outlets are protected with a plastic tube.

This box has been printed with a 3D printer to be used as a prototype.



CHAPTER VII. Conclusions and References

1. Conclusions

This Thesis sums up five months of working in The Moving Lab. In it I have tried to detail the work to the most so that other people can be able to learn, work and enhance my project. At the beginning of this Thesis, several goals were defined. To achieve them, I have been helped by fellows and professors till the last day.

During the development of this project I have learnt about solar energy, both the electrical part and the mechanical part. Now I understand better the operation of renewable energy systems. I have learned how to use the software tool Autodesk Inventor Professional 2018, a knowledge that will help me in my future career. With it I have been able to realize an effective, simple and real design of The Moving Lab, fulfilling the requirements and the demands of the project as well as the university's and my professor's.

As a priority I have been able to build the project myself. After arduous work we managed to meet the deadline, The Moving Lab has been completely built and is fully operational. On the days that this project ends, it is being exposed on other campuses.

Lastly, although we did not go beyond the prototype phase, we set the basis for future work on air quality measurement devices. Project that the university will take again next semester.

During my stay at the UCLL I have been able to develop my personal and professional skills. I have grown as a person and as an engineer. The opportunity they have given me, to make such a fascinating and beautiful project, to be able to build it with my hands, has been a wonderful experience. I have learned a lot and I am taking a new and different concept of engineering and its possibilities.

Finally, I would like to add a possible line of future improvement in The Moving Lab. From the beginning I had to discard the idea of developing a solar tracker due to the engineering and time requirements. But once the project was finished, the next step would be to automate the movement of the panels so that they would be able to vary their inclination with the sun and not be fixed at a certain angle. Requires new mechanical elements as well as knowledge in programming.

2. References

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- Photovoltaic Geographical Information System - Interactive Maps. JRC, European Commission. http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?lang=en&map=europe

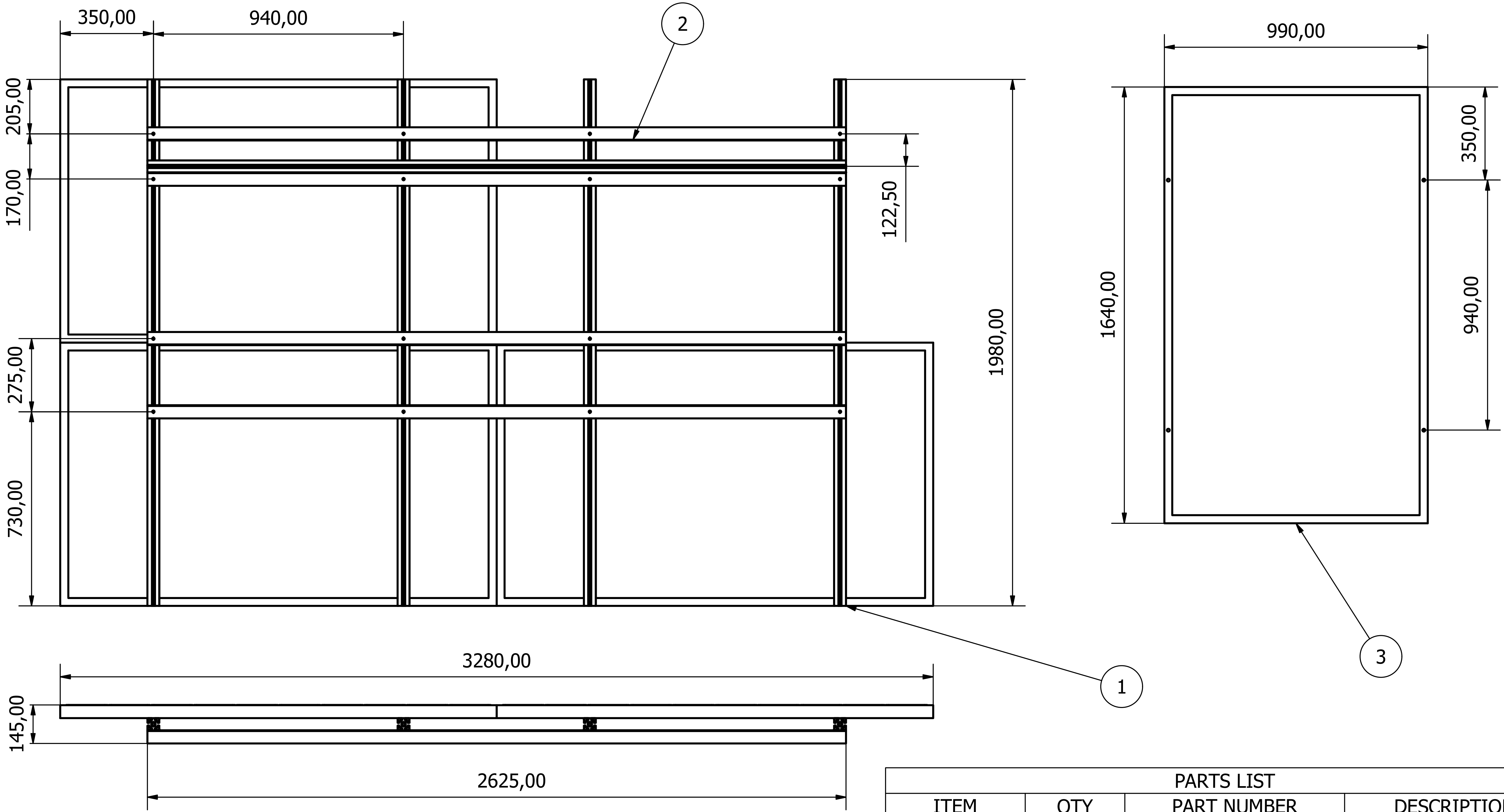
CHAPTER VIII. Annexes

Drawings

I. The Moving Lab – Top Frame
II. The Moving Lab – Support Frame – 1
III. The Moving Lab – Support Frame – 2
IV. The Moving Lab – Support Frame – Hinges
V. The Moving Lab – Lateral Frame
VI. The Moving Lab – Unfolded array
VII. The Moving Lab – Folded Array

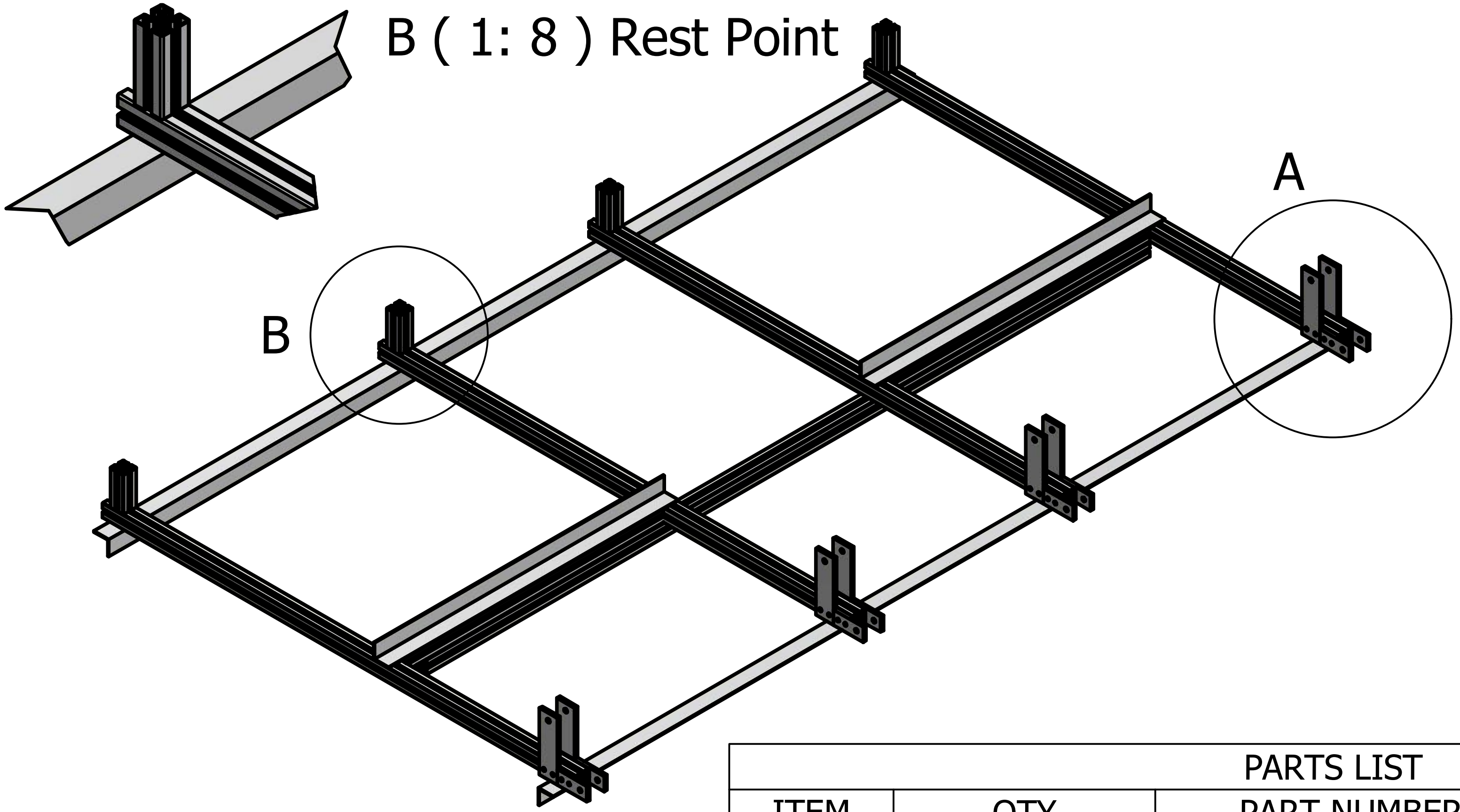
Datasheets

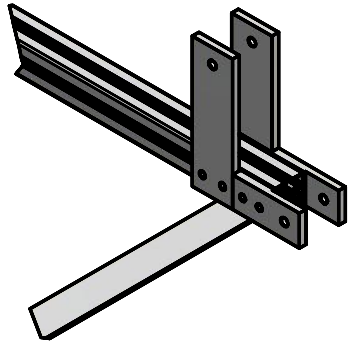
I. Solar Panel CSun 300 M60
II. Actuator Specifications
III. Gas Springs – Forces
IV. Gas Springs – Dimensions
V. Drone M600 Specifications
VI. NO2 Sensor
VII. OX Sensor
VIII. SO2 Sensor
IX. PM Sensor



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	10545,000 mm	Square Profile	45x45 , M10
2	10500,000 mm	L Profile	L 50x50x3
3	4	Solar Panel	

Design by: Pablo Posadas	Final Project Design and Drawings	Date: 21/06/2018
UC Leuven Limburg MOVING MINDS	Top Frame	
	The Moving Lab	Scale 1:15 / Page 1 / 7

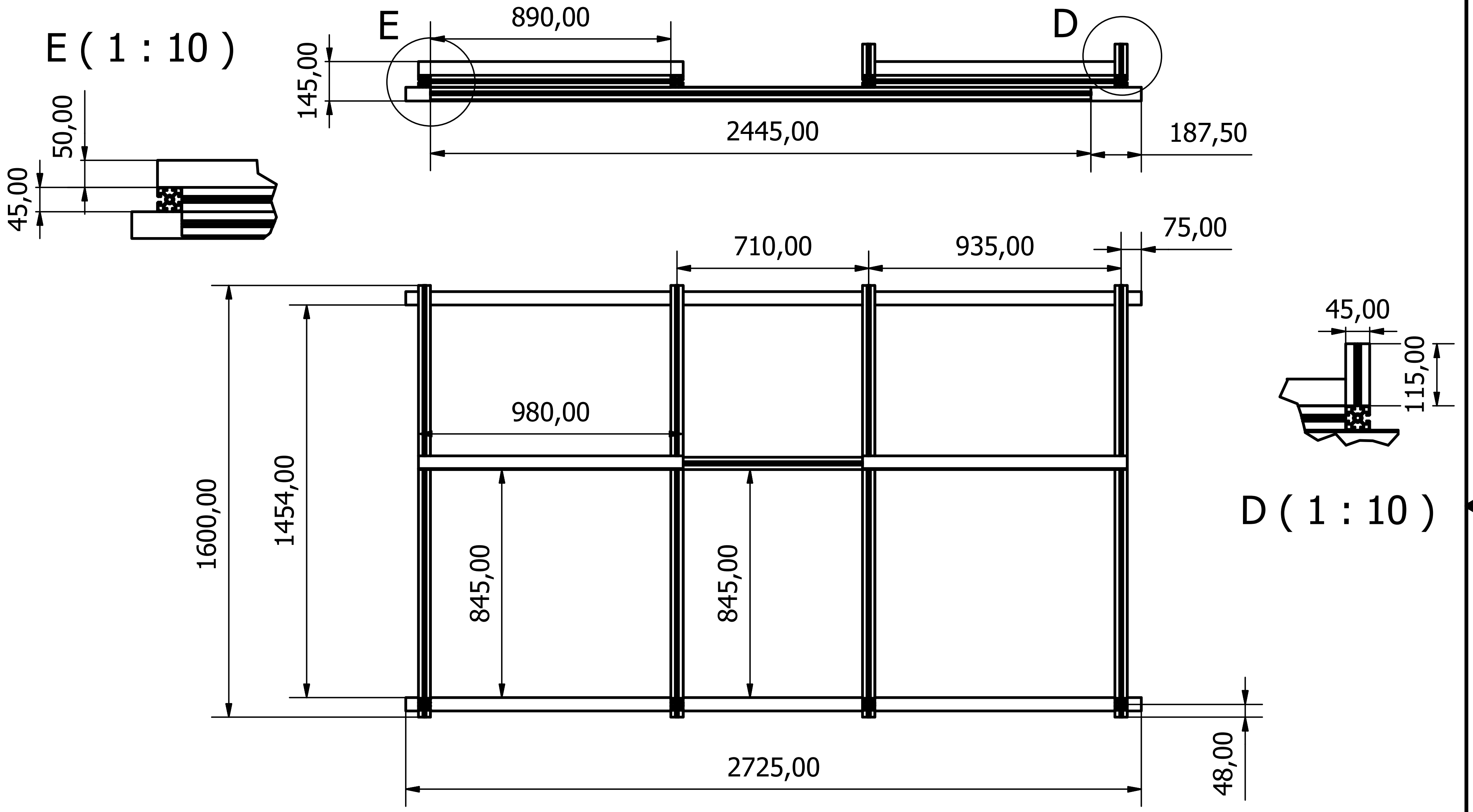




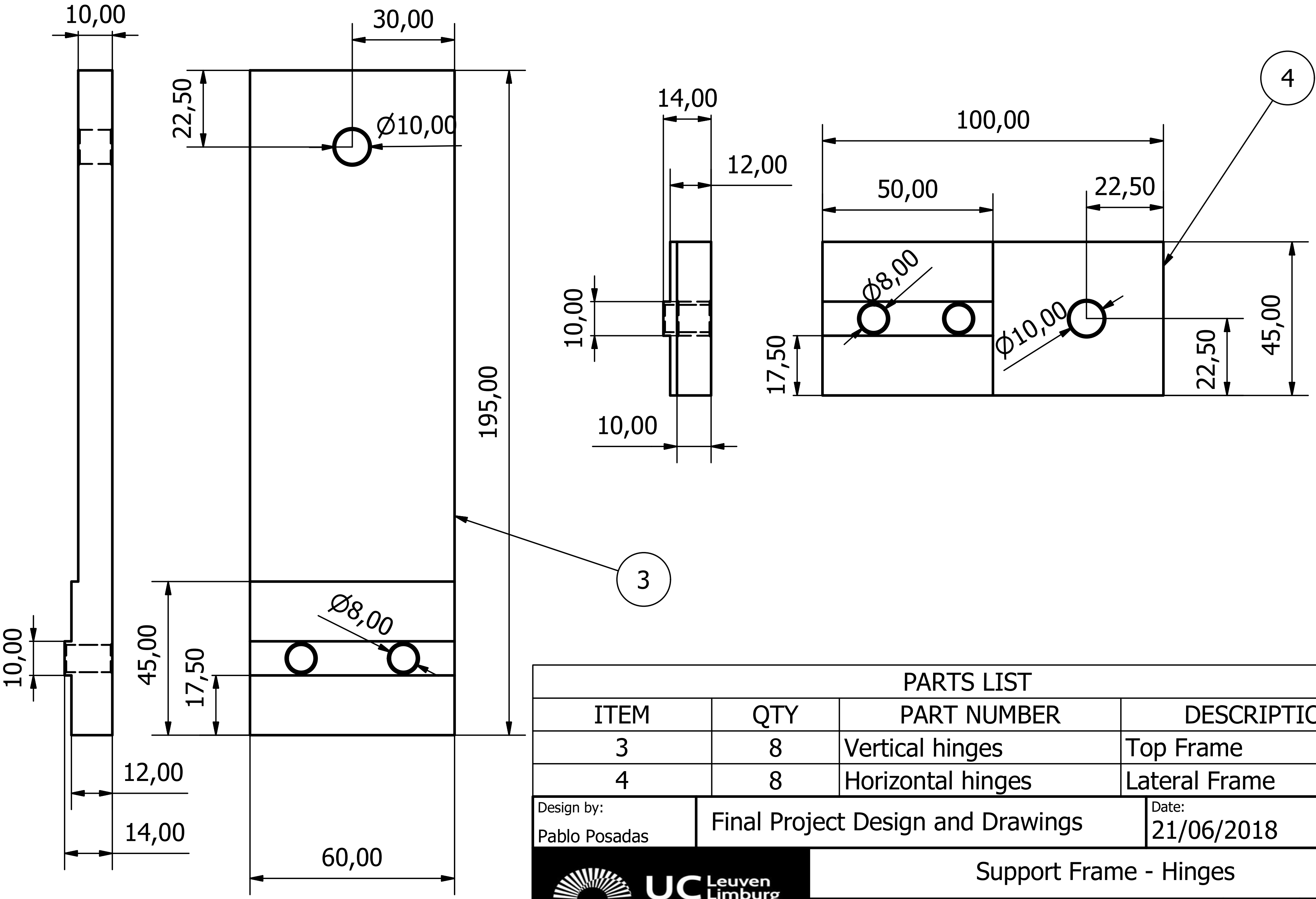
A (1: 8) Hinges

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	7410,000 mm	L Profile	L 50x50x3
2	11085,000 mm	Square Profiles	45x45 , M10
3	8	Vertical hinges	Top Frame
4	8	Horizontal hinges	Lateral Frame
5	4	Rest point	45x45 , M10

Design by: Pablo Posadas	Final Project Design and Drawings	Date: 21/06/2018
UC Leuven Limburg MOVING MINDS	Support Frame - 1	
	The Moving Lab	Scale 1:15 / Page 2 / 7

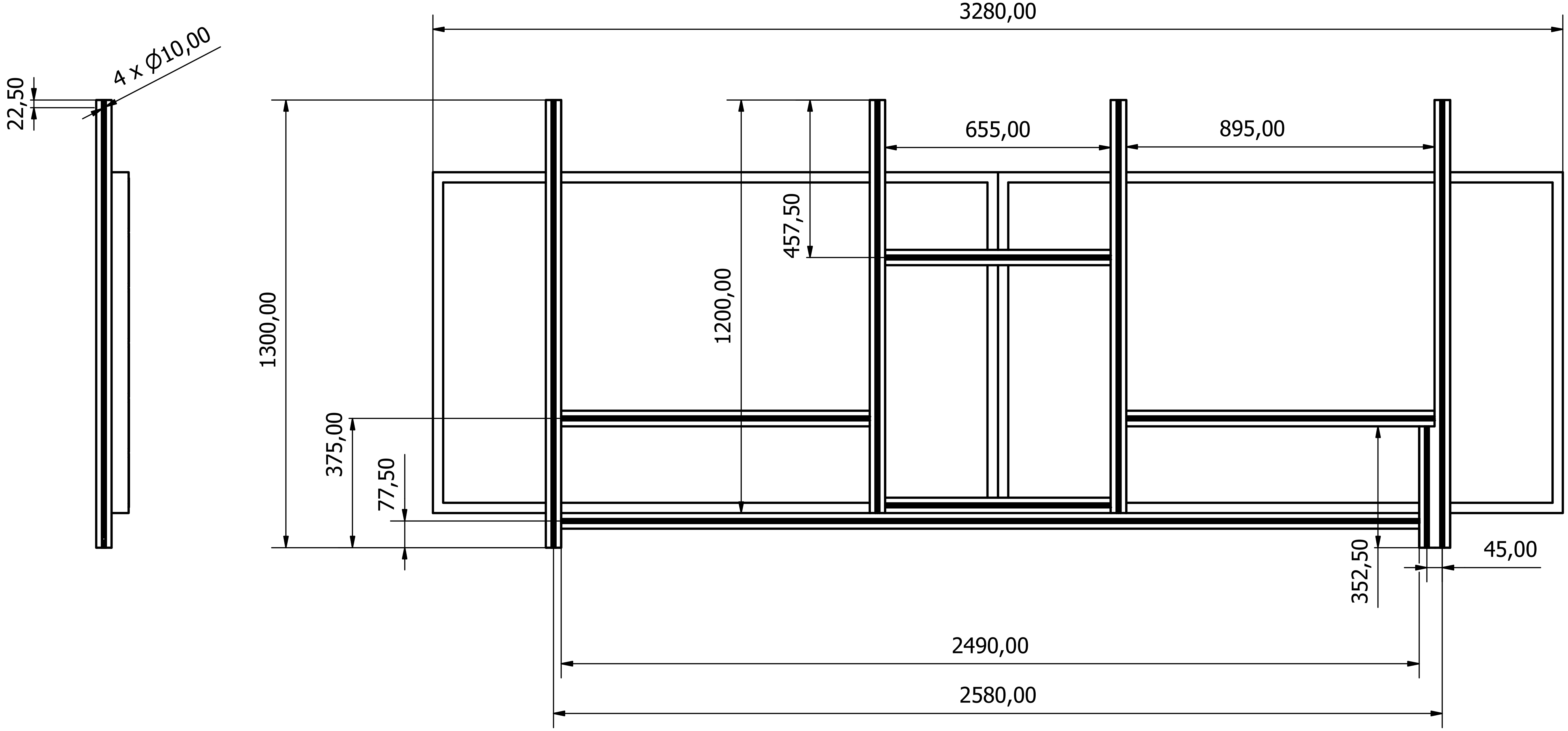


Design by: Pablo Posadas	Final Project Design and Drawings	Date: 21/06/2018
UC Leuven Limburg MOVING MINDS	Support Frame - 2	
	The Moving Lab	Scale 1:15 / Page 3 / 7



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
3	8	Vertical hinges	Top Frame
4	8	Horizontal hinges	Lateral Frame

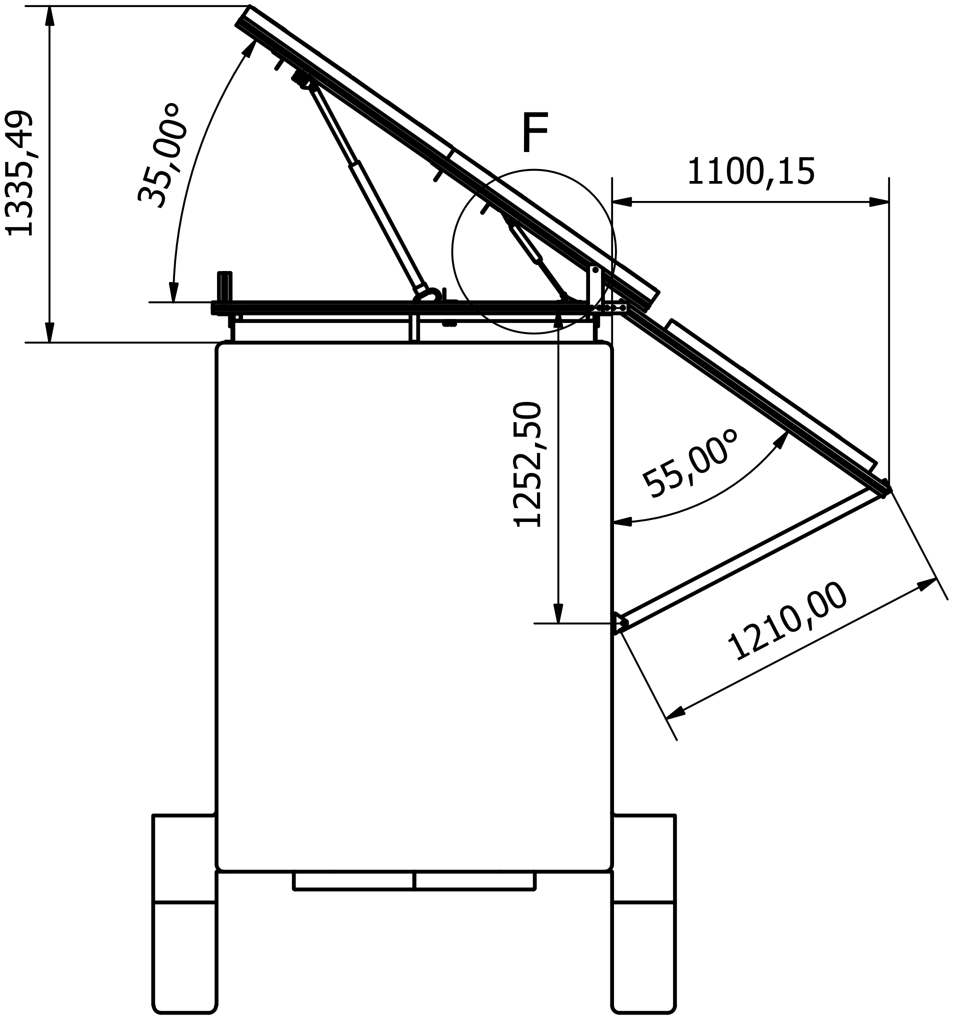
Design by: Pablo Posadas	Final Project Design and Drawings	Date: 21/06/2018
UC Leuven Limburg MOVING MINDS	Support Frame - Hinges	
	The Moving Lab	Scale 1 : 2 / Page 4 / 7



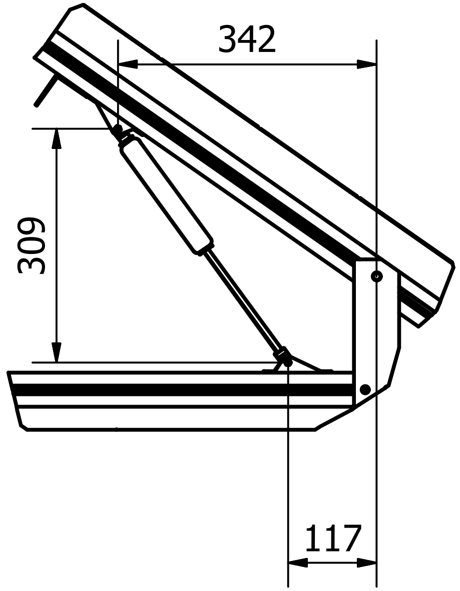
PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	Solar Panel	
2	10945,000 mm	Square profile	45x45 , M10

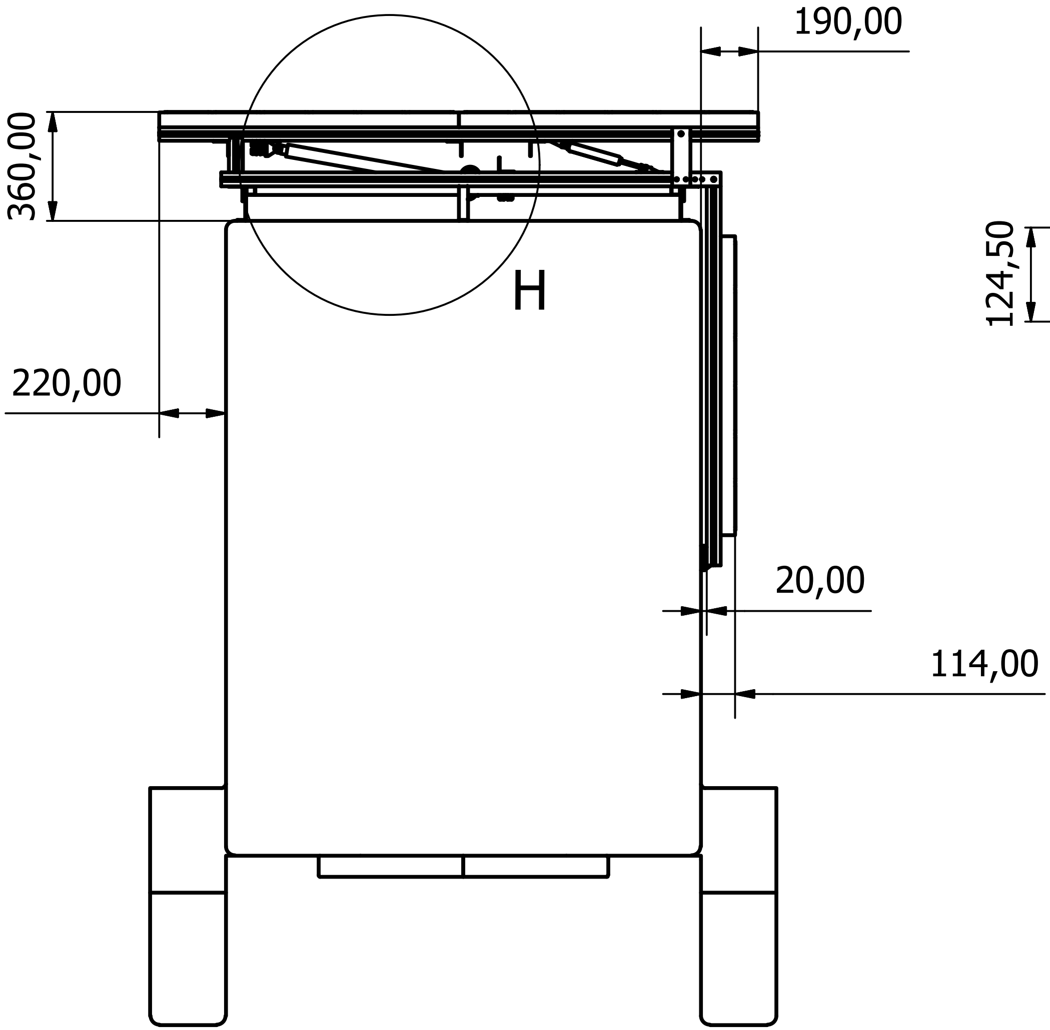
Design by: Pablo Posadas	Final Project Design and Drawings	Date: 21/06/2018
UC Leuven Limburg MOVING MINDS	Lateral Frame	
	The Moving Lab	Scale 1:15 / Page 5 / 7

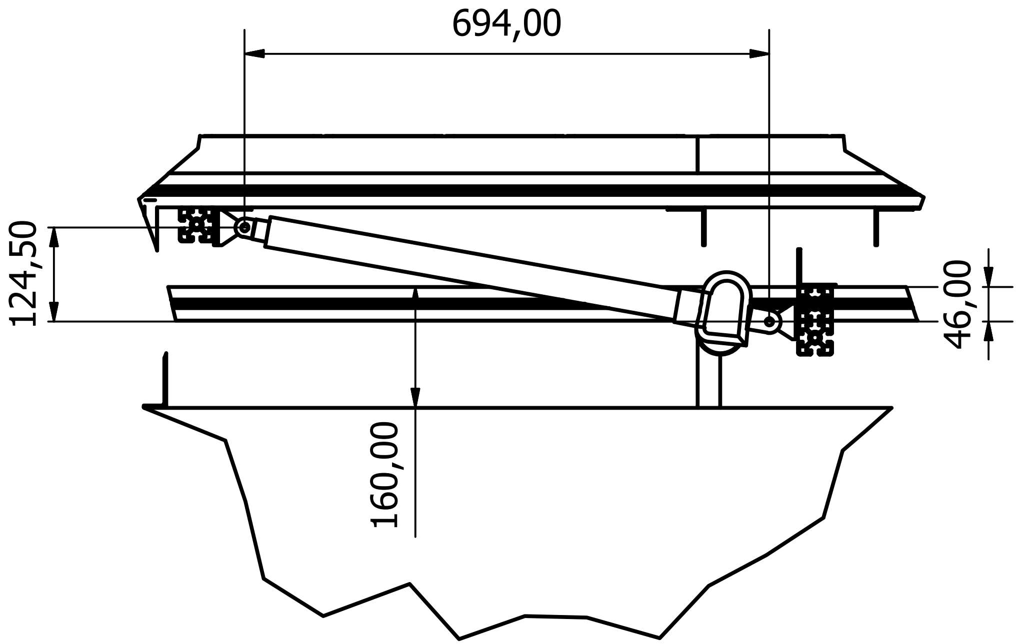


F (1 : 10)



Design by: Pablo Posadas	Final Project Design and Drawings		Date: 21/06/2018
UC Leuven Limburg MOVING MINDS	Unfolded Array		
	The Moving Lab	Scale 1 : 2	Page 6 / 7





H (1 : 10)

Design by: Pablo Posadas	Final Project Design and Drawings	Date: 21/06/2018
UC Leuven Limburg MOVING MINDS	Folded Array	
	The Moving Lab	Scale 1 : 25 · Page 7 / 7

CSUN
energy for today

Mono

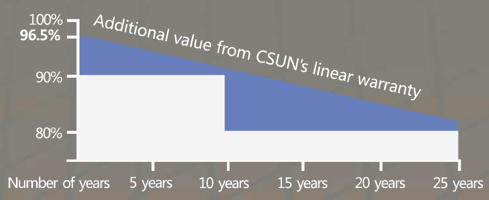
PowerGuard
SPECIALTY INSURANCE SERVICES

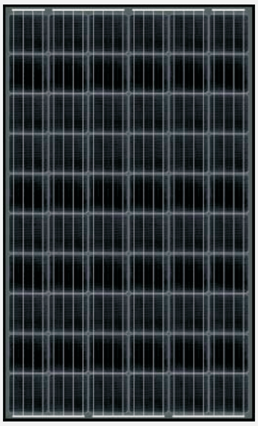
Powerguard Insurance Global Coverage

The power output shall not be less than 96.5% of the minimum power output stated in the product data sheet in the first year of the product' s life cycle. The loss of power output shall not exceed 0.7% per year thereafter, ending with 80.7% in the 25th year.

CSUN   Standard Warranty

CSUN's **NEW** linear performance warranty





CSUN300-60M-BB

High efficiency PERC technology for esthetic applications

CSUN300-60M-BB   CSUN295-60M-BB
CSUN290-60M-BB

18.48%
Module efficiency

300 W
Highest power output

10 years
Material & Workmanship warranty

25 years
Linear power output warranty

- PID-free
- World class mono efficiency
- Tighter product performance distribution and current sorting reduces the mismatch power loss in system operation
- positive tolerance offer
- Good temperature coefficient enables higher output in high temperature regions
- Excellent performance under low light conditions
- Certified for salt/ammonia corrosion resistance
- Load certificates: wind to 2400Pa and snow to 5400Pa

- China Sunergy Co., Ltd. designs, manufactures and delivers high efficiency solar cells and modules to the world from its production centers based in China, Turkey, South Korea and Vietnam.
- Founded in 2004, China Sunergy is well known for its advanced solar cell technology, reliable product quality, and excellent customer service.
- As one of leading PV enterprises, China Sunergy has delivered more than 4.0GW of solar products to residential, commercial, utility and off-grid projects all around the word.

- Note:
All specifications, warranties, certifications about module of "CSUN" series also apply to that of "SST".

All information and data are subject to change without notice.

www.csun-solar.com

Electrical Characteristics at Standard Test Conditions (STC)

Module Type	CSUN300-60M-BB	CSUN295-60M-BB	CSUN290-60M-BB
Maximum Power-Pmax (W)	300	295	290
Open Circuit Voltage - Voc (V)	39.8	39.6	39.5
Short Circuit Current - Isc (A)	9.60	9.54	9.47
Maximum Power Voltage - Vmpp (V)	32.2	32.0	31.9
Maximum Power Current - Impp (A)	9.31	9.22	9.10
Module Efficiency	18.48%	18.16%	17.86%

Standard Test Conditions [STC]: irradiance 1,000 W/m^2; AM 1,5G; module temperature 25°C. Measuring uncertainty of power is within ±3%. Tolerance of Pmpp:0~+3%. Certified in accordance with IEC61215, IEC61730-1/2 and UL1703.

Electrical Characteristics at Nominal Operating Cell Temperature (NOCT)

Module Type	CSUN300-60M-BB	CSUN295-60M-BB	CSUN290-60M-BB
Maximum Power-Pmax (W)	227	222	214
Open Circuit Voltage - Voc (V)	37.3	37.1	36.1
Short Circuit Current - Isc (A)	7.74	7.69	7.60
Maximum Power Voltage - Vmpp (V)	31.0	30.6	30.0
Maximum Power Current - Impp (A)	7.32	7.25	7.13

Nominal Operating Module Temperature(NOCT): irradiance 800W/m^2; wind speed 1m/s; ambient temperature 20°C.
Measuring uncertainty of power is within ±3%, Certified in accordance with IEC61215, IEC61730-1/2 and UL1703.

Temperature Characteristics

Voltage Temperature Coefficient	-0.307%/°C
Current Temperature Coefficient	+0.039%/°C
Power Temperature Coefficient	-0.423%/°C
NOCT	45±2°C

Maximum Ratings

Maximum system voltage(V)	1000
Series fuse rating(A)	20

Mechanical Characteristics

Dimensions	1640x990x35mm (LxWxH)
Weight	18. 3kg
Frame	Anodiz ed aluminum profile
Front Glass	White toughened safety glass, 3.2mm
Cell Encapsulation	EVA(Ethylene-Vinyl-Acetate)
Back Sheet	Composite film
Cells	6×10 pieces monocrystalline solar cells series strings (156mm×156mm
Junction Box	Rated current ≥13A, IP≥ 67, TUV&UL
Cable & Connector	Length 900mm,1x4mm^2, compatible with MC4

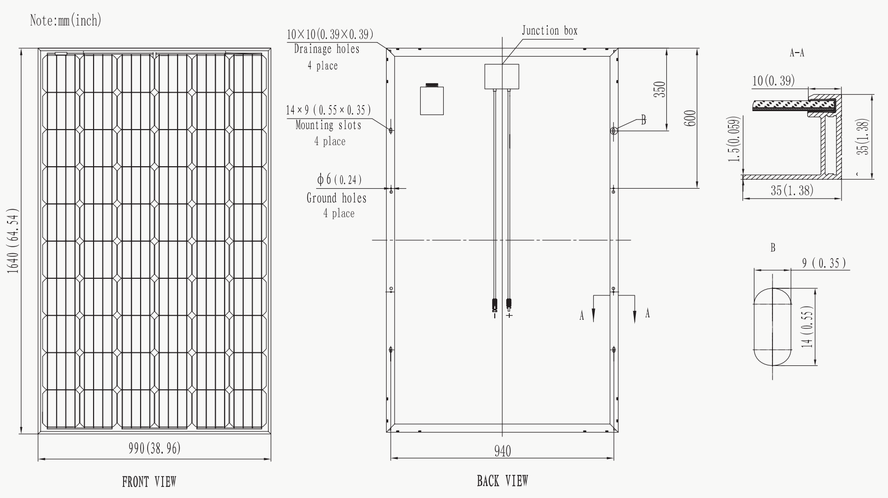
Packaging

Dimensions (L×W×H)	1700×1140×1137mm
Container 20'	360
Container 40'	840
Container 40' HC	896

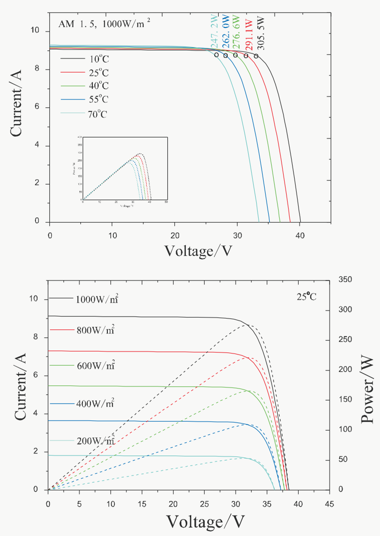
System Design

Temperature range	-40°C to +85°C
Hail	maximum diameter of 25mm with impact speed of 23m/s
Maximum surfaceload	5400Pa
Application class	class A
Safety class	class II

Dimensions



IV-Curves



Ⓔ NOODONTKOPPELING

Ontkoppeling van de aandrijfmotor (voor de linkermotor):

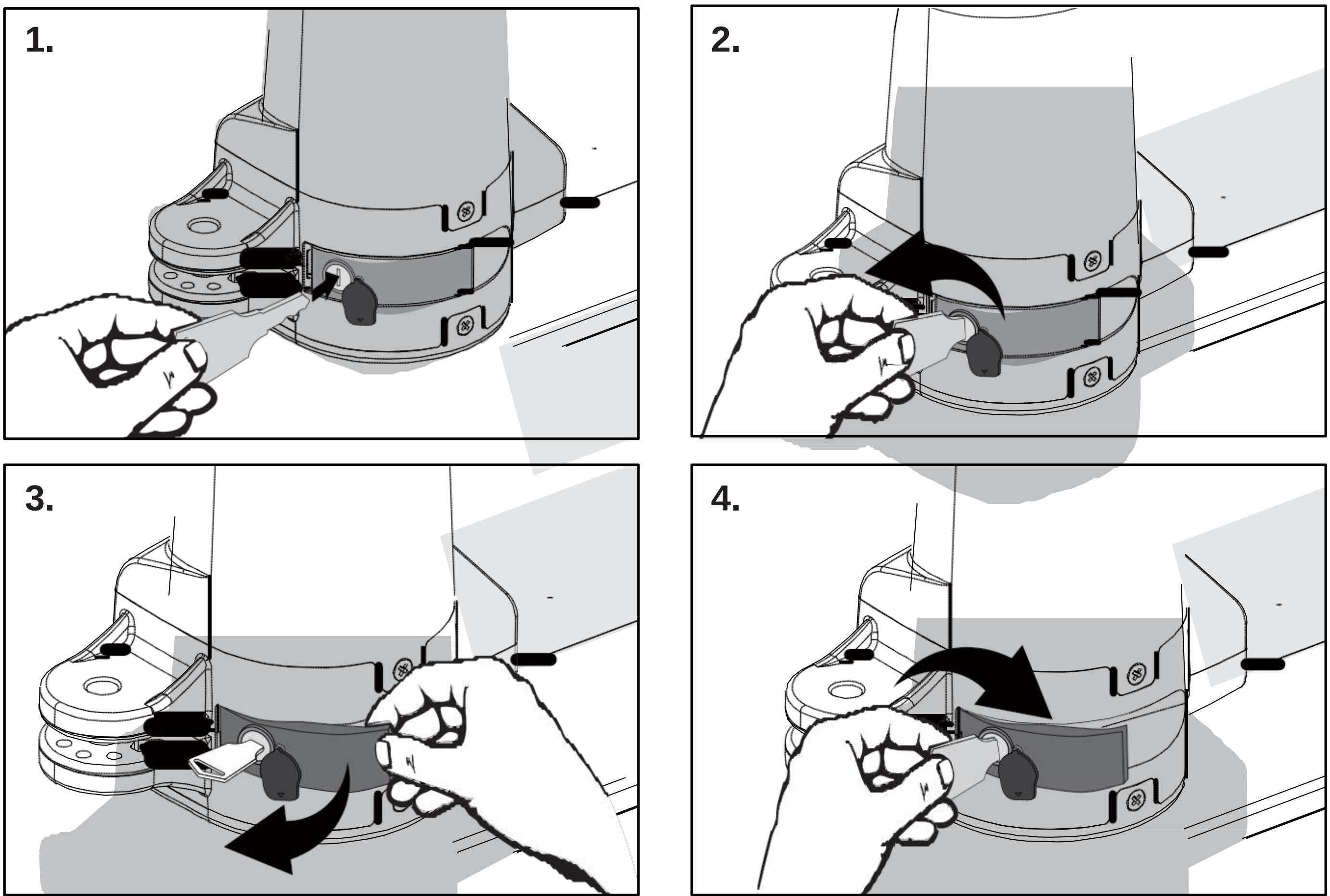
1). Steek de ontkoppelingssleutel in het ontkoppelingsgat.

2). Draai de ontkoppelingssleutel tegen de klok in.

3). Trek de ontkoppelinghendel uit.

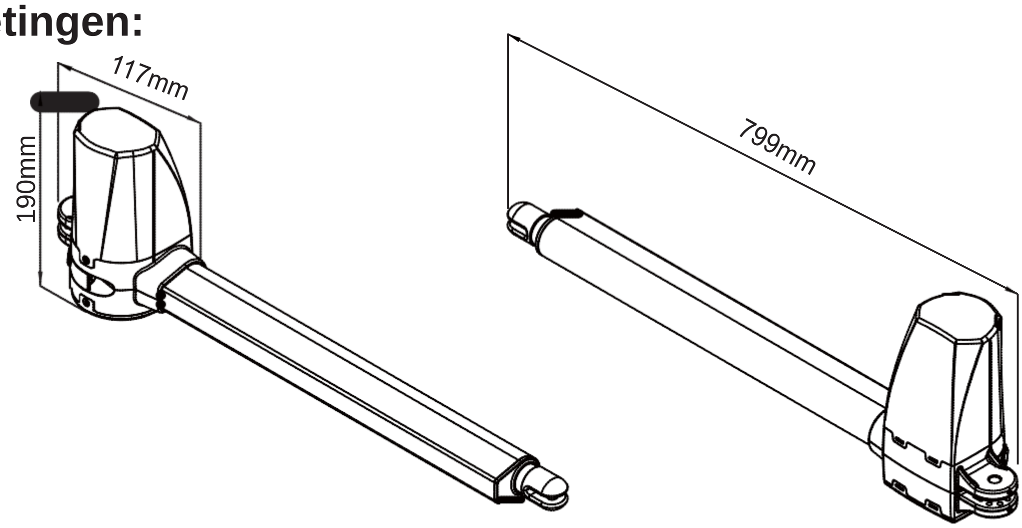
4). Draai de sleutel met de klok mee om de ontkoppelinghendel vast te zetten. De hendel moet in uitgetrokken positie zijn, wanneer u de sleutel met de klok meedraait.

5). De draairichting zal worden omgekeerd voor de rechtermotor.



1.3 TECHNISCHE KENMERKEN:

Ⓐ Afmetingen:



Ⓑ Technische kenmerken:

Motor	24Vgs motor met mechanische ontkoppeling
Aandrijvingstype	Wormwiel
Stuwkracht	2000N
Slaglengte	400mm
Voeding	24Vgs
Maximale werking	4,2A voor maximaal 10 seconden.
Maximaal gewicht	250 kg per poorthelft
Maximale lengte	2,5 meter
Inschakelcyclus	20%
Bedrijfstemperatuur	-20°C~+50°C
Afmetingen	799mm * 98mm * 170mm
Gewicht	3,6kg

1.4 Onderhoud:

Voer de volgende handelingen minimaal elke zes maanden uit. Hanteer bij intensief gebruik kortere periodes.

Koppel de voeding af:

(1) Maak de schroeven, pinnen en scharnier schoon en smeer ze in met vet.
(2) Controleer of de bevestigingspunten goed zijn aangedraaid.
(3) Zorg dat de bedrading in goede staat is.

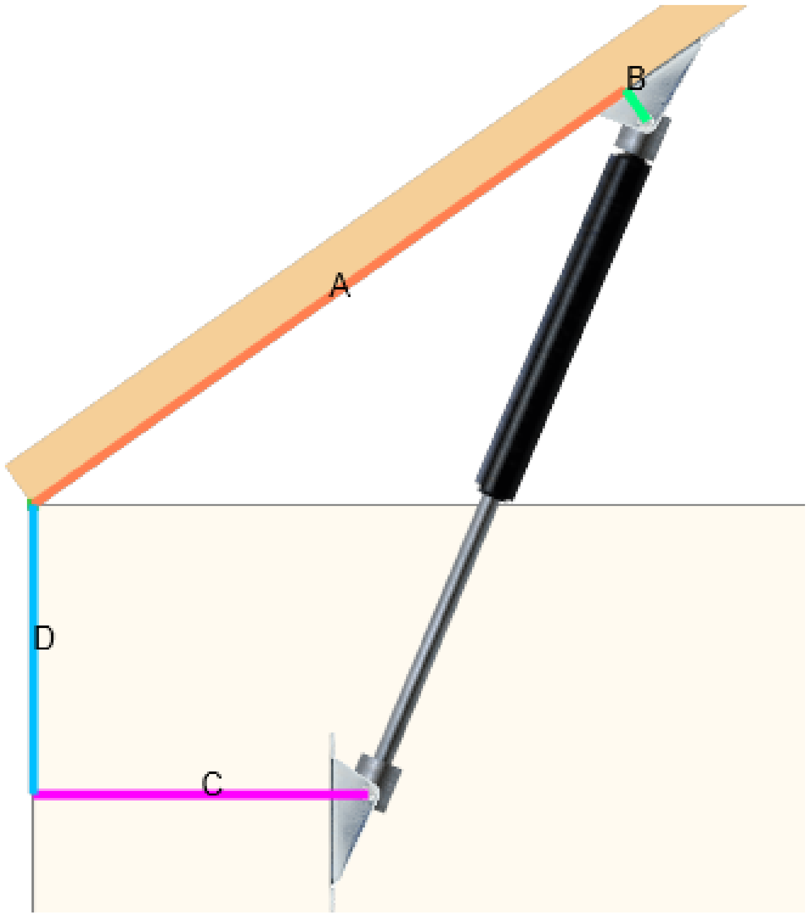
Sluit de voeding aan:

(1) Controleer de voedingsaanpassingen.
(2) Controleer de werking van de handmatige ontkoppeling.
(3) Controleer de werking van de fotocellen of andere beveiligingsapparatuur.

Gas Spring Force Requirements and Selection

Montagetekening © www.gasveerwinkel.nl

https://www.gasveerwinkel.nl/gasveer_berekenen/



A = 380 mm; B = 20 mm; C = 176 mm; D = 152 mm

Montagehandleiding van www.gasveerwinkel.nl

Probeer de gasveer voor het monteren niet met de hand in te drukken. De gasveer kan hierdoor beschadigen en vaak is de kracht die hier voor nodig is te groot.
1) Monteer eerst het bevestigingsdeel aan de vaste wereld volgens de maten C & D vanaf het scharnier.
2) Bevestig de gasveer aan dit bevestigingsdeel. Monteer de gasveer zo, dat tijdens gemiddeld gebruik de stang zo vaak mogelijk naar beneden wijst.
3) Bevestig het bevestigingsdeel aan de andere kant van de gasveer.
4) Positioneer de klep in de open stand. Beweeg het bevestigingsdeel langs de klep zodat de maten A & B vanaf het scharnier bereikt worden.
5) Controleer of de gewenste en in de berekening gebruikte openingshoek is bereikt.
6) Als dit het geval is, monteer dan ook het bevestigingsdeel aan de klep volgens de maten A & B vanaf het scharnier.
7) Doe de klep nu voorzichtig dicht. De eerste keer kan dit extra zwaar gaan omdat de gasveren dan een beetje vastgekleefd zitten.
Als het goed is gedraagt de klep zich nu ongeveer zoals in de simulatie op de website!
Als de klep zich niet als verwacht gedraagt, controleer dan de maten A, B, C en D en controleer bij een afwijking hiervan stap 1-7.

Appendix

Specifications

Aircraft	
Structure	
Diagonal Wheelbase	1133 mm
Dimensions	1668 mm×1518 mm×759 mm (with propellers, frame arms and GPS mount unfolded) 640 mm×582 mm×623 mm (with propellers, frame arms and GPS mount folded)
Package Dimensions	620 mm×320 mm×505 mm
Intelligent Flight Battery Quantity	6
Weight (with six TB47S batteries)	9.1 kg
Weight (with six TB48S batteries)	9.6 kg
Max Takeoff Weight	15.1 kg
Performance	
Hovering Accuracy (P-mode with GPS)	Vertical: ±0.5 m, Horizontal: ±1.5 m
Max Angular Velocity	Pitch: 300°/s, Yaw: 150°/s
Max Pitch Angle	25°
Max Speed of Ascent	5 m/s
Max Speed of Descent	3 m/s
Max Wind Resistance	8 m/s
Max Service Ceiling Above Sea Level	2500 m
Max Speed	18 m/s (No wind)
Hovering Time* (with six TB47S batteries)	No payload: 35 min, 6 kg payload: 16 min
Hovering Time* (with six TB48S batteries)	No payload: 40 min, 5.5 kg payload: 18 min
Propulsion System	
Motor Model	DJI 6010
Propeller Model	DJI 2170
Flight Control System	
Model	A3
Other	
Supported DJI Gimbals	Zenmuse X3, Zenmuse X5, Zenmuse XT; Zenmuse Z15 Series HD Gimbal: Z15-A7, Z15-BMPCC, Z15-5D III, Z15-GH4; Ronin-MX
Retractable Landing Gear	Standard
Operating Temperature	14° to 104° F (-10° to 40° C)

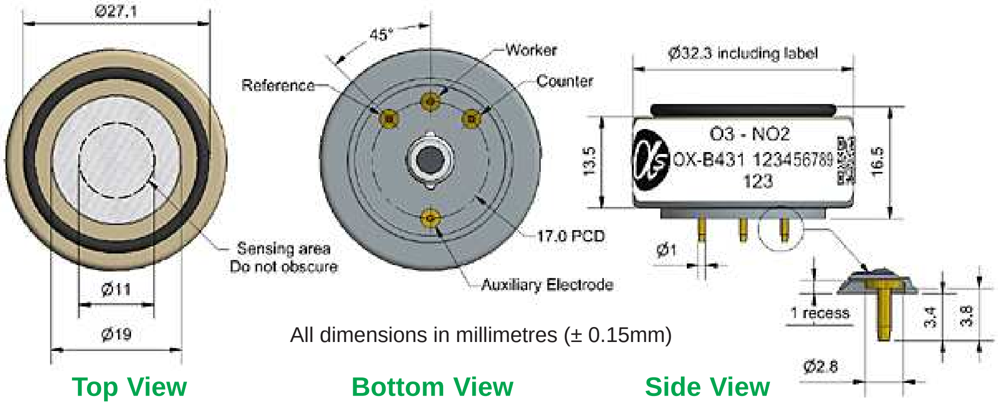
* The hovering time is based on flying at 10m above sea level in a no-wind environment and landing with 10% battery level.

Technical Specification

OX-B431 Oxidising Gas Sensor
Ozone + Nitrogen Dioxide
4-Electrode

Patented

Figure 1 OX-B431 Schematic Diagram



Specification O_3 Sensing

PERFORMANCE			
	Sensitivity	nA/ppm at 1ppm O_3	-225 to -650
	Response time	t_{90} (s) from zero to 1ppm O_3	< 45
	Zero current	nA in zero air at 20°C	-50 to 70
	Noise*	±2 standard deviations (ppb equivalent)	15
	Range	ppm O_3 limit of performance warranty	20
	Linearity	ppm error at full scale, linear at zero and 20ppm O_3	< ±0.5
	Overgas limit	maximum ppm for stable response to gas pulse	50

*** Tested with Alphasense AFE low noise circuit**

LIFETIME	Zero drift	ppb equivalent change/year in lab air	0 to 20
	Sensitivity drift	% change/year in lab air, monthly test	< -20 to -40
	Operating life	months until 50% original signal (24 month warranted)	> 24

ENVIRONMENTAL			
	Sensitivity @ -20°C	(% output @ -20°C/output @ 20°C) @ 2ppm O_3	70 to 90
	Sensitivity @ 40°C	(% output @ 40°C/output @ 20°C) @ 2ppm O_3	95 to 125
	Zero @ -20°C	nA	0 to 25
	Zero @ 40°C	nA	5 to 100

CROSS SENSITIVITY	H_2S	sensitivity % measured gas	@	5ppm	H_2S	< 170
	NO	sensitivity % measured gas	@	5ppm	NO	< 5
	Cl_2	sensitivity % measured gas	@	5ppm	Cl_2	< 90
	SO_2	sensitivity % measured gas	@	5ppm	SO_2	< -7
	CO	sensitivity % measured gas	@	5ppm	CO	< 0.1
	C_2H_4	sensitivity % measured gas	@	100ppm	C_2H_4	< 0.1
	NH_3	sensitivity % measured gas	@	20ppm	NH_3	< 0.1
	H_2	sensitivity % measured gas	@	100ppm	H_2	< 0.1
	CO_2	sensitivity % measured gas	@	5% Vol	CO_2	0.1
	Halothane	sensitivity % measured gas	@	100ppm	Halothane	< 0.1

KEY SPECIFICATIONS			
	Temperature range	°C	-30 to 40
	Pressure range	kPa	80 to 120
	Humidity range	% rh continuous	15 to 85
	Storage period	months @ 3 to 20°C (stored in sealed pot)	6
	Load resistor	Ω (AFE circuit recommended)	33 to 100
	Weight	g	< 13

NOTE: all sensors are tested at ambient environmental conditions, with 47 ohm load resistor, unless otherwise stated. As applications of use are outside our control, the information provided is given without legal responsibility. Customers should test under their own conditions, to ensure that the sensors are suitable for their own requirements.

Technical Specification

OX-B431 Performance Data

Figure 2 Sensitivity temperature dependence to 1ppm O_3

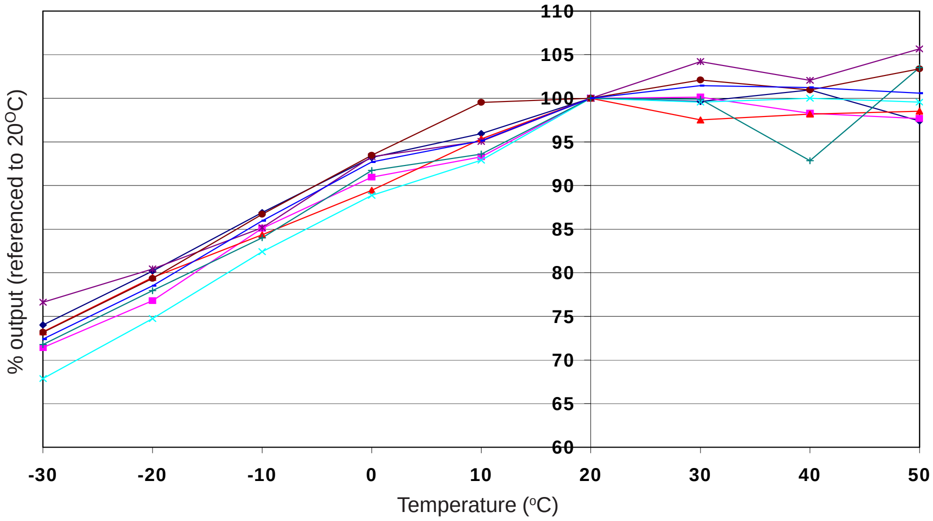


Figure 2 shows the temperature dependence of sensitivity at 1ppm O_3.

This data is taken from a typical batch of sensors.

Figure 3 Zero temperature dependence

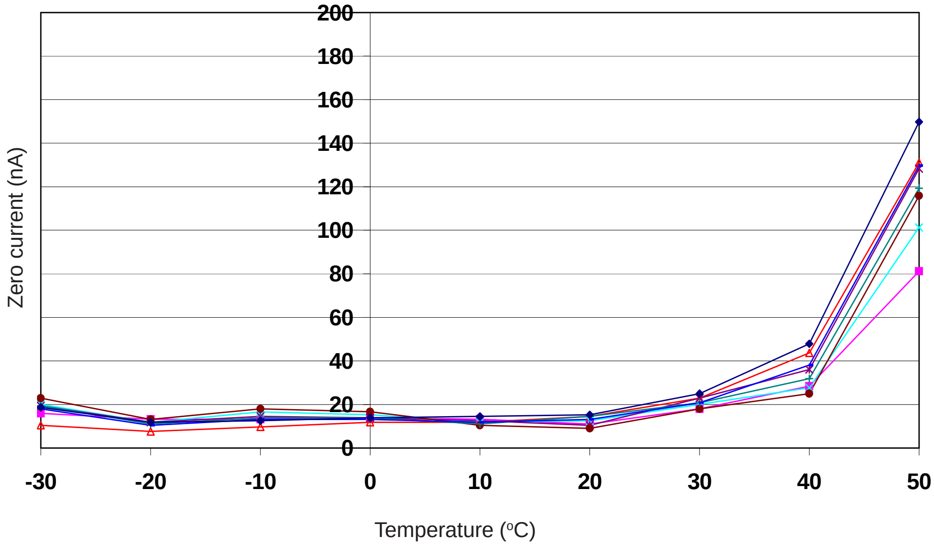


Figure 3 shows the variation in zero output of the working electrode caused by changes in temperature, expressed as nA.

This data is taken from a typical batch of sensors.

Contact Alphasense for futher information on zero current correction.

Figure 4 Response from 200 ppb to 0 ppb O_3

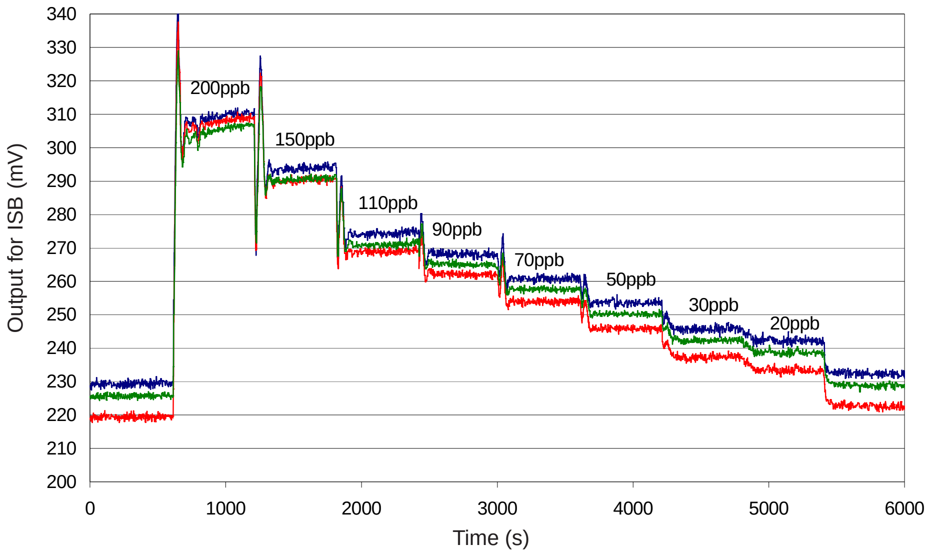


Figure 4 shows response from 200ppb O_3 to 0ppb O_3.

Use of Alphasense AFE circuit reduces noise to 15ppb, with the opportunity of digital smooting to reduce noise even further.

Offset voltage is due to intentional ISB circuit electronic offset.

Technical Specification

OX-B431 Oxidising Gas Sensor
Ozone + Nitrogen Dioxide
4-Electrode

Patented

The OX-B431 detects both ozone and nitrogen dioxide (O_3 +NO_2). The NO2-B43F measures only nitrogen dioxide, filtering out ozone. Using these sensors together allows you to calculate the O_3 concentration by subtracting the corrected NO2-B43F concentration from the corrected OX-B431 concentration.

Before subtracting to determine ozone concentration, ensure that the signals from the two sensors have been corrected for electronic zero offset, sensor zero offset and temperature dependence, and sensitivity (nA/ppm) calibration and temperature dependence.

Specification NO_2 Sensing

PERFORMANCE			
	Sensitivity to NO_2	nA/ppm at 2ppm NO_2	-250 to -650
	Response time	t_{90} (s) from zero to 2ppm NO_2	< 35
	Zero current	nA in zero air at 20°C	-50 to +70
	Noise*	±2 standard deviations (ppb equivalent)	15
	Range	ppm NO_2 limit of performance warranty	20
	Linearity	ppm error at full scale, linear at zero and 20ppm NO_2	< ±0.5
	Overgas limit	maximum ppm for stable response to gas pulse	50
	*** Tested with Alphasense AFE low noise circuit**		
LIFETIME	Zero drift	ppb equivalent change/year in lab air	0 to 20
	Sensitivity drift	% change/year in lab air, monthly test	< -20 to -40
	Operating life	months until 50% original signal (24 month warranted)	> 24
ENVIRONMENTAL			
	Sensitivity @ -20°C	(% output @ -20°C/output @ 20°C) @ 2ppm NO_2	70 to 90
	Sensitivity @ 40°C	(% output @ 50°C/output @ 20°C) @ 2ppm NO_2	95 to 110
	Zero @ -20°C	nA	0 to 25
	Zero @ 40°C	nA	5 to 50

CROSS SENSITIVITY	H_2S	sensitivity % measured gas	@	5ppm	H_2S	< 170
	NO	sensitivity % measured gas	@	5ppm	NO	< 5
	Cl_2	sensitivity % measured gas	@	5ppm	Cl_2	< 90
	SO_2	sensitivity % measured gas	@	5ppm	SO_2	< -7
	CO	sensitivity % measured gas	@	5ppm	CO	< 0.1
	C_2H_4	sensitivity % measured gas	@	100ppm	C_2H_4	< 0.1
	NH_3	sensitivity % measured gas	@	20ppm	NH_3	< 0.1
	H_2	sensitivity % measured gas	@	100ppm	H_2	< 0.1
	CO_2	sensitivity % measured gas	@	5% Vol	CO_2	0.1
	Halothane	sensitivity % measured gas	@	100ppm	Halothane	< 0.1

KEY SPECIFICATIONS			
	Temperature range	°C	-30 to 40
	Pressure range	kPa	80 to 120
	Humidity range	% rh continuous	15 to 85
			< 13

At the end of the product's life, do not dispose of any electronic sensor, component or instrument in the domestic waste, but contact the instrument manufacturer, Alphasense or its distributor for disposal instructions.

NOTE: all sensors are tested at ambient environmental conditions, with 47 ohm load resistor, unless otherwise stated. As applications of use are outside our control, the information provided is given without legal responsibility. Customers should test under their own conditions, to ensure that the sensors are suitable for their own requirements.

Alphasense Ltd, Sensor Technology House, 300 Avenue West, Skyline 120, Great Notley. CM77 7AA. UK
Telephone: +44 (0) 1376 556 700 Fax: +44 (0) 1376 335 899 E-mail: sensors@alphasense.com Website: www.alphasense.com

Technical Specification

OX-B431 Performance Data

Figure 5 Sensitivity temperature dependence to 2ppm NO_2

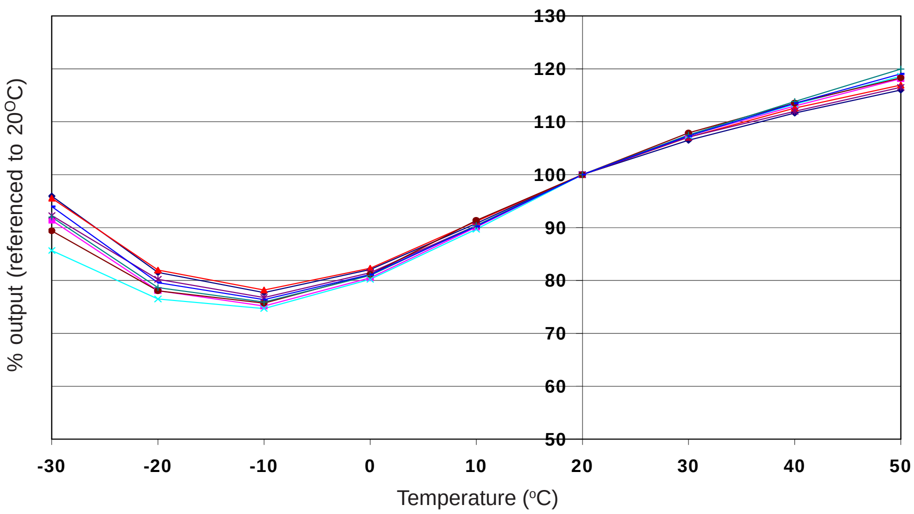


Figure 5 shows the temperature dependence of sensitivity at 2ppm NO_2.

This data is taken from a typical batch of sensors.

Figure 6 Response to 50ppb NO_2

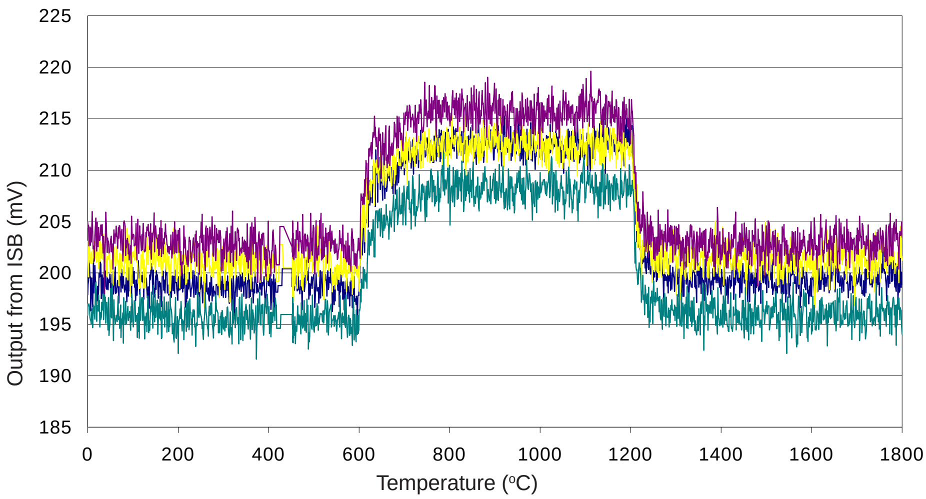


Figure 6 shows the fast response and good baseline recovery of the OX-B431 to 50ppb NO_2.

Figure 7 Response from 200 ppb to 0 ppb NO_2

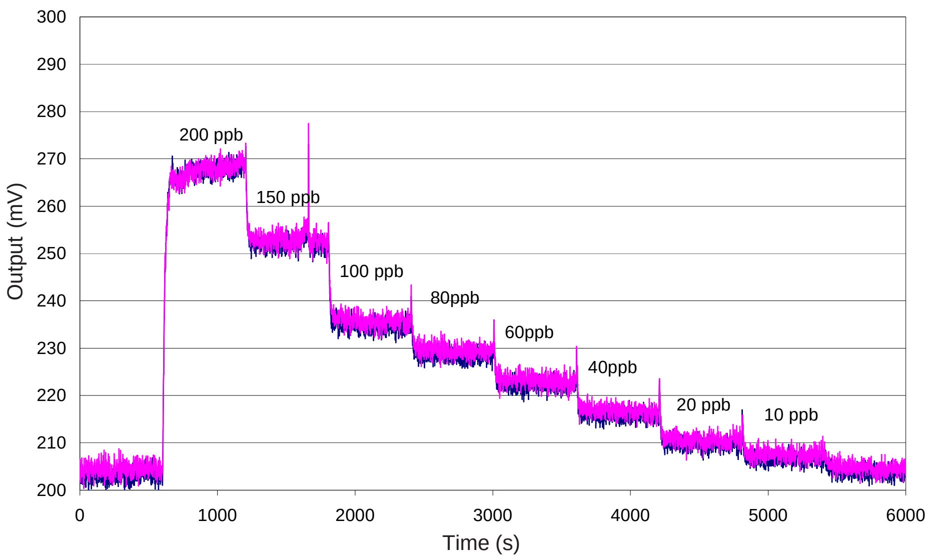


Figure 7 shows response from 200ppb NO_2 to 0ppb NO_2.

Use of Alphasense AFE circuit reduces noise to 15ppb, with the opportunity of digital smooting to reduce noise to less than ± 5ppb.

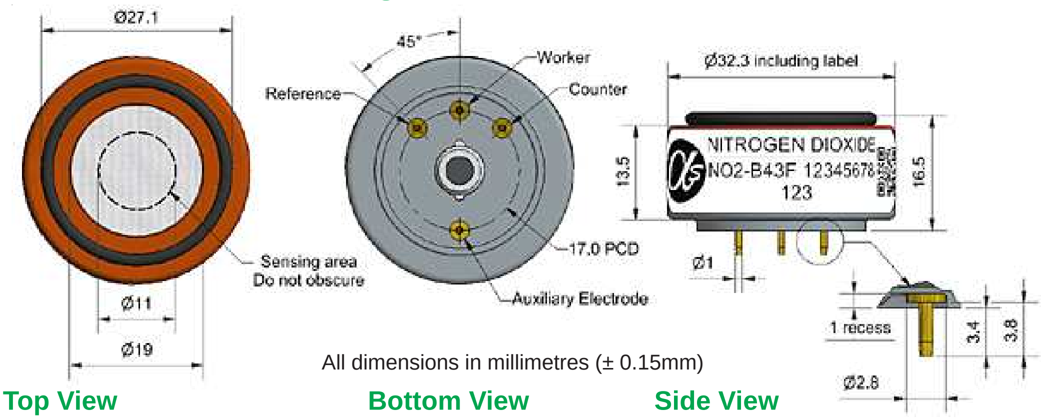
Offset voltage is due to intentional ISB circuit electronic offset.

For further information on the performance of this sensor, on other sensors in the range or any other subject, please contact Alphasense Ltd. For Application Notes visit "www.alphasense.com".

Technical Specification

NO2-B43F Nitrogen Dioxide Sensor
4-Electrode

Figure 1 NO2-B43F Schematic Diagram



PERFORMANCE

Sensitivity	nA/ppm at 2ppm NO_2	-200 to -650
Response time	t_{90} (s) from zero to 2ppm NO_2	< 60
Zero current	nA in zero air at 20°C	< 70
Noise*	±2 standard deviations (ppb equivalent)	15
Range	ppm NO_2 limit of performance warranty	20
Linearity	ppb error at full scale, linear at zero and 20ppm NO_2	< ±0.5
Overgas limit	maximum ppm for stable response to gas pulse	50

*** Tested with Alphasense ISB low noise circuit**

LIFETIME

Zero drift	ppb equivalent change/year in lab air	0 to 20
Sensitivity drift	% change/year in lab air, monthly test	-20 to -40
Operating life	months until 50% original signal (24 month warranted)	> 24

ENVIRONMENTAL

Sensitivity @ -20°C	(% output @ -20°C/output @ 20°C) @ 2ppm NO_2	60 to 80
Sensitivity @ 40°C	(% output @ 40°C/output @ 20°C) @ 2ppm NO_2	95 to 115
Zero @ -20°C	nA	0 to 25
Zero @ 40°C	nA	-10 to 50

CROSS SENSITIVITY

O_3	Filter capacity (ppm.hr)	@	0.5ppm	O_3	> 500
H_2S	sensitivity % measured gas	@	5ppm	H_2S	< -80
NO	sensitivity % measured gas	@	5ppm	NO	< 5
Cl_2	sensitivity % measured gas	@	5ppm	Cl_2	< 65
SO_2	sensitivity % measured gas	@	5ppm	SO_2	< 1
CO	sensitivity % measured gas	@	5ppm	CO	< 3
H_2	sensitivity % measured gas	@	100ppm	H_2	< 0.1
C_2H_4	sensitivity % measured gas	@	100ppm	C_2H_4	< 0.1
NH_3	sensitivity % measured gas	@	20ppm	NH_3	< 0.1
CO_2	sensitivity % measured gas	@	5% Vol	CO_2	< 0.1
Halothane	sensitivity % measured gas	@	100ppm	Halothane	nd

KEY SPECIFICATIONS

Temperature range	°C	-30 to 40
Pressure range	kPa	80 to 120
Humidity range	% rh continuous	15 to 85
Storage period	months @ 3 to 20°C (stored in sealed pot)	6
Load resistor	Ω (ISB circuit is recommended)	33 to 100
Weight	g	< 13

At the end of the product's life, do not dispose of any electronic sensor, component or instrument in the domestic waste, but contact the instrument manufacturer, Alphasense or its distributor for disposal instructions.

NOTE: all sensors are tested at ambient environmental conditions, with 47 ohm load resistor, unless otherwise stated. As applications of use are outside our control, the information provided is given without legal responsibility. Customers should test under their own conditions, to ensure that the sensors are suitable for their own requirements.

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Telephone: +44 (0) 1376 556 700 Fax: +44 (0) 1376 335 899 E-mail: sensors@alphasense.com Website: www.alphasense.com

Technical Specification

NO2-B43F Performance Data

Figure 2 Sensitivity Temperature Dependence

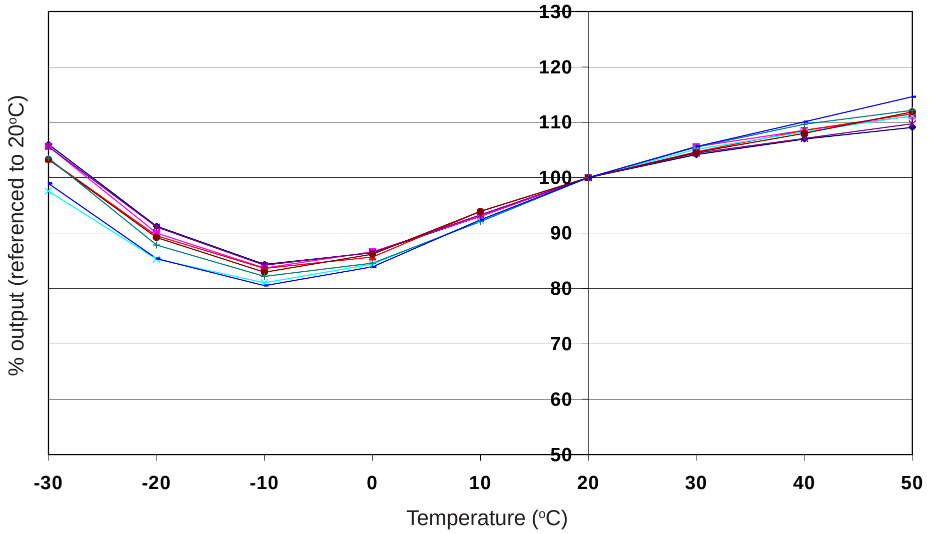


Figure 2 shows the temperature dependence of sensitivity at 2ppm NO_2.

This data is taken from a typical batch of sensors.

Figure 3 Zero Temperature Dependence

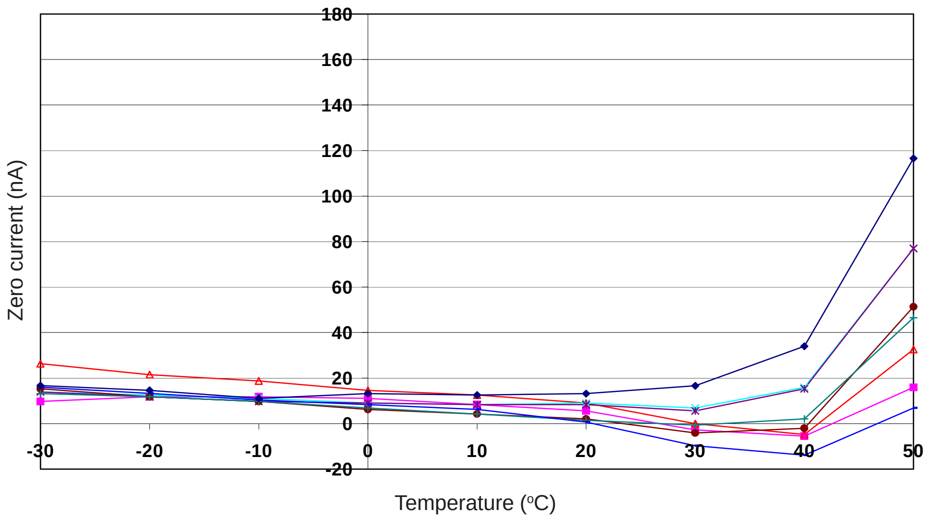
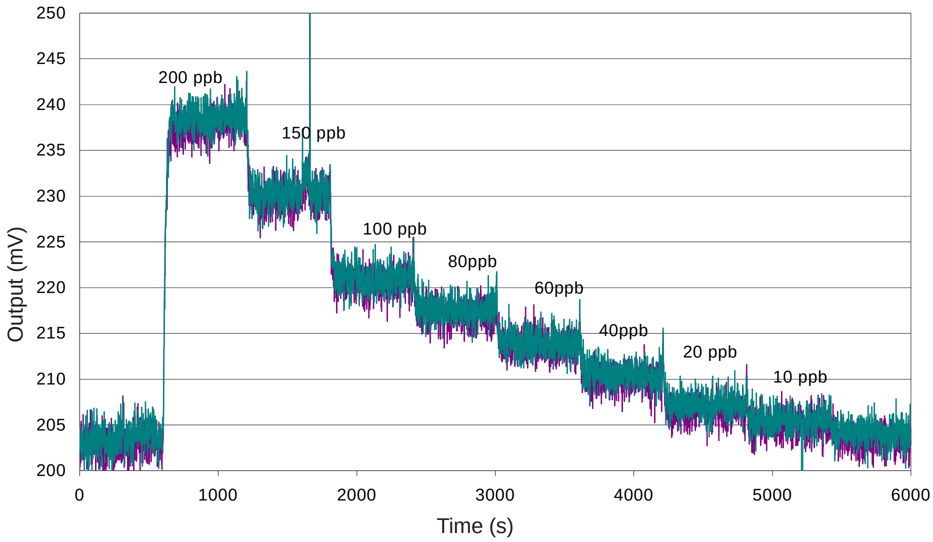


Figure 3 shows the variation in zero output of the working electrode caused by changes in temperature, expressed as nA.

This data is taken from a typical batch of sensors.

Contact Alphasense for futher information on zero current correction.

Figure 4 Response to 200 ppb NO_2



With a 33 Ω load resistor, the NO2-B43F shows excellent resolution, even at the ppb level: ideal for outdoor air environmental testing.

Use of Alphasense ISB circuit reduces noise to 15ppb, with the opportunity of digital smoothing to reduce noise even further.

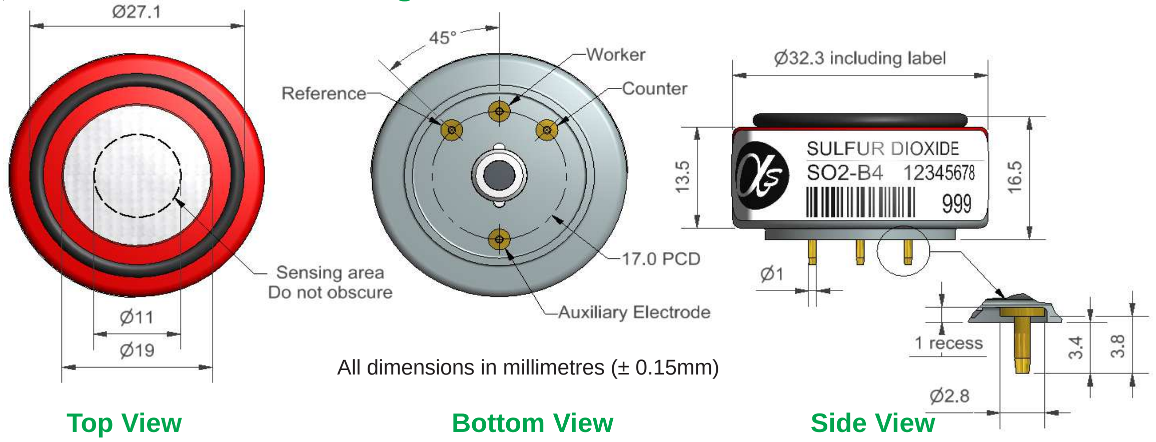
Offset voltage is due to intentional ISB circuit electronic offset.

For further information on the performance of this sensor, on other sensors in the range or any other subject, please contact Alphasense Ltd. For Application Notes visit "www.alphasense.com".

Technical Specification

SO2-B4 Sulfur Dioxide Sensor
4-Electrode

Figure 1 SO2-B4 Schematic Diagram



PERFORMANCE	Sensitivity	nA/ppm at 2ppm SO_2	275 to 475
	Response time	t_{90} (s) from zero to 2ppm SO_2	< 40
	Zero current	nA in zero air at 20°C	-80 to +80
	Noise*	±2 standard deviations (ppb equivalent)	5
	Range	ppm limit of performance warranty	100
	Linearity	ppb error at 100ppm SO_2, linear at zero and 10ppm SO_2	0 to -2
	Overgas limit	maximum ppm for stable response to gas pulse	200

*** Tested with Alphasense ISB low noise circuit**

LIFETIME	Zero drift	ppb equivalent change/year in lab air	< ±20
	Sensitivity drift	% change/year in lab air, monthly test	< ±15
	Operating life	months until 50% original signal (24 month warranted)	> 36

ENVIRONMENTAL	Sensitivity @ -20°C	(% output @ -20°C/output @ 20°C) @ 2ppm SO_2	75 to 90
	Sensitivity @ 50°C	(% output @ 50°C/output @ 20°C) @ 2ppm SO_2	95 to 110
	Zero @ -20°C	nA change from 20°C	0 to -10
	Zero @ 50°C	nA change from 20°C	10 to 30

CROSS SENSITIVITY	Filter capacity	ppm·hrs				450
	H_2S sensitivity	% measured gas	@	5ppm	H_2S	< 2
	NO_2 sensitivity	% measured gas	@	5ppm	NO_2	< -160
	Cl_2 sensitivity	% measured gas	@	5ppm	Cl_2	< -40
	NO sensitivity	% measured gas	@	5ppm	NO	< -2
	CO sensitivity	% measured gas	@	5ppm	CO	< 2
	H_2 sensitivity	% measured gas	@	100ppm	H_2	< 0.5
	C_2H_4 sensitivity	% measured gas	@	100ppm	C_2H_4	< 1
	NH_3 sensitivity	% measured gas	@	20ppm	NH_3	< 0.1
	CO_2 sensitivity	% measured gas	@	5%	CO_2	< 0.1

KEY SPECIFICATIONS	Temperature range	°C	-30 to 50
	Pressure range	kPa	80 to 120
	Humidity range	% rh continuous (see note below)	15 to 90
	Storage period	months @ 3 to 20°C (stored in sealed pot)	6
	Load Resistor	Ω (ISB circuit is recommended)	33 to 100
	Weight	g	< 13

Note: Above 85% rh and 40°C a maximum continuous exposure period of 10 days is warranted. Where such exposure occurs the sensor will recover normal electrolyte volumes when allowed to rest at lower % rh and temperature levels for several days.

At the end of the product's life, do not dispose of any electronic sensor, component or instrument in the domestic waste, but contact the instrument manufacturer, Alphasense or its distributor for disposal instructions.

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Telephone: +44 (0) 1376 556 700 Fax: +44 (0) 1376 335 899 E-mail: sensors@alphasense.com Website: www.alphasense.com

Technical Specification

SO2-B4 Perfomance Data

Figure 2 Sensitivity Temperature Dependence

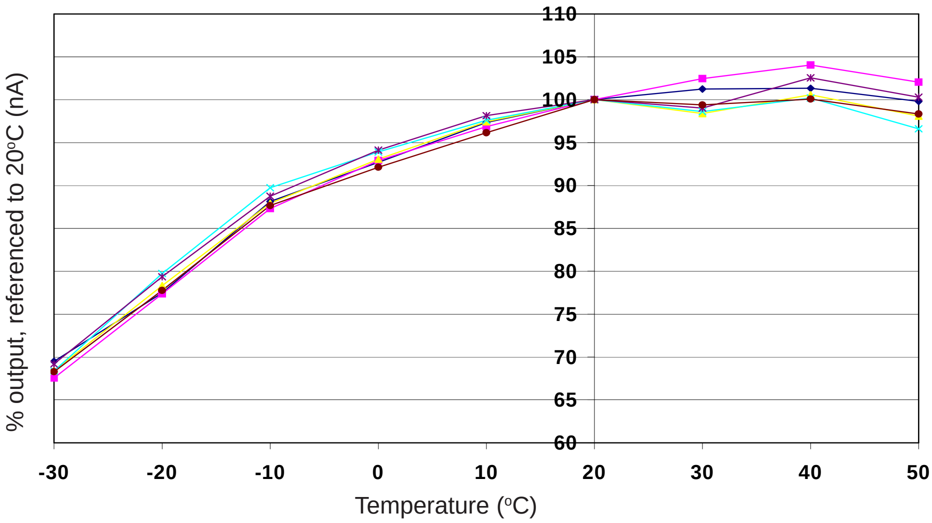


Figure 2 shows the temperature dependence of sensitivity at 2ppm SO_2.

This data is taken from a typical batch of sensors.

Figure 3 Zero Temperature Dependence

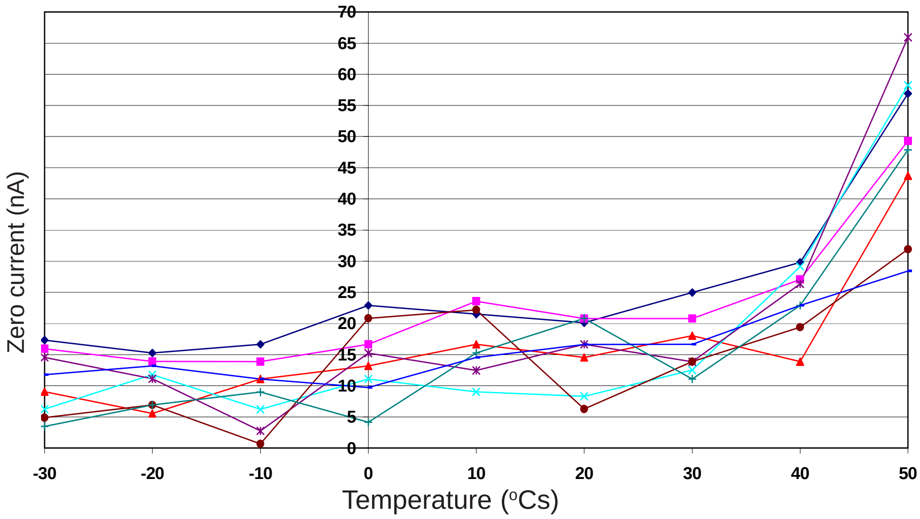


Figure 3 shows the variation in zero output of the working electrode caused by changes in temperature, expressed as nA.

This data is taken from a typical batch of sensors.

Contact Alphasense for futher information on zero current correction.

Figure 4 Response to 200ppb SO_2

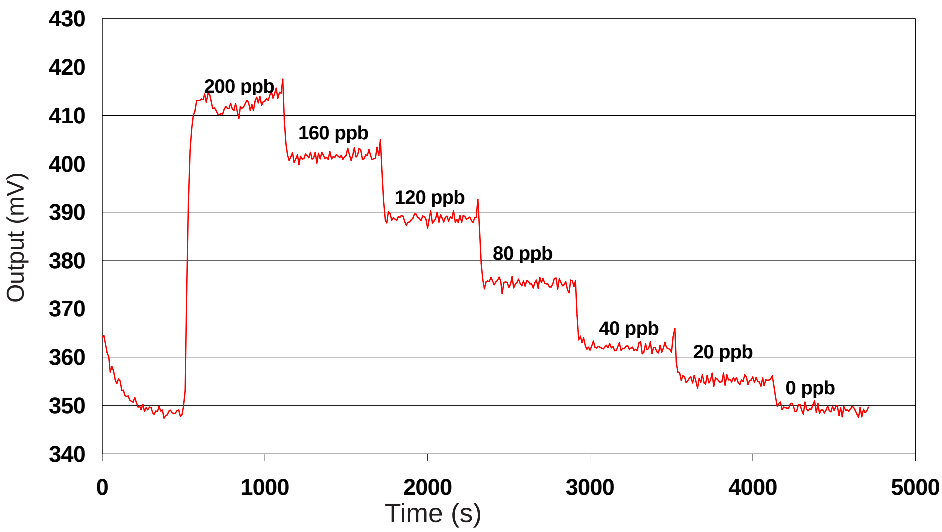


Figure 4 shows response from 20 to 200ppb SO_2.

Use of Alphasense ISB circuit reduces noise to 5ppb, with the opportunity of digital smooting to reduce noise even further.

For further information on the performance of this sensor, on other sensors in the range or any other subject, please contact Alphasense Ltd. For Application Notes visit "www.alphasense.com".

Digital universal particle concentration sensor

PMS5003 series data manual

Writer	Zhou Yong	Version	V2.3
Verifier	Zheng Haoxin	Date	2016-06-01

Main characteristics

- Zero false alarm rate
- Real-time response
- Correct data
- Minimum distinguishable particle diameter :0.3 micrometer
- High anti-interference performance because of the patent structure of six sides shielding
- Optional direction of air inlet and outlet in order to adapt the different design

Overview

PMS5003 is a kind of digital and universal particle concentration sensor, which can be used to obtain the number of suspended particles in the air, i.e. the concentration of particles, and output them in the form of digital interface. This sensor can be inserted into variable instruments related to the concentration of suspended particles in the air or other environmental improvement equipments to provide correct concentration data in time.

Working principle

Laser scattering principle is used for such sensor, i.e. produce scattering by using laser to radiate suspending particles in the air, then collect scattering light in a certain degree, and finally obtain the curve of scattering light change with time. In the end, equivalent particle diameter and the number of particles with different diameter per unit volume can be calculated by microprocessor based on MIE theory. Please find the functional diagram of each part of sensor from Figure 1 as follows.

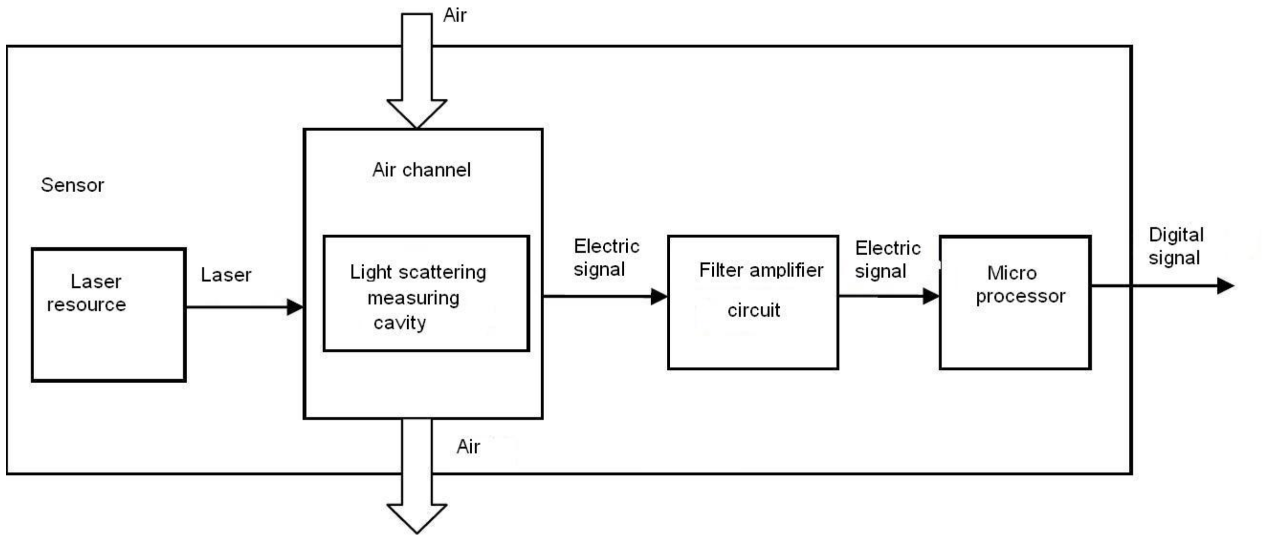


Figure 1 Functional block diagram of sensor

Technical Index

Parameter	Index	unit
Range of measurement	0.3~1.0；1.0~2.5；2.5~10	Micrometer（μ m）
Counting Efficiency	50%@0.3μ m 98%@>=0.5μ m	
Effective Range（PM2.5 standard）	0~500	μ g/m³
Maximum Range（PM2.5 standard）*	≥1000	μ g/m³
Resolution	1	μ g/m³
Maximum Consistency Error (PM2.5 standard data)*	±10%@100~500μ g/m³ ±10μ g/m³ @0~100μ g/m³	
Standard Volume	0.1	Litre（L）
Single Response Time	＜1	Second（s）
Total Response Time	≤10	Second（s）
DC Power Supply	Typ:5.0 Min:4.5 Max: 5.5	Volt（V）
Active Current	≤100	Milliampere（mA）
Standby Current	≤200	Microampere（μ A）
Interface Level	L <0.8 @3.3 H >2.7@3.3	Volt（V）
Working Temperature Range	-10~+60	℃
Working Humidity Range	0~99%	
Storage Temperature Range	-40~+80	℃
MTTF	≥3	Year（Y）
Physical Size	50×38×21	Millimeter（mm）

Note 1: Maximum range means that the highest output value of the PM2.5 standard data is not less than 1000.
Note 2:"PM2.5 standard data" is the "data2" in the appendix.

Pin Definition

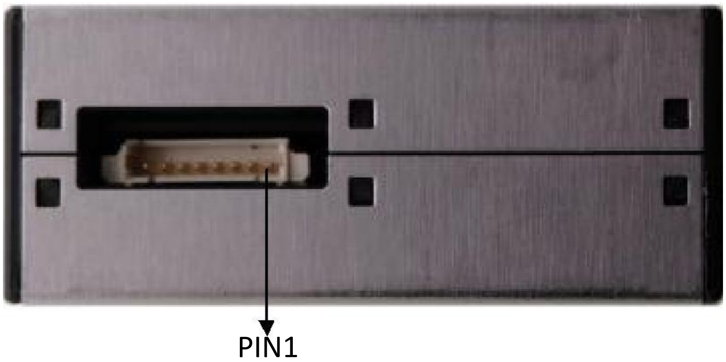


Figure 2 Connector Definition

PIN1	VCC	Positive power 5V
PIN2	GND	Negative power
PIN3	SET	Set pin /TTL level@3.3V，high level or suspending is normal working status, while low level is sleeping mode.
PIN4	RX	Serial port receiving pin/TTL level@3.3V
PIN5	TX	Serial port sending pin/TTL level@3.3V
PIN6	RESET	Module reset signal /TTL level@3.3V，low reset.
PIN7/8	NC	

Output result

Mainly output as the quality and number of each particles with different size per unit volume, the unit volume of particle number is 0.1L and the unit of mass concentration is μ g/m³ .

There are two options for digital output: passive and active. Default mode is active after power up. In this mode sensor would send serial data to the host automatically .The active mode is divided into two sub-modes: stable mode and fast mode. If the concentration change is small the sensor would run at stable mode with the real interval of 2.3s.And if the change is big the sensor would be changed to fast mode automatically with the interval of 200~800ms, the higher of the concentration, the shorter of the interval.

Typical Circuit

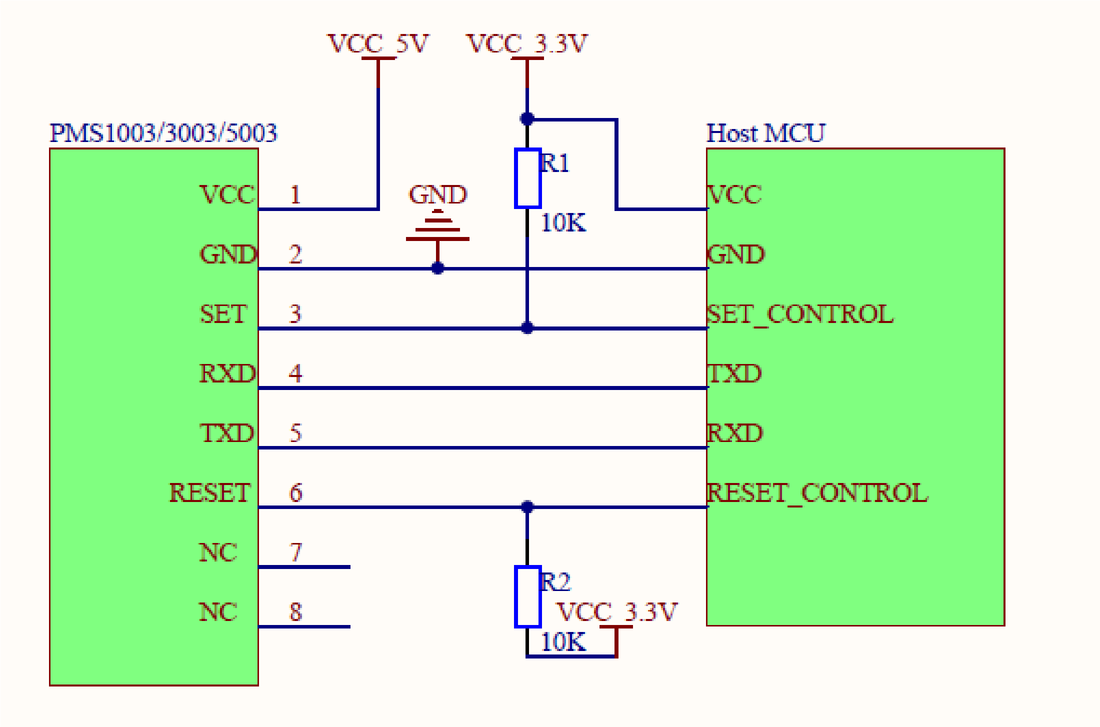


Figure 3 Typical Circuit

Typical Output Characteristic

Definition of axis Y: PM2.5 concentration , unit: μ g/m³

Definition of axis X: number of samples, unit: time

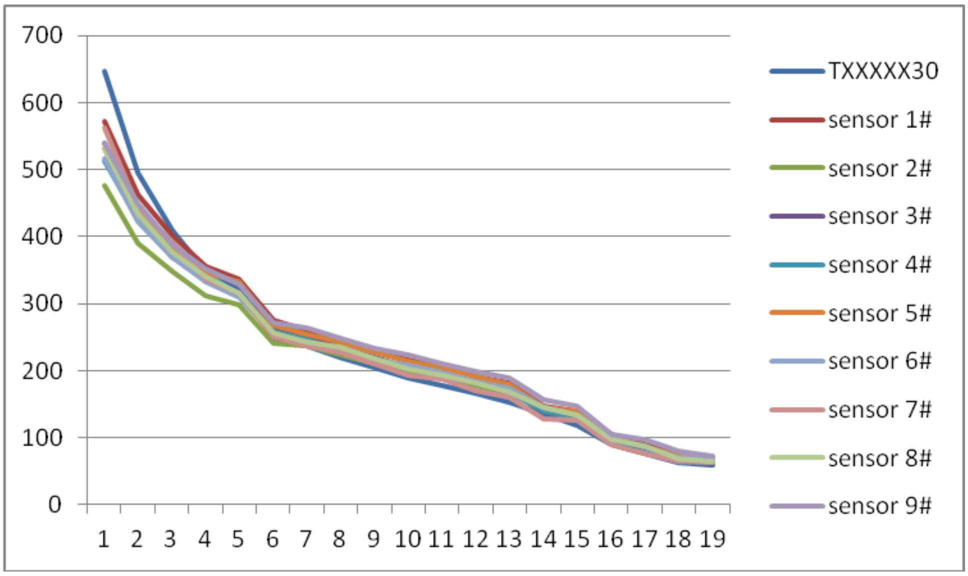


Figure 4-1 Consistency at 20℃

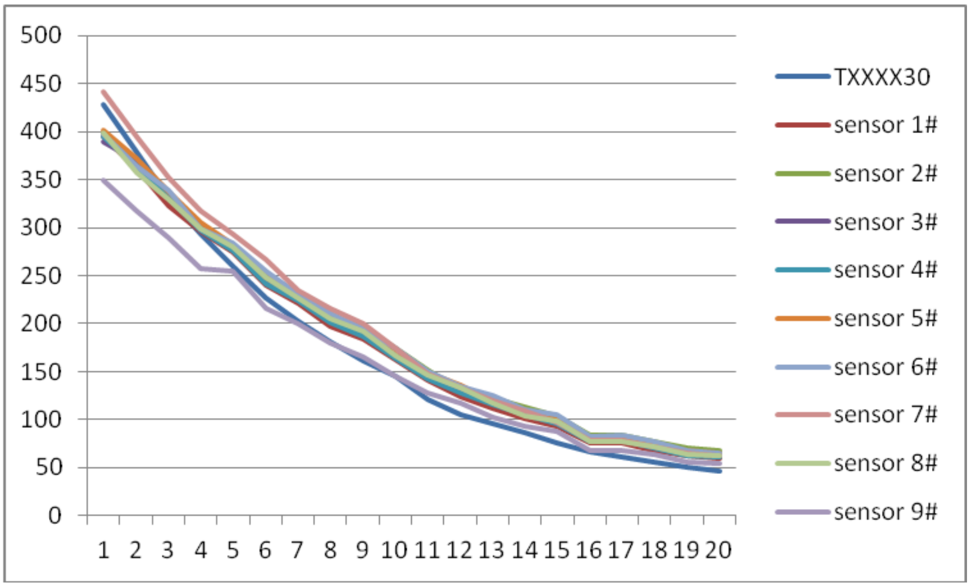


Figure 4-2 Consistency at 43℃

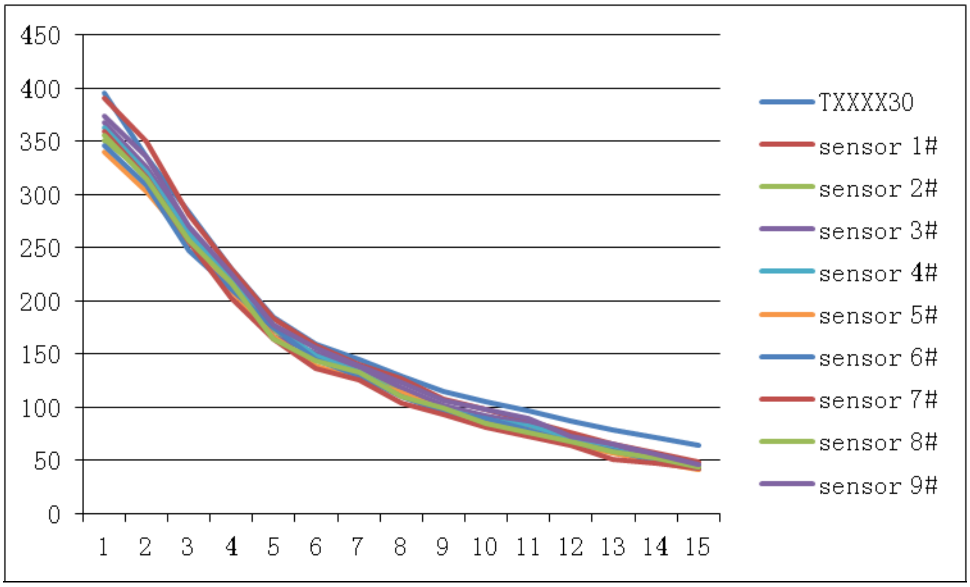


Figure 4-3 Consistency at -5℃

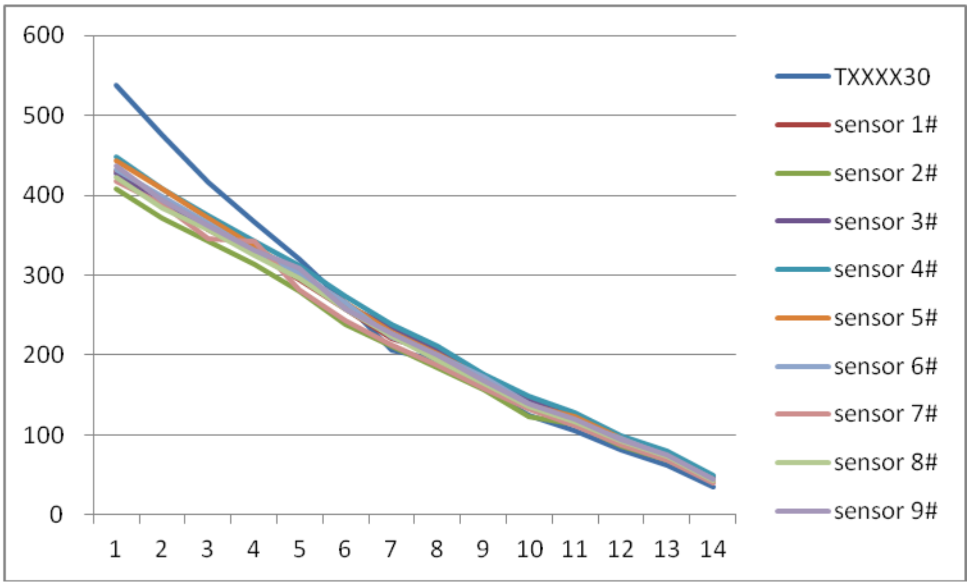


Figure 4-4 Consistency after 30 days' running

Relationship of Temperature and Consistency

Definition of axis Y: Maximum Error Modulus(%)

Definition of axis X: Temperature(℃)

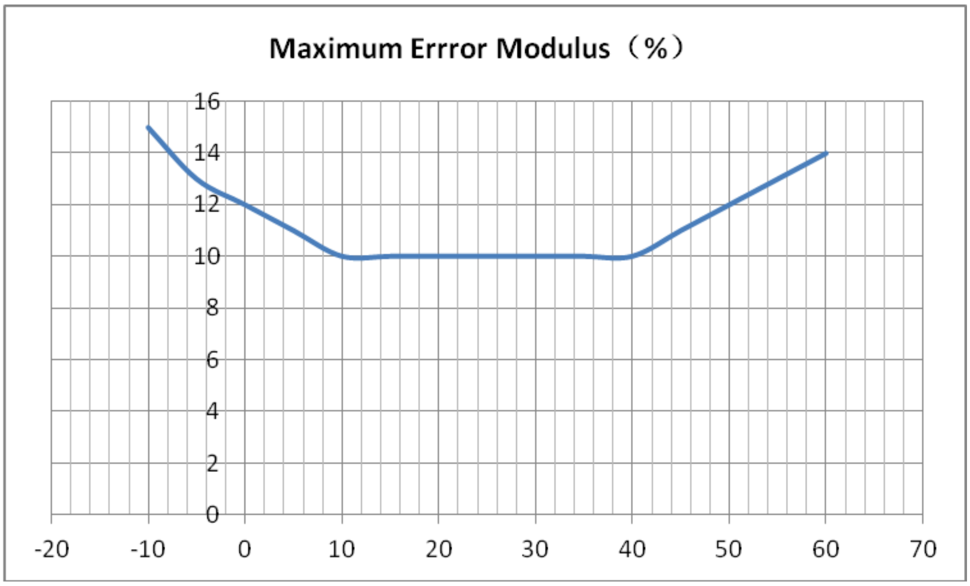


Figure 5 Consistency Vs Temperature

Endurance Characteristics

No	Item	Test Method	Characteristics	n C
1	Long Running	1. 10 ㎡ closed Lab,，20~25℃，humidity 30%~70%，particle generator and air cleaner 2. DC 5V power supply 3. Check consistency after 720 hours' running	10 samples during 0~500μ g/m^3 0~100μ g/m^3 Maximum Error≤ ±15μ g/m^3 100~500μ g/m^3 Maximum Error≤ ±15% FAN does not screeched	n=30 C=0
2	High Temperature Operation	1. 10 ㎡ constant temperature Lab 2. 43℃，humidity 70%， 3. particle generator and air cleaner 4. DC 5V power supply 5. Check consistency		n=10 C=0
3	Cold Operation	1. 10 ㎡ constant temperature Lab 2. -5℃，humidity 30%， 3. particle generator and air cleaner 4. DC 5V power supply 5. Check consistency		n=10 C=0
4	Vibration	1. 10 ㎡ closed Lab,，20℃，humidity 50%，particle generator and air cleaner 2. DC 5V power supply and check consistency 3. Frequency：50Hz。 4. acceleration：9.8/ S^2 。 5. Direction：X、Y、Z 6. Vibration Amplitude：±2mm。 7. Time：X、Y、Z –way, Per 1 hour		n=5 C=0
5	High Temperature and Humidity Storage	1. Constant temperature cabinet 2. 70℃，humidity 90%~95， 3. Check consistency after 500 hours' storage	10 samples during 0~500μ g/m^3 0~100μ g/m^3 Maximum Error≤ ±10μ g/m^3 100~500μ g/m^3 Maximum Error≤ ±10%	n=10 C=0
6	Cold Storage	1. Constant temperature cabinet 2. -30℃，humidity 90%~95， 3. Check consistency after 500 hours' storage		n=10 C=0
7	Variation of	4. 10 ㎡ closed Lab,，20℃，humidity		n=5

	Power Supply	50%， particle generator and air cleaner 5. Power varies as the cycles of 4.5V to 5.5V ,then 5.5V to 4.5V with the pace of 0.1V/min for 2 hours. 6. Check consistency during Variation	FAN does not screeched	C=0
8	Power On-Off Cycle	1. 10 ㎡ closed Lab,，20℃，humidity 50%， particle generator and air cleaner 2. DC 5V power supply，keep On-Off frequency 0.5Hz for 72 hours and check consistency		n=10 C=0
9	Sleep Set On-Off Cycle	1. 10 ㎡ closed Lab,，20℃，humidity 50%， particle generator and air cleaner 2. DC 5V power supply， keep Sleep Set Pin High-Low frequency 0.5Hz for 72 hours and check consistency		n=10 C=0
10	Laser On-Off Cycle	1. 10 ㎡ closed Lab,，20℃，humidity 50%， particle generator and air cleaner 2. keep laser On-Off frequency 50Hz for 240 hours and check consistency		n=10 C=0
11	Salt Spray	5% industrial salt water, hydrolysis spray 100 hours, clean with purified water and store for 48 hours	No rust and discoloration of metal parts	n=1 C=0

Circuit Attentions

1) DC 5V power supply is needed because the FAN should be driven by 5V. But the high level of data pin is 3.3V. Level conversion unit should be used if the power of host MCU is 5V.
2) The SET and RESET pins are pulled up inside so they should not be connected if without usage.
3) PIN7 and PIN8 should not be connected.
4) Stable data should be got at least 30 seconds after the sensor wakeup from the sleep mode because of the fan's performance.

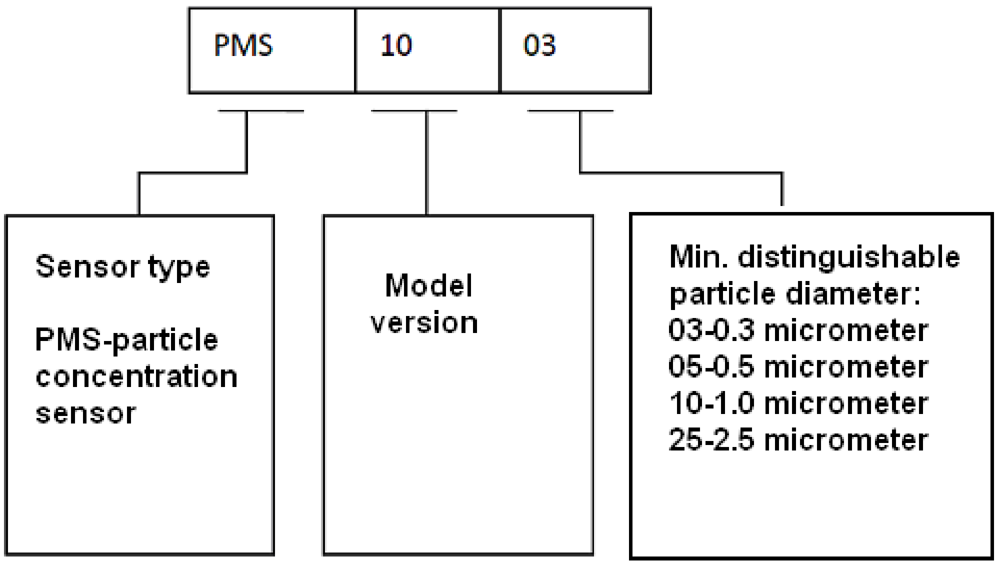
Installation Attentions

1) Metal shell is connected to the GND so be careful not to let it shorted with the other parts of circuit except GND.
2) The best way of install is making the plane of inset and outset closely to the plane of the host. Or some shield should be placed between inset and outset in order to prevent the air flow from inner loop.
3) The blowhole in the shell of the host should not be smaller than the inset.
4) The sensor should not be installed in the air flow way of the air cleaner or should be shielded by some structure.
5) The sensor should be installed at least 20cm higher than the grand in order to prevent it from blocking by the floc dust.
6) Do not break up the sensor.
7) M2 self-tapping strew should be used to fix the sensor but it should not be deeper than 5mm into the sensor.

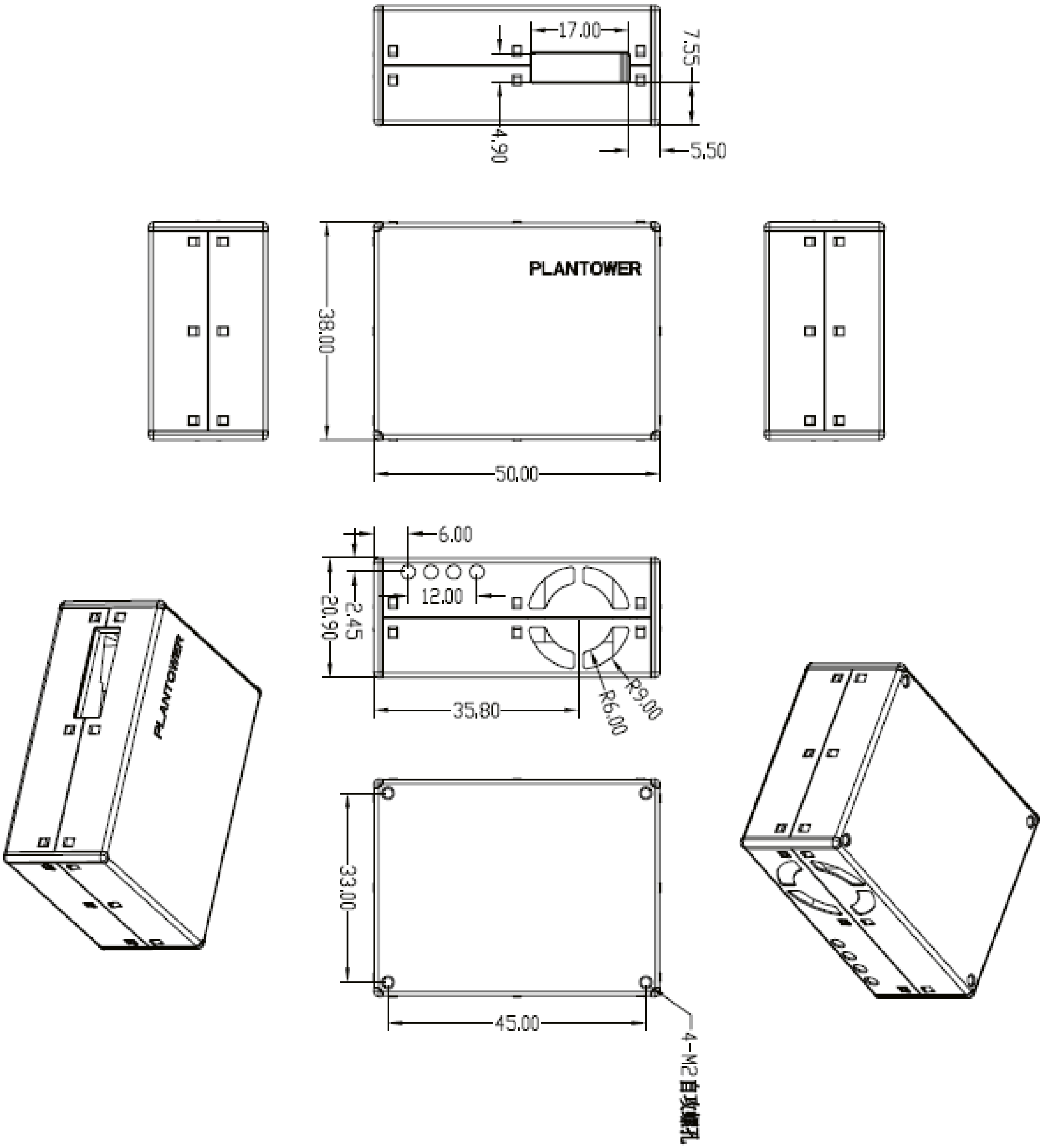
Other Attentions

1) Only the consistency of all the PM sensors of PLANTOWER is promised and ensured. And the sensor should not be checked with any third party equipment.
2) The sensor is usually used in the common indoor environment. So some protection must be added if using in the conditions as followed:
   a) The time of concentration ≥300μ g/m³ is longer than 50% of the whole year or concentration≥500μ g/m³ is longer than20% of the whole year.
   b) Kitchen
   c) Water mist condition such as bathroom or hot spring.
   d) outdoor

Part Number Definition



Physical Size (mm)



Appendix I：PMS5003 transport protocol-Active Mode

Default baud rate：9600bps Check bit：None Stop bit：1 bit

32 Bytes

Start character 1	0x42 (Fixed)	
Start character2	0x4d (Fixed)	
Frame length high 8 bits	……	Frame length=2x13+2(data+check bytes)
Frame length low 8 bits	……	
Data 1 high 8 bits	……	Data1 refers to PM1.0 concentration unit μ g/m3（CF=1，standard particle）*
Data 1 low 8 bits	……	
Data2 high 8 bits	……	Data2 refers to PM2.5 concentration unit μ g/m3（CF=1，standard particle）
Data2 low 8 bits	……	
Data3 high 8 bits	……	Data3 refers to PM10 concentration unit μ g/m3（CF=1，standard particle）
Data3 low 8 bits	……	
Data4 high 8 bits	……	Data4 refers to PM1.0 concentration unit * μ g/m3（under atmospheric environment）
Data4 low 8 bits	……	
Data5 high 8 bits	……	Data 5 refers to PM2.5 concentration unit μ g/m3（under atmospheric environment）
Data5 low 8 bits	……	
Data6 high 8 bits	…….	Data 6 refers to concentration unit (under atmospheric environment) μ g/m3
Data6 low 8 bits	……	
Data7 high 8 bits	……	Data7 indicates the number of particles with diameter beyond 0.3 um in 0.1 L of air.
Data7 low 8 bits	……	
Data8 high 8 bits	……	Data 8 indicates the number of particles with diameter beyond 0.5 um in 0.1 L of air.
Data8 low 8 bits	……	
Data9 high 8 bits	……	Data 9 indicates the number of particles with diameter beyond 1.0 um in 0.1 L of air.
Data9 low 8 bits	……	

Data10 high 8 bits	……	Data10 indicates the number of particles with diameter beyond 2.5 um in 0.1 L of air.
Data10 low 8 bits	……	
Data11 high 8 bits	……	Data11 indicates the number of particles with diameter beyond 5.0 um in 0.1 L of air.
Data11 low 8 bits	……	
Data12 high 8 bits	……	Data12 indicates the number of particles with diameter beyond 10 um in 0.1 L of air.
Data12 low 8 bits	……	
Data13 high 8 bits	……	Data13 Reserved
Data13 low 8 bits	……	
Data and check high 8 bits	……	Check code=Start character 1+ Start character 2+……..+data 13 Low 8 bits
Data and check low 8 bits	……	

Note: CF=1 should be used in the factory environment

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Appendix II：PMS5003 transport protocol-Passive Mode

Default baud rate：9600bps Check bit：None Stop bit：1 bit

Host Protocol

Start Byte 1	Start Byte 2	Command	Data 1	Data 2	Verify Byte 1	Verify Byte 2
0x42	0x4d	CMD	DATAH	DATAL	LRCH	LRCL

1. Command Definition

CMD	DATAH	DATAL	说明
0xe2	X	X	Read in passive mode
0xe1	X	00H-passive 01H-active	Change mode
0xe4	X	00H-sleep 01H-wakeup	Sleep set

2. Answer
   0xe2: 32 bytes , same as appendix I
3. Verify Bytes :
   Add of all the bytes except verify bytes.