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Renewable Energy - RENE

MSc Thesis

FASCOM – The Solar Hub for Smart Cities

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Instituto Superior Técnico, Portugal | École Polytechnique (ParisTech), France
Abstract

In this work, a solar streetlight is analysed from both a technical and a commercial point of view. The prototype developed by SIARQ in the previous years is presented, illustrating the different parts, highlighting the decisions about the design and the photovoltaic module and comparing the differences between a conventional streetlight.

Then, the main challenge faced is described. The reduced air circulation inside the device produced high temperatures on the battery and on the solar module, limiting the performance and reducing the expected lifetime. Different designs have been studied, and the benefits of the final one are underlined.

Therefore, different battery technologies are analysed, showing the most suitable type depending on the climate and revealing their expected cycle life. Moreover, the algorithm governing the battery's operation is briefly explained.

In the last part, a new market opportunity for the device is considered. Observing the recent exponential rise of the Smart City environment, it has been decided to pivot the streetlight in the sector. The definition of a Smart City is discussed, unveiling the different sub-sectors and the most important factors to consider when launching a project. Afterward, the sensors that can be installed on the device are listed, and the most promising communication technologies to connect them with the cloud are compared.

Consequently, the role of the sensors and the connectivity protocols in the development of a new business model is suggested.

In conclusion, it is highlighted how the market segment and the business model proposed will be validated in a collaborative process, following the Design Thinking methodology.
Acknowledgements

Dealing with distances is never an easy task, and requires unremitting cooperation from the people you love the most. Therefore, I want to express an immense gratitude to all my family for the support received during these two years: they are the reason why this thesis has been possible in first place.  
Huge thanks then to my girlfriend. Regardless of distance, it is as if she has been always with me, in every moment or decision.

I am grateful to the whole SIARQ's team, for the positive attitude they welcomed me and for the countless lessons I have learnt during these months.

Thanks to my supervisor, Mrs Ivette Rodríguez, who assisted me in a difficult situation and provided very useful feedback.

Finally, a mention goes to all the friends I have met during this journey, who inspired me and left me stunning memories.

Enrico Furnari

Barcelona, July 2015

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## Glossary

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<th>Description</th>
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<tbody>
<tr>
<td>ABS</td>
<td>Acrylonitrile butadiene styrene</td>
</tr>
<tr>
<td>Ah</td>
<td>Ampere-hours</td>
</tr>
<tr>
<td>C&lt;sub&gt;ah&lt;/sub&gt;</td>
<td>Battery Capacity in Ah</td>
</tr>
<tr>
<td>CIGS</td>
<td>Copper indium gallium (di)selenide</td>
</tr>
<tr>
<td>CRM</td>
<td>Customer relationship management</td>
</tr>
<tr>
<td>GPRS</td>
<td>General Packet Radio Service</td>
</tr>
<tr>
<td>CPU</td>
<td>Central Processing Unit</td>
</tr>
<tr>
<td>CRI</td>
<td>Color Rendering Index</td>
</tr>
<tr>
<td>CV21</td>
<td>Clean Venture 21</td>
</tr>
<tr>
<td>DNI</td>
<td>Direct Normal Irradiance</td>
</tr>
<tr>
<td>DOD</td>
<td>Depth of Discharge</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FP7</td>
<td>Seventh Framework Programme for Research and Technological Development</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GFRP</td>
<td>Glass-Fiber Reinforced Plastic</td>
</tr>
<tr>
<td>HPS</td>
<td>High-Pressure Sodium</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and communications technology</td>
</tr>
<tr>
<td>LCOE</td>
<td>Levelized Cost of Electricity</td>
</tr>
<tr>
<td>LED</td>
<td>Light Emitting Diode</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------</td>
<td>------------</td>
</tr>
<tr>
<td>lm</td>
<td>Lumens</td>
</tr>
<tr>
<td>LoRaWAN</td>
<td>Long Range Wide-Area Network</td>
</tr>
<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
</tr>
<tr>
<td>MPPT</td>
<td>Maximum Power Point Tracker</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
</tr>
<tr>
<td>SIMPLE</td>
<td>Semi-Implicit Method for Pressure-Linked Equations</td>
</tr>
<tr>
<td>SoC</td>
<td>State of Charge</td>
</tr>
<tr>
<td>RAM</td>
<td>Random Access Memory</td>
</tr>
<tr>
<td>RANS</td>
<td>Reynolds-averaged Navier–Stokes</td>
</tr>
<tr>
<td>TRL</td>
<td>Technology Readiness Level</td>
</tr>
<tr>
<td>US</td>
<td>United States</td>
</tr>
<tr>
<td>W</td>
<td>Watts</td>
</tr>
<tr>
<td>Wh</td>
<td>Watthours</td>
</tr>
<tr>
<td>WP0</td>
<td>Work Package 0</td>
</tr>
</tbody>
</table>
1. Introduction

The world electricity consumption was estimated to be over 20 trillion kWh in 2014, with a 4% increasing trend each year (Index Mundi, 2015).

Lighting alone accounts for around 19% of the global electricity consumption (The Climate Group, 2015).

The need for light has been indeed the reason in first place to generate electricity. The earliest commercially viable electric light bulb was released by Thomas Edison on October 21, 1879. A light bulb is made of a tungsten filament that glows light when heated to high temperature. In this process, most of the energy is dissipated to heat, with just around 5% of the electricity converted into light. To verify the quality of a lamp, a more precise parameter is the luminous efficacy, defined as the ratio of the perceived power of light (which in turn is the luminous flux, measured in lumens) to the electrical power consumed. For incandescent bulbs, this parameter is around 10-15 lumens per watt. Moreover, they present a short lifetime, between one and five thousand hours of utilization.

It is astonishing to report that, after 150 years, 62% of residential lights and 10% of the outdoor ones still use the very first option invented (DiLouie, 2012).

Indeed, even if the technology showed great improvements throughout the years, the adoption of more efficient lights was not resilient enough, in particular in the residential sector. Streetlight applications exhibited more response to the advancements, due to higher running hours per nights (and thus higher costs associated).

The first substitutes of light bulb for street illumination were the fluorescent lamp, deployed in the ’30s. Their efficiency was considerably high for the period, with luminous efficacy around 60 lumens per watts, and a lifetime ranging from 10 to 20 thousand hours. Other drawbacks prevent a massive usage, such us non-directional light emission, their substantial size and their fragility.

Mercury vapour lights were developed in the late ’40s. Even if the consumption was a little higher than fluorescent lamps, the high brightness and the directionality facilitated the adoption. A coating was necessary to improve the Color Rendering Index (CRI – the ability of a light source to reveal the colors faithfully), as the initial effect was bluish-green light. Other disadvantages have been the depreciation over the lifetime and the ultraviolet output, which
hindered their diffusion. Due to the presence of mercury, a hazard compound, their production was banned in 2008 in the United States (US) and in 2015 in the European Union (EU).

The technology currently dominating the streetlight market was invented in the ‘70s: the High-Pressure Sodium lamp (HPS). They present a luminous efficiency up to 130 lumens per watt and a lifetime in the same range of the fluorescent lamps. Their main drawback is a low CRI, which results in a yellow light. A variant of HPS is the low-pressure sodium option, which presents even higher efficiency, at the cost a Color Rendering Index equal to zero, meaning that they can produce a single wavelength of yellow light.

The latest technology available in the market is the Light Emitting Diode (LED), a p-n junction that release energy in the form of photons when a suitable voltage is applied. This phenomenon is called electro-luminescence.

The latest high-end LEDs devices are already exceeding all other available technologies by every aspect, while the research is pushing the boundaries even further.

LEDs present high and predictable lifetime, up to 100 thousand hours, a high luminous efficiency, around 100-150 lumens per watt, a CRI close to the unit value, and dimming capabilities. The main obstacle to a wide diffusion has been the high initial investment required, but costs are dropping down, and now LEDs are already competitive with other technologies in a time span of 20 years’ time (Grah LED Lighting) (Energy Star).

To put in perspective the benefits that would come from converting all indoor and outdoor lighting to LEDs, some statistics are presented:

- The global electricity consumption for lighting would be less than half.
- 735 million tonnes of CO$_2$ emissions would be avoided each year, equivalent to the CO$_2$ emissions of UK and Spain combined.
- 25 GW of capacity could be saved (The Climate Group, 2015).

The switching in the private sector will happen thanks to the phasing out of old, inefficient lamps, which is already regulated in many countries in the world, led by US and EU (European Parliament, 2009) (EIA, 2011) (UNEP, 2012).

In the streetlight sector, the higher potential savings have already started the process.

There are over 304 million streetlights in the world, which release more than 100 million CO$_2$ per year. This market is expected to grow to 352 million total streetlights by 2025 (Northeast Group, 2015).
Out of these, more than 55 million are in Europe, of which around 18 million run on a 1930s standard. The potential yearly saving that the switch from old to new street lighting technology is of 3 billion euros (EPEC, 2013).

The shift to a LED-based illumination system will not bring just energy saving, but a real disruption in the sector. The business model of all the companies in the streetlight industry has been related to the bulb replacements and components maintenance needed every four years by the traditional lighting technologies. LEDs, on the other hand, come with a warranty of 10 years, and they might end up during even more, up to 20 years. For firms to thrive, a strategy related just to the substitution of old lamps with LEDs is not sustainable in the long-term. Therefore, many manufacturers have started the transition to a service-related business, where the real value is not placed on the streetlight itself, but on the ecosystem built around it (Forbes, 2014). Consequently, the presence of a software to control and monitor the lamp has opened a whole new world of applications.

LEDs have an even more central role towards more sustainable cities than it might appear. The current lighting options confer the cities an orange look, due to the low CRI of the lamps, and stain the sky because of the lack of directionality, bringing all the issues related to light pollution, from hidden stars to wildlife disturbance. Thanks to the directional light and the dimming capabilities, LEDs would solve these problems, increasing at the same time both the light actually reaching the roads and the CRI index, which is crucially important for distinguish people.

Moreover, the presence in the past of a massive baseload power, such as coal and nuclear, has made the electricity so cheap during the night to hinder the diffusion of more efficient lights (Wright, 2014). The paradigm has begun to change in the last few years, as renewable energy is replacing conventional forms of generating electricity. In particular, solar installations obviously do not produce energy during the night; therefore, a country that wants to invest heavily on it has the need to reduce the night consumption and to ensure grid stability with some sort of storage. Streetlights can serve both purpose, as it is possible to install solar panel on them and integrate a battery acting as a buffer between the energy supply, when the sun shines, and the energy demand, during the evening. The main issue related to this new type of device is a poor integration in the city environment, as the aesthetic of photovoltaic panels can create unwanted contrasts, especially in places full of history.

These transformations, from light bulbs and a conventional business model to LEDs and innovations, will result in much more enjoyable, safer and sustainable cities.
The scope of this work is to present a device that have the potential to satisfy all the needs presented above, while explaining the main challenges encountered in designing the prototype and positioning it in the market.
2. Initial Prototype presentation

SIARQ, an acronym for Studio Itinerante Arquitectura, is a privately owned company, based in Barcelona, Spain. It was co-founded in 2003 by Alessandro Caviasca and Axelle Verges.

SIARQ has the aim of integrating solar energy in the urban environment by creating new sustainable products able to combine design with advanced smart technologies, in order to create more sustainable and enjoyable cities.

Among the wide product portfolio developed in more than ten years of experience, solar streetlights are the most frequent.

The value chain of these products, from designing to the market, has always been made more complicated by the presence of many intermediate suppliers involved, slowing down the process and hindering the perfect integration of all the components.

The need for a unified solution, which could lead to less material usage, faster production, assembly and transport, generated the first idea about a new product.

At the same time, a research for a design that could blend better into the city started, and resulted in dome’s shape, as curved lines provide a better aesthetic within the urban landscapes.

The curvature at each point was studied further, in order to avoid the deposit of dust and snow and optimize the energy production, generating enough electricity during the winter months without compromising too much summer performances.
The expected production for a standard power is presented in Figure 1.

![Figure 1 - Power yield of the solar streetlight prototype for a typical day in summer and winter Source: (SIARQ)](image)

A European project initially began, within the Seventh Framework Programme for Research and Technological Development (FP7), EU's main instrument for funding research.

The aim was proving the feasibility of a curved photovoltaic module, inside the “Solar Design” consortium, a collaboration between companies, universities and research centres with the objective of introducing novel and flexible photovoltaics materials into the market. The framework was the Horizon 2020, the biggest EU Research and Innovation project with nearly €80 billion of funding available until 2020 (European Commission).

The preliminary studies showed great promises, and led to the official kick-off of the streetlight project, which happened in January 2013. The device has been called FASCOM, FArola Solar COMpacta, “compact solar streetlight” in Spanish.

After proving the structural stability, SIARQ finalized the design of the dome, which was then patented. Tecnalia, a Spanish technological centre specialized in innovative research, was chosen as a partner to manufacture a photovoltaic panel that would fit into the body of the device. While the testing of this part was still founded by the EU project, additional resources were needed to develop more in details the streetlight as a whole. Therefore, the project was
presented to KIC InnoEnergy in November 2013, and accepted as an Innovation Project in February 2014. A Work Package 0 (WP0), demonstrating the feasibility of the device, the business plan and the investments required, was then delivered.

At January 2016, when this work started, the product was at a Technology Readiness Levels (TRL) of six, as all the subsystems have been tested in a relevant environment. In particular, the photovoltaics module was still in development, as different materials and encapsulation techniques have to be tested, to select the most suitable one for the prototype. Even without the PV, a dome has already been produced as a test, together with the cap and the support pole, even if the latter does not have the final length of six meter. The LEDs and the electronics were already installed in this device.

All the components in this first configuration will be explained in details, and the modifications applied throughout the months will be then justified.

The final product to be commercialized is expected to look like the render in Figure 2.

![Figure 2 - Render of the dome's shape of FASCOM. Source: (SIARQ)](image)

The components at the most advanced stage of development were the LEDs. A Cree® XLamp® XT-E LEDs has been the model selected. The device presents high performance characteristics, with a power consumption of just 6 W, and a cool white efficacy up to 148 lm/W at 85°C and 350 mA. The datasheet is provided in the references (Cree, 2016). The installation of six LEDs in the product would ensure the minimum luminosity of 3000 lumens required by the cities’ legislation in any working condition. The final product would allow selecting different photometry, being able to adapt to a wide range of lighting requirements by
changing/combining the optical lenses, and will have two different power configurations (24W-3000 lumens or 48 W – 6000 lumens).

The LEDs are positioned at the bottom of the base, in order to focus the light directly and just to the ground, in the effort of reducing the light pollution in the cities. The lights communicate with a motion sensor, which dims the intensity in case no movements are detected for few minutes, providing an even more consistent saving. As an average, it is expected that 110 Wh per night will be consumed.

The LED assembly is displayed in Figure 3.

A heat sink has been installed on the internal side of the base, to ensure that the LEDs will constantly be below the 85°C recommended by the manufacturer. A thermal analysis has been performed on the chosen dissipator, to ensure its suitability.

![Figure 3 - Prototype of a LED group. Source: (SIARQ).](image)

The prototype has been equipped with a lithium-polymer battery, which presents great characteristics at standard temperatures, but has a range not suitable for neither hot nor cold climates. As the battery revealed to be the critical component of the system, a more comprehensive comparison between the different technologies is reported in section 4.

The photovoltaics module, due to its peculiar shape, has been a huge challenge. As mentioned above, however, the production was assigned to Tecnalia, and not to SIARQ. The specific details of the process towards the final choice are not at the author’s comprehensive knowledge, but here an overview is presented.

The technology most suitable for the application appeared to be Copper indium gallium (di)selenide (CIGS).
The main advantages of these materials are the flexibility and the thinness, thanks to the high absorbent coefficient that allows capturing the sun energy in a reduced thickness. Furthermore, it presents a low temperature coefficient, meaning that it works well even at high temperatures, and high efficiency in low light conditions, as it is able to maximize the energy harvesting from the diffuse radiation. This characteristic is crucial for the FASCOM’s shape, as half of the device will always be shaded.

The record efficiencies are 22.3% at lab scale and 14.3% for a commercial module.

All these characteristics result in a cost of 0.4 €/Wp and a Levelized Cost of Electricity (LCOE) as low as 4.8 €/Wh (cigs-pv, 2016).

However, these numbers are applicable for standard flat module produced in large scale. The shape of FASCOM requires cells with variable dimensions, designed in a close partnership with the supplier. In particular, 108 cells, with a dimension of 15x5 cm, are necessary to cover the surface.

The Austrian Sunplugged was the only company that accepted to produce this custom design. However, some problems emerged with this supplier. The factory expected to produce the PV was built recently, and the shipment of the first products began just in August 2015, with selected partners (not being Tecnalia). As the timeline to deliver the product has not been provided by the Austrian company, Tecnalia decided to test the adaptability of different technologies for the application.

As a first choice, a standard silicon technology has been experimented, from a European manufacturer called Metsolar, based in Lithuania and specialized in custom-made products and already with experience in the street lighting market (Metsolar, 2016). The polycrystalline cells provided have an efficiency between 16.2% and 18%, but the peculiar dimensions raised the costs to 5 €/Wp, almost ten times the market price for commercial modules. Moreover, the silicon does not present a high flexibility and, despite the careful encapsulation technique studied by Tecnalia, tended to break due to the rounded design.

Considering the not excellent results of previous alternatives, the efforts has been directed towards another technology, which still uses silicon as a material, but arranged in tiny spheres. The cells, produced by the Japanese company Clean Venture 21 (CV21), have the key advantages of flexibility and reduction in the usage of silicon. The efficiency, around 11%, is suitable for the purpose, and the price is estimated to be of 3.5 €/Wp for the prototype, with lower prices as the production increases. A cell can be observed in Figure 4, and the datasheet of the technology is available in the ANNEX.
A visual overview of the technologies is presented in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Si</th>
<th>CIGS – Sun plugged</th>
<th>Spherical Si</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Efficiency</strong></td>
<td>16-18%</td>
<td>3-5%</td>
<td>11%</td>
</tr>
<tr>
<td><strong>Availability</strong></td>
<td>Lituania</td>
<td>Austria</td>
<td>Japan</td>
</tr>
<tr>
<td><strong>Price</strong></td>
<td>5 €/Wp</td>
<td>2€/wp</td>
<td>3,5 €/Wp</td>
</tr>
<tr>
<td><strong>Temperature Performance</strong></td>
<td>0,38 %/ °C</td>
<td>0,3% / °C</td>
<td>0,5% / °C</td>
</tr>
<tr>
<td><strong>Low Light Performance</strong></td>
<td>Medium</td>
<td>Good</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Integration</strong></td>
<td>Acceptable</td>
<td>Good</td>
<td>Ok</td>
</tr>
<tr>
<td><strong>Manufacturing</strong></td>
<td>Break</td>
<td>Still Wrinkles</td>
<td>Possible</td>
</tr>
</tbody>
</table>

The photovoltaic module is connected to the battery and a micro-inverter, able to feed the grid or use the stored energy when the sun is not shining. The electronic has been bought from Faktor3, a Danish company. The power management unit is called SOLVEI. Tecnalia has developed a specific Maximum Power Point Tracker (MPPT), designed for the rounded shapes and the presence of diffuse light on one side.
The streetlight is completed by a cap, from which is possible to insert and remove the battery effortlessly, the base and a 6 meters tall support pole. The first two parts are presented in Figure 5.

![Figure 5 - First prototype’s cap and base. Source: (SIARQ)](image)

The described product manifested some challenges that have to be overcame before the first sales. In particular, the most urgent technical problem was related to temperatures. The device is equipped with a battery, which is a sensitive component. Most of the currently available technologies have an operating temperature range between 0°C and 40°C, with few exceptions pushing the limits specifically for the deployment of photovoltaics applications in hot climates. These boundary conditions would dramatically reduce the location in which the device could be utilized, as many places have lower temperatures in winter and/or higher in summer. At the same time, the photovoltaic modules reduce their performances if they get too hot: therefore, increasing the ventilation on the internal side would also increase the power output of the device.

The following sections will study different possibilities that have been examined to overcome these troublesome problems.

At the same time, as briefly mentioned in the introduction, there is a global trend towards the development of Smart Cities, especially for LEDs streetlights companies. The compact nature, together with the presence of a battery, an electronic system and available space inside, situate FASCOM in an advantageous position for making it a playground for sensors, security cameras, antennas, and any another add-ons that could be useful for a modern city. For this reason, the possibility of replacing the device in the Smart City market will be examined, together with the development of an innovative business model.
3. Thermal Analysis

A thermal analysis has been carried out to improve the performance of the prototype. As mentioned above, the problem is double-folded, as both hot and cold temperatures drastically reduce the battery lifetime.

The adopted strategy has been to increase the ventilation inside FASCOM in order to reduce the temperatures, while researching for a different battery technology that could withstand a wider operating temperatures range.

The chosen software for the analysis has been ANSYS, due to the powerful capabilities. The hardware on which the simulations are performed is a laptop running Windows 10 64-bit, equipped with a CPU Intel Core i7-4500U at 1.8 GHz (2.4 GHz in Turbo Boost) and 8 GB of RAM. Even if it is highly recommended to run these type of problems on a workstation, the lack of an available one constrained the choice. At the same time, the memory available is below the minimum of 16 GB suggested (ANSYS, 2015). For these reasons, some decisions have been taken to simplify the problem as much as possible, and they are anticipated here:

- The supporting pole has not been included in the geometry, to reduce the bodies to be meshed.
- The mesh quality is appropriate near the most interesting points, but the elevated growth rate decreases the quality close to the boundaries.
- The simulation has been performed only in steady-state conditions.
- Reynolds-averaged Navier–Stokes (RANS) equations have been used.
- The residuals’ convergence has been set to $10^{-3}$.
- The segregated method has been chosen.
- Emission and reflection from surfaces are not considered in the radiation model.

The aim of the simulations is to assess the temperatures of the battery and the photovoltaics module, and to develop designs to reduce them.
3.1 Definition of the case

The simulations have been performed in the worst conditions possible for the chosen locations, which means considering the hottest day of the last three summers, at solar midday. In this situation, the radiation is maximum and also the temperature usually peaks or it is near to it. Moreover, the wind has been considered at a value below the monthly average for the location, and it is hitting the dome’s face not exposed to the sun (meaning that the one exposed is less ventilated). Obviously, the worst condition possible is the situation where there is no wind at all; since the air’s behaviour at the inlets is to be assessed, this case is not of particular interest. Studying the worst conditions allow the simulation to be steady state, substantially reducing the computational effort. Moreover, solving the problems for this situation automatically means getting through all other more favourable cases.

The boundary conditions influencing photovoltaics module and battery temperatures are related to the location of the installation, and are in particular:

- The ambient temperature.
- The sun radiation hitting the device.
- The ambient wind velocity.
- The wind velocity inside FASCOM.

As the first three are fixed, it is clear that the wind velocity inside the dome determines the operating temperatures. The design should then favour the income of as much air as possible, while ensuring the mechanical stability, the IP65 certification of the device, without compromising the aesthetical design.

The simulations have been performed in three locations: in Saudi Arabia, in Barcelona and in Cadiz (Spain).

Saudi Arabia has been chosen due to the harsh weather, characterized by extremely high temperatures and strong irradiance. Moreover, when the sun peaks it is almost overhead, making the inclination of FASCOM’s photovoltaics module unfavourable. For these reasons, an installation in such a place it is unlikely, and it has been simulated just to assess the behaviour of the system in the worst-case scenario. Jeddah is reported to be the hottest city of Saudi Arabia, and it has been selected for the purpose (2014).

The prototype will be tested in Cadiz from June to late August; therefore, it will be possible to verify the simulations’ results, and eventually update them with empirical data.

Eventually, a simulation with the final design will be carried out in Barcelona, as it will most likely be the location of the first pilot line installation.
The main sources of data have been (Weather Underground) for temperatures and wind velocity, and PVGIS (JRC) for sun radiation; both provide comprehensive data with a time step of one hour or lower. In PVGIS, the direct normal irradiance (DNI) and the diffuse irradiance at solar noon have been used. Regarding the wind velocity, the monthly average has been calculated and then reduced by 20%. As can be seen in Figure 6, the wind velocity actually peaks in the considered hours; thus, the situation considered is rather conservative.

![Wind profile in Arabia on the chosen day.](image)

The wind follows a similar behaviour in Cadiz and Barcelona; hence, the same considerations are valid as well.

The hottest days of the last summers, from 2013 to 2015, are:

- The 20th of August 2015 for Jeddah.
- The 15th of July 2015 for Cadiz.
- The 5th of July 2015 for Barcelona.

The condition in the given days are summarize in Table 2.

<table>
<thead>
<tr>
<th>Coordinates</th>
<th>Max T [°C]</th>
<th>Average Wind Velocity [m/s]</th>
<th>Wind Velocity Used [m/s]</th>
<th>DNI at Earth’s Surface [W/m²]</th>
<th>Diffuse Irradiance [W/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arabia</td>
<td>Lat 21.3</td>
<td>49</td>
<td>3.3</td>
<td>2.6</td>
<td>878</td>
</tr>
<tr>
<td></td>
<td>Long  39.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cadiz</td>
<td>Lat 36.53</td>
<td>39</td>
<td>2.5</td>
<td>2.0</td>
<td>836</td>
</tr>
<tr>
<td></td>
<td>Long -6.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barcelona</td>
<td>Lat 41.4</td>
<td>33</td>
<td>3.4</td>
<td>2.7</td>
<td>725</td>
</tr>
<tr>
<td></td>
<td>Long  2.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The materials composing the product are categorized below.

- The base is made of aluminium.
- The photovoltaic module is encapsulated into a material called glass-fiber reinforced plastic (GFRP). This material has been manually created in the program.
- The cap is fabricated in Acrylonitrile butadiene styrene (ABS), a type of polymer.
• The battery is composed of many materials. As the envelope is made of plastic, it has been considered of ABS as well.

The properties of the three materials are listed below in Table 3 (Hawileh, 2011) (2016) (Dotmar).

<table>
<thead>
<tr>
<th>Table 3 - FASCOM materials</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Density [kg/m³]</strong></td>
</tr>
<tr>
<td>Aluminium</td>
</tr>
<tr>
<td>ABS</td>
</tr>
<tr>
<td>GFRP</td>
</tr>
</tbody>
</table>

While the characteristics of the solid materials can be considered constant in the temperatures range analysed, the same cannot be said for air. Indeed, the air properties vary strongly with the temperature, and it has been necessary to model them in the program. In order to acquire the values for the temperatures examined, an interpolation has been done (The Engineering Toolbox). The results for the inlet conditions are shown in Table 4.

<table>
<thead>
<tr>
<th>Table 4 - Air Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arabia</strong></td>
</tr>
<tr>
<td>Temperature [°C]</td>
</tr>
<tr>
<td>Pressure [Pa]</td>
</tr>
<tr>
<td>Air Specific Heat [J / kg k]</td>
</tr>
<tr>
<td>Air Thermal Conductivity [W / m °C]</td>
</tr>
<tr>
<td>Heat Capacity Cp [J / kg k]</td>
</tr>
<tr>
<td>Air Velocity [m/s]</td>
</tr>
<tr>
<td>Air density [kg/m³]</td>
</tr>
<tr>
<td>Air Dynamic Viscosity [kg/ m s]</td>
</tr>
</tbody>
</table>
In order to simulate the airflow, the device has been enclosed in a cube, as depicted in Figure 7, where the location of the inlet can also be observed.

![Figure 7 - Enclosure](image)

It can be noted that the supporting pole is not part of the simulation. As its effect on the airflow is minimum, it has been decided not to include it, to simplify the geometry and reduce the required RAM for the meshing process.

### 3.2 Numerical model

The following step has been to estimate the Reynolds number, with (1). It expresses the ratio of the inertial to the viscous forces, and gives an indication about the nature of the flow.

\[
Re = \frac{\rho L u}{\mu}
\]  

(1)

where:
- \( \rho \) is the density in kg/m\(^3\).
- \( L \) is the side of the cube in meter, equal to 0.4 m.
- \( u \) is the wind velocity in m/s.
- \( \mu \) is the dynamic viscosity in kg/ m s.

In the three situations examined, the Reynolds number is always above 45 000, which corresponds to a turbulent flow.

The numerical model adopted consequently has been the standard k-\( \varepsilon \), due to its suitability for small pressure gradients situations. The two-equations representing the behaviour of the flow are showed in (2) for \( k \) and (3) for \( \varepsilon \) (cfd-online, 2011) (Fakhrai, 2015).
\[
\frac{\partial (\rho k)}{\partial t} + \text{div}(\rho k \mathbf{U}) = \text{div} \left[ \frac{\mu_t}{\sigma_k} \text{grad} k \right] + 2\mu_t E_{ij} \cdot E_{ij} - \rho \varepsilon \quad (2)
\]

\[
\frac{\partial (\rho \varepsilon)}{\partial t} + \text{div}(\rho \varepsilon \mathbf{U}) = \text{div} \left[ \frac{\mu_t}{\sigma_\varepsilon} \text{grad} \varepsilon \right] + C_{1 \varepsilon} \frac{\varepsilon}{k} 2\mu_t E_{ij} \cdot E_{ij} - C_{2 \varepsilon} \rho \frac{\varepsilon^2}{k} \quad (3)
\]

The Prandtl number \(\sigma_k\) connects the diffusivity of \(k\) to the eddy viscosity, and a typical a value of 1.0 is used.

The model equation for \(\varepsilon\) (3) is derived by multiplying the \(k\) equation by \((\varepsilon/k)\) and introducing model constants. The Prandtl number \(\sigma_\varepsilon\) and the constants \(C_{1 \varepsilon}\) and \(C_{2 \varepsilon}\) have been left to the original values of 1.30, 1.44 and 1.92 respectively.

In both the equations, the terms on the left-hand side represent the rate of increase and the convective transport of the property, while on the right-hand the diffusive transport, the rate of production and the rate of destruction are depicted.

The energy equation solved is presented in (4).

\[
\frac{\partial (\rho \varepsilon)}{\partial t} + \text{div}(\mathbf{U} (\rho E + p) = \text{div} \left( k_{\text{eff}} \text{grad} T - \sum_j h_j J_j + (\tau_{\text{eff}} \mathbf{v}) \right) + S_h \quad (4)
\]

where:

- \(k_{\text{eff}}\) is the effective conductivity, which is the average conductivity of a material.
- \(J_j\) is the diffusion flux.
- \(S_h\) represents the volumetric heat sources, which are not present in the considered problem.

The first two terms on the left-hand side exemplify the rate of increase of energy of a fluid particle per unit volume.

The radiation equation has not been defined, as the emission and reflection form surfaces are neglected to preserve computational power. The Solar Tray Calculator specified in the program automatically determines how the sun hits the body.

As the model name suggests, it is required to estimate the parameters \(k\) and \(\varepsilon\) at the inlet and at the outlet to set up the program, and few intermediate steps are required. The document “Guidelines for Specification of Turbulence at Inflow Boundaries” has been used as a main reference for the following equations (Saxena).

The turbulence intensity expresses on a scale how much the wind velocity is variating, as it is the ratio of root-mean-square of the velocity fluctuations to the mean free stream velocity.
In the cases where no experimental data are available, it can be approximated by an empirical formula (5).

\[ I = 0.016 \times \text{Re}^{-\frac{1}{8}} \]  \hspace{1cm} (5)

In external flows, the turbulence intensity is expected to be below 1% (Saxena). The value calculated is within the range, as it can be seen in Table 5.

Thereafter, a quantity named turbulence length scale and representing the size of the large eddies in turbulent flow was determined (6).

\[ l = 0.07 \times L \]  \hspace{1cm} (6)

where L is the reference length, which is the side of the cube in this case.

It is eventually possible to estimate the desired parameters, as shown in (7) and (8).

\[ k = \frac{3}{2} \times (I^*u)^2 \]  \hspace{1cm} (7)

\[ \varepsilon = 0.1643 \times \frac{k^{1.5}}{l} \]  \hspace{1cm} (8)

The values of the properties for each location are listed below, in Table 5.

<table>
<thead>
<tr>
<th></th>
<th>Arabia</th>
<th>Cadiz</th>
<th>Barcelona</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reynolds number</strong></td>
<td>58489,33</td>
<td>47636,67</td>
<td>66544,47</td>
</tr>
<tr>
<td><strong>Turbulence Intensity</strong></td>
<td>4,057E-03</td>
<td>4,163E-03</td>
<td>3,992E-03</td>
</tr>
<tr>
<td><strong>Turbulence Intensity [%]</strong></td>
<td>0,41</td>
<td>0,42</td>
<td>0,40</td>
</tr>
<tr>
<td><strong>Turbulent Length Scale</strong></td>
<td>0,03</td>
<td>0,03</td>
<td>0,03</td>
</tr>
<tr>
<td><strong>Turbulent kinetic energy [J/kg]</strong></td>
<td>1,669E-04</td>
<td>1,040E-04</td>
<td>1,743E-04</td>
</tr>
<tr>
<td><strong>Turbulent Dissipation Rate [J / kg s]</strong></td>
<td>1,265E-05</td>
<td>6,221E-06</td>
<td>1,350E-05</td>
</tr>
</tbody>
</table>
3.3 Boundary Conditions

The described case has been fitted into the proposed numerical model through the boundary conditions.

The wind velocity at the inlet has been set accordingly to Table 2, with the turbulent kinetic energy and the turbulent dissipation rate depicted in Table 5. These parameters determine how the airflow will evolve in the control volume.

The outlet has been positioned at the opposite side of the enclosure, simulating a straight airflow. The outlet turbulence variables are imposed equal to the inlet’s one; even if the presence of the device between the two boundaries might change the conditions, the lack of available empirical data has constrained the choice.

The air at both inlet and outlet has a fixed temperature, depending on the location (49°C, 39°C or 33°C), and it changes inside the control volume due the interaction with the device, which is warmer as a results of the sun irradiance hitting it.

The DNI and the diffuse irradiance are inserted as boundary conditions, while the program automatically detects the position of the sun accordingly to location and hour of the day previously defined, and consequently computes which bodies are exposed.

The wall boundaries do not participate in the energy equation, and the roughness has been set to zero to minimize the turbulence generated there, since they are not physical walls.
3.4 Numerical Method

The preferred method to solve the equations has been the Semi-Implicit Method for Pressure-Linked Equations (SIMPLE), where a guessed pressure field is used to solve the momentum equations, and a pressure correction equation, from the continuity equation, is solved to obtain a pressure correction field, that in turn is used to update velocity and pressure field.

In the segregated method, chosen due to the lower computational power required, an equation for a certain variable is solved for all cells. The process is then repeated for all the variables.

The integrated convection-diffusion equation has been discretized for the solution, and it is shown in (9). The detailed steps to reach it can be found in the references (Versteeg, et al., 2007 p. 134-141).

\[ F_e \phi_e - F_w \phi_w = D_e (\phi_E - \phi_P) - D_w (\phi_P - \phi_W) \]  
\[ (9) \]

where:

- \( F \) is the convective mass flux per unit area, and it is equal to \( \rho u \).
- \( D \) is the diffusion conductance per unit area, and it is equal to \( \Gamma / \delta x \).
- \( \phi \) is the considered property

The second order upwind differencing scheme has been set for the spatial discretization, due to its suitability for directional convective flows. The value of \( \phi \) is calculated from the two cells upstream of the face, as it is displayed in Figure 8.

The meshed body and a section, together with the used parameters, are displayed in Figure 9 and Figure 10.
In the improved designs, slight modifications have been applied to the setting, in the effort to maximize the quality with the available RAM. Overall, the size of the mesh is in the same range as in Figure 9, therefore these tweaks are not presented for the sake of brevity.
The assembly mesh option, which refers to meshing an entire model as a single mesh process, has been selected over the part-based meshing, due to more accurate results and convergence detected.

The Relevance option, which controls the fineness of the mesh for the entire model, has been set to the higher value possible with the available RAM. Additional tests have been performed for each design increasing the value with steps of 10 until the mesh process ran out of memory. The Advanced Size Function has been specified to curvature and proximity, meaning that the meshes are finer at the edges and where the body has curves.
3.5 Results and discussion

The first simulation has been conducted for the alpha prototype. The design is displayed again in Figure 11.

![Figure 11 - Alpha Prototype Design. Source: (SIARQ).](image)

The simulation has been run for more than 500 iterations, with a considered convergence of $10^{-3}$ for the residuals, which are displayed in Figure 12.

![Figure 12 - Residuals](image)

The condition is not reached in the continuity equation, which expresses the transport of the air from the inlet to outlet. Indeed, the equation’s residuals are highly affected by the mesh quality, and it would have been required to reduce their size to reach the desired convergence.
However, the mass flow balance can be considered satisfactory for the nature of the problem (Figure 13). Considering the limited RAM, it has been decided to accept these residuals.

<table>
<thead>
<tr>
<th>Mass Flow Rate</th>
<th>(kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>inlet</td>
<td>5.4291358</td>
</tr>
<tr>
<td>outlet</td>
<td>-5.4290204</td>
</tr>
<tr>
<td>Net</td>
<td>0.0001159459</td>
</tr>
</tbody>
</table>

Figure 13 - Mass Flow Balance

In Figure 14, the wind flow is displayed in a lateral section plane, which is a vertical plane running from front to back following the wind direction and dividing the body into right and left sides.

Figure 14 - Velocity in a lateral plane section - Fist Design

It can clearly be noted that just a minimal amount of air is entering inside the dome, and the wind flows around FASCOM. The turbulence generated by the wind hitting the front side reduces the air reaching the left side vents. The velocity is higher before right side apertures, but it is drastically slowed down in the process of entering the device.
In Figure 15, the wind behaviour can be observed in a frontal plane, which is a vertical plane from side to side that divides the body into anterior and posterior portions.

![Figure 15 - Velocity in a frontal plane section - Fist Design](image)

It can be spotted that the air is trapped within the base cavity, but it is not able to penetrate inside the dome.

Being mainly stagnant there, the air is heated by the sun radiation passing through the PV module, producing an oven-like effect.

The temperatures can be observed in Figure 16.

The right side of the module, exposed to the sun, reaches punctually a maximum temperature of 100 °C. On average, the side has a temperature of 88°C. Considering the temperature coefficient of the spherical silicon cells, presented in Table 1, it would produce a 30% loss in efficiency, which considerably reduces the available energy. Moreover, the battery is exposed to a temperature close to 80°C, which is a lot higher that the 50°C recommended.

In any case, it is logical to assess that the limit will not be respected for any design, as the environment temperature is of 49°C.

Overall, the air temperatures oscillate between 50°C and 70°C inside the dome. On the right side, it is slightly lower due to better ventilation, even if it the face exposed to the sun.
The simulation has been performed also with the Cadiz’s conditions. As it can be imagined, the wind profile is similar to the just described one. Therefore, just the temperature side view is visualized in Figure 17.

Figure 16 - Temperatures in Arabia in the lateral plane section - Fist Design

Figure 17 - Temperatures in Cadiz in the lateral plane section - Fist Design
The temperatures on the module reach 90° C, which is still a critical value. The battery manifests temperatures between 60° C and 70°C, meaning that a lithium-based battery would not be suitable.

Considering the results exhibited, a change in the design was necessary, pursuing an increased ventilation inside the dome.

Two parallel paths have been taken. On one side, the air slots in the base have been re-positioned, to find the most suitable location for the wind to enter. On the other side, also the cap has been edited, since it has been noticed that the wind velocity peaks there. Additionally, it could be an exit for warmed air.

The new cap design is exhibited in Figure 18. It presents eight opening ventilation of 630 mm² each. The apertures on the base have been kept to assess only the role of the cap modifications.

![Figure 18 - New Cap Design](image)

The results of the thermal simulation are presented below, in Figure 19.
The air is able to penetrate partially through the cap, but the difference is barely perceivable. The reason is that the main function of the cap should be to facilitate the exit of warm air, which is less dense and tends therefore to rise. The absence of incoming air drastically reduces the expected benefits.

Useful base vents are required to make the cap work as it has been designed to do.

From Figure 15, it can be observed that the air velocity at the top of the cavity is higher than at the entrance. Hence, it seemed logical to position the air vents there, as displayed in Figure 20.

Figure 19 - Velocity in a lateral plane section - Cap Improvements

Figure 20 - New Base Design
However, the modification did not bring the expected results: the air struggled even more to enter the device, as it can be seen in Figure 21 and, consequently, the operating temperatures were found to be higher than the previous case.

![Figure 21 - Velocity in a lateral plane section - 2nd Base Design](image)

Therefore, it was stated that the apertures should not be located on the base cavity, as the turbulence generated results in lower velocity there. The vents must be moved where the air is forced to enter, and the obvious place for the purpose would be the front of the device. However, it has to be reminded that the wind direction is not known, it might change unexpectedly during the year and it depends on the location. Hence, the slots should be symmetric, without favouring any orientation.

After several brainstorming sessions with the team, a solution satisfying all the mentioned requirements has been developed. Twelve small apertures at the intersection of base and photovoltaics module have been opened, equally distributed along the circumference. One vent is 10 mm high and has a length of approximately 12 cm.

The design is displayed in Figure 22.
The design has produced consistent improvements, as can be noted Figure 23.

The path taken by the air is clearly visible, as it enters through the aperture at the bottom-left and then rises following the base contour. Part of the air is discharged through the cap, while a portion goes down to the base again and exits there.
The confirmation about the effectiveness of the new base holes can be seen in Figure 24. The air velocity at the inlets is around 3.5 m/s.

The increased ventilation produces diminished temperatures, as can be observed in Figure 25.

The boundary conditions made of strong radiation and hot climate still produce high temperatures, but the improvements from the previous version are noticeable.

In particular, the average temperature of the PV is 62°C, with just a punctual maximum of 78 °C, which would result in energy production 31% higher than in the previous case, thanks to a greater PV efficiency.
The battery’s temperatures are as low as 60° C, even if on a corner 78° C are reached, as can be better observed in Figure 26.

![Battery and base’s temperatures in Arabia- Final Design](image)

Considering the extremely harsh ambient conditions, an average battery temperature of 65° C is a satisfactory outcome. There are battery technologies able to work in that range, as it will be disclosed in section 4.

The main problem can arise from the uneven distribution, which can create thermal stress on the electrolytes. However, it has to be reminded that the real battery is not made just of plastic, as it been modelled in the program, but it is a mixture of many materials, and some of them conduct the heat better than plastics. Moreover, it is more significant the temperature inside the battery, than the peripheral one. Hence, the thermal inequality in the real prototype should be less evident.

Overall, this improved design would allow installation of FASCOM in harsh climates, as Africa and Middle East, expanding considerably the potential market.

The consistent improvements have led to the decision to produce the first working prototype with the presented design. Therefore, it has been performed a simulation with the Cadiz’s conditions. The temperatures on the lateral plane section are visualized in Figure 27.
The average temperature of the exposed side is not very different from the Arabia’s case. Indeed, the irradiances are similar, and the reduced air velocity counters balance the decreased temperature.

On the other hand, the temperature inside the dome is abated, from 58° C to 49° C.

The battery presents temperatures between 50° and 60° C, with an average of 55°C, which is more than 10°C lower than the initial design.

The obtained results will be tested in the first prototype, installed in middle June in the University of Cadiz, where it will remains until late August. In order to prove the outcomes, seven thermal sensors have been positioned on the battery, on the internal side of the photovoltaic module and on a LEDs heat sink. The data will be collected by the University, and SIARQ will receive weekly updates starting from July.

Considering that the worst conditions have been analysed, it is expected that the experimental results will show equal or lower temperatures.

In section 4, it will be shown that the conditions analysed above are not very common. Therefore, there is confidence that the prototype will be able to withstand the temperatures during these summer months.

As revealed before, a pilot line will be installed in Barcelona in October. Considering that almost two months are required to order and assemble the different parts, there will not be enough time to analyse the data from the prototype, identify the problems, anticipate the solutions and test them. Therefore, it is likely that the current design will be confirmed.
Figure 28 displays the temperatures in the Barcelona’s case.

The temperatures on the solar panel are within the usual ones encountered in flat panels, with an average around 55°C.

Inside the dome, the average temperature is around 40°C, proving the effectiveness of the ventilation.

The battery still presents an uneven distribution of temperatures, as can be seen in Figure 29.

The average value of 45°C is appropriate for the battery design parameters.
As previously stated, the battery is the most delicate component in the system, as it can withstand just a limited range of temperatures.

In section 4, the considered technologies will be analysed, in order to understand which one will be suitable for the different applications.

An electronic-controlled solution to avoid damages in extreme conditions will also be presented.

Before investigating the battery’s technologies, the thermal analysis will be completed by the assessment of the temperatures at the LEDs, another temperature-sensitive component.
3.6 LEDs Heat Sink

As mentioned in the introduction, the thermal performance of the LEDs heat sink will be computed, to document its behaviour.

Even if LEDs are much more efficient than traditional bulbs, they still convert an unneglectable part of the consumed electric power to heat, which in turn warms up the LEDs.

The installed Cree® XLamp® XT-E LEDs have to work at a temperature below 85°C to ensure the declared lifetime of 60 thousand hours, equivalent to 13 year of normal operation, according to (10), where the daily hours have been overestimated to a value of twelve. Hence, the device might last even more.

\[
\text{Lifetime}_{\text{years}} = \frac{\text{Lifetime}_{\text{hours}}}{\text{Hours}_{\text{daily}} \times \text{Day}_{\text{yearly}}} = \frac{60 \, 000 \, h}{12 \, h/\text{day} \times 365 \, d/\text{y}} \approx 13 \, y
\]  

The percentage of electricity converted to heat, also called royal blue wall plug efficiency or simply electrical efficiency, is the parameter required to estimate the heat generation. According to the provided datasheet of the selected device, the efficiency is up to 53% at 85°C and 350 mA, which is the maximum current that will circulate in the FASCOM’s LEDs. However, the average efficiency is expected to be lower; according to test performed (Candlepower, 2011), a 37% average efficiency has been computed, which means that 63% of the power supplied to the LEDs is dissipated in heat.

The chosen heat sink has been provided by Tecnoal, an Italian company specialized in the sector, and it is displayed in Figure 30, together with the sizing parameters.

![Figure 30 - Heat Sink](image)
The $R_t$ indicated is the thermal resistance, defined as the rate of temperature increase for the dissipated power, and calculated in (11)

$$R_{th} = \frac{T_s - T_{amb}}{Q}$$

$$T_s = T_{amb} + R_{th} \ast Q$$

Where:
- $T_s$ is the LED junction temperature
- $T_{amb}$ is the air temperature around the dissipator, in this case being the temperature inside the dome.
- $Q$ is the power generated by the LED, which has to be dissipated. Considering that each LEDs assembly has a power of 4 W and the electrical efficiency is equal to 37%, the thermal power that has to be dissipated is equal to $4 W \ast 0.63 = 2.52 W$.

Therefore, lower thermal resistance results in lower junction temperature.

Considering the worst-case scenario, in which the outdoor temperature is 49°C, the temperature around the heat sink is expected to be 65°C or less, depending on which side of the base the LED is. The required thermal resistance in this situation is equal to 7.94 °C/W, which is much higher than the 1.65 °C/W offered by the K66B.

In order not to change LEDs and base configuration, the dimensions had to remain unchanged. Therefore, it has been decided to modify the existing heat sink, rather than looking for a new one. In particular, the two walls at the edge have been removed, cutting the dissipation area, thus increasing the thermal resistance. As the parameter is not available for custom configuration, a simulation in the ANSYS software has been performed to determine it.

A LED has an estimated volume of 7.28 mm$^3$, and produce a 0.63W of thermal energy when turned on. The internal heat generation is hence equal to 86 MW/m$^3$.

A graphite layer is interpose between the LEDs and the heat sink, which is made of aluminium. The air surrounding the fins has been considered stagnant, to simulate the worst-case scenario.
The results when the air inside the dome is at 65°C are displayed in Figure 31.

It can be observed that the maximum temperature is just under the manufacturer’s limit of 85°C. The narrow temperature difference between the LEDs and the extremity of the fins is an indicator that the heat sink is just enough for the required dissipation. This statement can be confirmed calculating the thermal resistance, with the formula exhibited in (11). The value, equal to 6.75 °C/W, is close but below the estimated limit, and has then been reaffirmed running simulation at different internal temperatures (38°C, 50°C and 75°C).
For the sake of brevity, the outcomes are exhibited only for the middle situations, in Figure 32.

![Figure 32 - LEDs and Heat Sink Temperatures, with fins’ temperature equal to 50° C](image)

It has to be reminded that the LEDs’ temperature has to be below 85 °C during operational hours, which are from sunset to sunrise. It is extremely unlikely that outside temperatures at sunset are around 45-50 °C (that would lead to the described internal temperature of 65°C).

In particular, it is virtually impossible that this would happen in Spain or in Europe, the initial market for the device.

Moreover, the temperature after the sunset will surely decline.

Considering these aspects and the results of the simulation, it is expected that the heat sink will ensure adequate working temperatures in any situations, even with some margins.

Therefore, it has been installed in the first prototype in Cadiz, and the presented outcomes will be validated in the following months.
4. Battery System

The battery mounted on the first prototype has been sized according to both technical and market requirements, listed below:

- Energy consumption: 110 Wh/day.
- Energy autonomy: 3 days. Standard value for the Spanish market.
- Minimum weight.
- Operating voltage: 12 V.
- Environmentally friendly.
- Output conversion efficiency, being the ratio between the useful energy output and the input, equal to 90%. It can also be referred as Coulombic Efficiency.
- Lifecycle: at least 1500 cycle are recommended. The cycle life is the number of charge/discharge cycles that the battery is able to support before that the capacity falls under 80% of its original value.
- Depth of Discharge (DOD), which is the fraction of the energy that can be withdrawn from the battery without compromising the lifetime, equal at least to 80%.

Set these parameters, it is possible to estimate the required capacity of the battery in Ampere-hours (Ah) \( C_{ah} \) using (13).

\[
C_{ah} = \frac{E_{consumption} \cdot Days_{autonomy}}{Output\_efficiency \cdot DOD \cdot V_{Battery}} \tag{13}
\]

As already explained in previous sections, the battery is located inside the luminaire, so it is under the effect of high temperatures due to the radiation incident to the PV module and other devices like LEDs and electronics, as well as the greenhouse effect that could be produced inside the PV domed module, due to low air circulation. For these reason, the temperature is the most restrictive requirement for the selection of the battery technology.

Lead Crystal has been the first considered, thanks to the low-cost nature and wide temperatures range, from -40 °C to 70 °C.

It is an improvement from the previously dominant design, the Lead-acid, which presented environmental concern for the hazardous elements used and poor lifetime. The Lead Crystal battery uses a new electrolyte, non-corrosive acidic SiO₂ solution, resulting in a safe, fluid-less, higher performance and environmentally friendlier battery.

The lead crystal battery have an expected useful life of more than double that lead-acid battery, but it is strongly dependent on the Depth of Discharge of the cycles.
In standard conditions (25 °C), it would last more than 7 thousand cycles with a 10% DOD, while just 600 cycles are guaranteed on full discharges. However, it tolerates the possibility of being discharged to 0 volt, which was not possible with Lead-acid.

The chosen manufacturer has been Betta Battery. The proposed module presents an output conversion efficiency of 90%, and it is possible to operate with a DOD of 80%, which results in a battery with a capacity of 40 Ah, according to (13). The complete datasheet is referenced in the ANNEX.

Even if it is claimed that temperatures up to 70°C can be withstood, it can be observed in Figure 33 that the performances drastically reduce in warm conditions.

![Figure 33 - Temperatures and Lifetime for the Lead Crystal Battery](image)

Tests carried out by Tecnalia have noticed that the behaviour is even worse than the displayed one, especially for deep cycles. For this reason, Lead Crystal is not the first option for FASCOM, but just a low-cost alternative for price-sensitive applications, as it can be as cheap as 80 euros.

Therefore, it has been chosen to equip the first prototype with a Lithium Iron Phosphate (LiFePO₄). The main advantages are a higher energetic density (100 Wh/kg), which results in a battery of 5 kg instead of 14 kg, a good thermal stability, which also means safer operations, and a longer life cycle. In comparison with other lithium-ion systems, it withstands better full-charge and high voltage conditions. The main downside is related to temperatures, as the operating range during charge is from 0 °C to 45°C, dramatically reducing the suitable locations. Lithium-based options are also more expensive than Lead Crystal: the price of the selected device is around 300 euros, in line with the market price of 0.6 euro per watt-hour.

The chosen manufacturer has been the Heter Electronics Groups, a Chinese technology enterprise focused in the field of green energy.
The data sheet of the battery that will be tested in Cadiz from June 2016 has been provided in the ANNEX.

Despite the limited 0-45°C range, the Lithium battery is still a valid option for many scenarios, as the real condition are often less severe than the worst one previously simulated.

Considering for example the Cadiz's case, the examined temperature of 39°C has happened just once in 2015. Overall, just five days in a year had more than 35°C, as it can be noted in Figure 34 (Weather Underground).

![Figure 34 - Maximum Temperatures in Cadiz in 2015](image1)

Evaluating the daily average temperatures, the situation is even more favourable (Figure 35). Only two days in the entire 2015 had more than 30°C averaged, and the temperature dropped below 10°C just few times.

![Figure 35 - Average Temperatures in Cadiz in 2015](image2)
Being the temperatures within the desired range for most of the time, it can be expected that the Lithium battery will not be damaged and it will present a good lifetime.

In Table 6, the cycle life at different temperatures is exposed. It can be noted that the battery works particularly well in the 10-50°C range during discharge, while the performances decline steadily in more extreme conditions.

Assuming a cycle each day, the claimed lifetime of the device should be between 4 and 6 years.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Discharge Capacity</th>
<th>Cycle Times</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20°C</td>
<td>About 23.55Ah</td>
<td>About 50 Times</td>
</tr>
<tr>
<td>-10°C</td>
<td>About 31.88Ah</td>
<td>About 100 Times</td>
</tr>
<tr>
<td>0°C</td>
<td>About 36.50Ah</td>
<td>About 300 Times</td>
</tr>
<tr>
<td>10°C</td>
<td>About 38.80Ah</td>
<td>About 1200 Times</td>
</tr>
<tr>
<td>20°C</td>
<td>About 41.55Ah</td>
<td>About 2000 Times</td>
</tr>
<tr>
<td>30°C</td>
<td>About 41.75Ah</td>
<td>About 2000 Times</td>
</tr>
<tr>
<td>40°C</td>
<td>About 41.05Ah</td>
<td>About 1500 Times</td>
</tr>
<tr>
<td>50°C</td>
<td>About 40.95Ah</td>
<td>About 1200 Times</td>
</tr>
<tr>
<td>60°C</td>
<td>About 40.30Ah</td>
<td>About 200 Times</td>
</tr>
</tbody>
</table>

The tests have been performed at 100% DOD and with a C-rate of 0.2 C. The C-rate is a measure of the discharging current relative to its maximum capacity. A 1C rate means that the discharge current will discharge the entire battery in 1 hour, while 0.2 C means 5 hours will be required.

In the 24 W configuration, 20 hours are necessary to discharge a 480 Wh battery. Hence, the C-rate is equal to 0.05. Moreover, the daily DOD, which is the predicted DOD during sunny days, is around 33%, while the maximum is 80%.

Therefore, the device is working with lower DODs and lower discharge currents, which both lead to better life cycle performance. It can be foreseen that the actual performance will be better than the results presented in Table 6. For this reason, it has been estimated that the lifetime will be around 8 years.
In order to achieve the target, it has to be ensured that the battery will not be damaged when the temperatures will reach not desirable values. The task will be carried out by the Battery Management System (BMS), an electronic regulator that monitors and controls the charge and the discharge, aiming at increasing as much as possible the lifetime duration of a battery.

The BMS keeps track of main power voltage, cell voltage, charging and discharge rates, temperatures of the cells, and disconnects the battery from charging/discharging whenever a condition is outside the designed range.

A battery management system typically has a charge and a discharge MOSFET, which are transistors used as switches to interrupt the current flux in or out of the battery (Rouse, et al., 2014).

For a solar streetlight application, the important parameters are the voltage and the temperature, as charging and discharging rates are usually well above the recommendation, as calculated previously.

The voltage control disconnects the battery from the load when it is below a certain State of Charge (SoC), and stops the charge when it is full.

The temperature restriction is an effective way to ensure that the battery will always be within the desired range, extending considerably the lifetime of the battery.

At the same time, disconnecting the battery when the temperatures are not suitable means that the load cannot work. It would imply that during cold nights the LEDs would not be on, and the sensors would not collect data during hot days, or when the battery’s voltage is too low.

An effective solution to overcome the problem has been adopted. In case of necessity, the battery will be bypassed, and the load (being the LEDs or the sensors) will be directly feed by the grid, as illustrated in Figure 36.

Another advantage of the layout is an improved efficiency. The electricity passing through the battery is subjected to the output conversion efficiency, which produce a 10-20% loss. Avoiding this step reduces the amount of electricity needed from the grid, hence cutting the running cost.
The configuration is not yet implemented in the Cadiz’s prototype, but it will be in the pilot installation in Barcelona, thanks to a micro inverter that will serve the purpose.

The BMS is included in the battery, and the SOLVEI electronic will be able to read it and act accordingly.

Moreover, a more advanced algorithm will be implemented after the pilot installation, which will be able to read the energy prices and act accordingly. Indeed, the difference between peak and low hours is conspicuous: the former has a 0.167658 €/kWh tariff, while the latter only 0.057190 €/kWh. It is important to charge an empty battery (due to consecutive cloudy days) in the low-price periods, which are between 10 PM and 12 AM during the winter and between 11 PM and 1 PM during the summer. An effective strategy would be to charge the battery during the morning in case no sun is expected.

However, this algorithm will be implemented most likely in 2017; thus, it is not a priority of this report.

Nevertheless, it has to be reminded that the energy bought from the grid must be minimum, to reduce the running costs associated with FASCOM and to minimize the environmental impact. Undeniably, the grid’s energy is not as clean as the one produced by the solar panels, and it must be avoided if possible.

Therefore, a deeper research into the battery technologies has been carried out, in order to find one suitable for extreme climates.
The best option currently the market is the Nickel Metal-Hydrde (Ni-MH) battery. NiMH is the most readily available rechargeable battery for consumer use, especially in the AA and AAA sizes. The drawbacks of this technology, such as high self-discharge, low Coulombic efficiency and damage over deep cycles, have prevent the diffusions to big battery packs. Recently, ARTs Energy, a French company in the storage sector, has managed to overcome all the listed disadvantages, producing a device that has outstanding characteristics in different aspects. It can work between -40°C and +70°C with little impact on the lifetime of the battery, and it withstands transient temperatures up to 100°C, making it one of the most rugged battery in the market, without compromising on other aspects. It presents indeed a long lifecycle, with a 20% loss capacity in more than five thousands cycles at 50°C, as exhibited in Figure 37.

Considering cycles at 50% DOD, it is possible to reach 3500 cycles, which is correspondent to 10 years life duration, while at 80% DOD the cycle life is equal to 2500.

![VHT F cycling @ 25% DOD @ 50°C permanent](image)

Figure 37 - Lifecycle of the proposed Ni-Mh at 50°C

The simulation has been performed with an average temperature of 50°C, meaning that it comprehend temperatures as high as 70°C combined with lower ones.

The battery can be discharged down to 0%; therefore, the Depth of Discharge has a unit value. Considering a 90% output conversion efficiency, a 30 Ah would be enough, according to (9). The lower capacity would counter balance the two main drawbacks of the technology: the high price per Wh and the low specific energy density. The weight of the 30 Ah battery is 10 kg, while it costs around 500 euro.

The Ni-Mh would be equipped with the same BMS algorithm described above, but the usage of the grid energy will be reduced only to the situation of empty battery.
In conclusion, the three battery candidates have been presented.

The Lead-Acid technology, despite its low price, has been temporarily neglected, due to poor deep cycle performance in the tests carried out. Additional attempts will be made in case a low-cost option will be required.

The Lithium battery appears to be the most suitable technology for the short term. Great deep cycle characteristics and low weight outweigh the limited temperature range, making it the perfect option for temperate climates, such as Cadiz and central-southern Europe.

In case of extreme climates, as the Nordic countries and the Middle East, the Ni-Mh is the only technology that would provide sufficient performance. In fact, the Ni-Mh would work smoothly in every situation, but the high price restricts the locations where it is convenient to utilize it.
5. Smart City Product

More than half of the world’s population lives in cities, which consume 75% of the world’s energy and produce 80% of greenhouse emissions (World Resource Institute, 2008).

By 2030, the urbanization percentage will reach 60%, as nearly 1.4 million residents are added to urban areas each week, in particular in developing countries, resulting in a 2% annual increase (Paes, 2016).

As can be expected, these numbers vary greatly depending on the location. The urbanization percentage fluctuate from the 25.6% of Kenya (but with an annual urbanization rate of almost 5%), to the 98% of Belgium. Both Northern and Latin America have 80% percent of the people living in the cities. Europe and Oceania follow with a share between 70 and 75, while Asia and Africa still have an urbanization percentage around 40-45% (Statista, 2015).

Tokyo is the largest urban agglomeration, defined as both the city and the suburban fringe adjacent to the boundaries of the city. It is bigger than many countries in the world, with an astonishing number of 38 million people living there. (CIA, 2015).

The main reason for urbanization has always been moving closer to the work place, or to a place where finding a job would have been easier, and increasing the quality of life.

The creation of massive, highly populated cities is putting in danger both paradigms. Wider city area means more time to commute to work or school, especially due to the traffic congestion generated. The amount of car circulating, together with industries based in or near the city, are creating enormous problems related to the air quality, a crucial parameter for excellent life standard.

The need to enhance quality, performance and interactivity of urban services, while reducing cost and resources consumption have led to the concept of Smart City. The term is quite new and very broad, and there is no universally accepted definition of it.

Some focus on the fundamental role of Information and Communications Technology (ICT) in linking city services, while others provide wider perspectives, highlighting more the need of the citizens and the necessity to involve them.

Undoubtedly, the role of technology and communication is crucial, as it allows an effective integration of different projects and services.
For this report, it has been chosen to adopt the definition given by European Parliament: a Smart City is ‘a city seeking to address public issues via ICT-based solutions on the basis of a multi-stakeholder, municipally based partnership’ (European Parliament, 2014).

To be classified as a Smart City, an initiative addressing at least one of the six fundamental characteristics should be deployed. They are:

- **Smart Environment.** It comprehend renewable energy usage, waste management, smart street lighting, energy-efficient measurements, green buildings, effective water usage, pollution control, presence of green spaces.
- **Smart Economy.** It methodically uses e-business and e-commerce, with an increased productivity and embedding it internationally.
- **Smart Mobility.** Transports are ICT supported and integrated, with real-time information available, shared systems, and long-term planning prioritizing clean options.
- **Smart Governance.** Public, private, civil and European Community organizations are joined in a within-city and across-city governance.
- **Smart People.** People are educated and trained in e-skills, thanks to a society that encourages creativity and fosters innovation.
- **Smart Living.** It means an ICT-enabled life style, behaviour and consumption, for a healthy and safe living, with high levels of social cohesion and good quality housing.

The implementation of all characteristics requires a comprehensive framework and a strong collaboration between different stakeholders. The most important factors contributing to the creation of a fertile environment for projects to flourish have been researched, and are presented below.

- **Vision.** The desire to transform the city into a place with a better quality of life is the main driver. The strategy should combine long-term vision with immediately results, not sacrificing disruptive ideas for benefits now and, the same time, not forgetting to show some results to investor.

  The astonishing rate of improvement of technology, and Internet of Things (IoT) in particular, make the planning extremely challenging.

- **People.** An active participation of the citizen in the processes, through a bottom-up approach, could ensure that real problems are being tackled.
• **Process.** The coordination of the initiatives should be local and central. Designers of Smart City strategies and initiatives should ensure that they are based on Specific, Measurable, Achievable, Realistic, and Time-dependent (SMART) objectives, clearly aligned to innovation and development city plans and to Europe 2020 targets.

• **Cooperation.** Private companies should collaborate with municipalities, which should assist each other sharing good practices. Data have to be open source, allowing developers to create useful apps. Ideally, processes should be standardized everywhere.

• **Size.** As needs are more urgent in big cities, projects are more common there. 90% of cities bigger than 500,000 inhabitants have at least one Smart City characteristic, while the percentage drops to 43% if the population is between 100,000 and 200,000. However, it is much easier to test and deploy pilot installations in smaller cities, due to faster bureaucracy.

FASCOM will be developed considering this framework, which should guarantee the generation of a product suited for Smart Cities’ applications.

In the following sections, the main selling points of the device for the new considered market will be explained. The possibility of adding a variety of sensors and a connectivity to link them together, and the advantages of being the results of a collaborative process between different key actors will be discussed.
5.1 Sensors

A sensor is, by definition, a device that detects or measures a physical property and records, indicates, or responds to it (Google, 2016). It is usually connected to a Printed Circuit Board (PCB), which powers the sensor and connects it to the cloud or to a physical computer.

Hence, a sensor receives an input from the environment, sends it to the board, which in turn dispatches the information to a platform able to analyse it, possibly in a user-friendly way. The processed data could then be used to perform actions.

Some sensors are built with an integrated PCB, while others use an external one. Examples of the two different configurations are displayed in Figure 38 (Urbiotica, 2016) (Arduino, 2016).

![Figure 38 - Integrated Solution (Noise sensor by Urbiotica) and external PCB connected to a sensor (Arduino)](image)

Integrated products are easier to deploy because of their plug and play characteristic. No specific knowledge is required to install them.

On the other side, separated boards allow more flexibility. For example, Arduino is an open-source electronic platform that permits connecting different type of sensors from different vendors. There are different boards, covering an immense range of possible projects.

It is necessary, though, to connect physically each sensor to Arduino, and to write the code required for the specific application.

Solutions at the intersection of the two are also available. They provide external board with a large set of sensors that can be connected, while supplying the code, simplifying to a great deal the set up.
Sensors are the technology that enabled the creation of Smart City, thanks to the possibility of monitoring virtually any aspect of the urban area, and acting consequently in an efficient manner. Two examples of applications will be presented below.

Copenhagen (Denmark) is one of the greenest city in the world, and aims to become the world’s first carbon-neutral capital by 2025, mainly through renewable energy consumption and sustainable mobility. Wind power already produced 42.1% of the electricity in the country, and there is a 150% tax on cars sales, in order to promote cleaner type of transportation (Treacy, 2016) (Barrett, 2015). Indeed, 50% of the citizens use bikes to commute every day. Traffic lights are coordinated to allow continuous circulation on the main bicycle routes, creating the so-called green wave. At the same time, GPS sensors are installed on busses, and traffic lights turn green when they are approaching.

To ensure that all the measurements have an effect on life quality, thousands of sensors are installed in the city. Many aspects are monitored, such as the presence of contaminants in the air (CO₂, CO, O₃, NO, NO₂, SO₂, NO, etc.), the traffic situation, the noise pollution, detailed information about the weather (such as pressure, wind, humidity and UV levels). All the collected data are stored in the Copenhagen's City Data Exchange, together with other statistics, as the citizens’ energy consumption, the location of the greener infrastructures in the city, details about demographics, crime statistics and other information.

The platform has been built in cooperation with Hitachi, a Japanese conglomerate. Most of the raw data collected are freely available to the public, providing valuable indications on life quality and best districts to live in.

At the same time, the platform is able to extract processed data, which have a higher intrinsic value. This type of information is on sales for enterprises and developers that want to create solutions for the city (CHP Post, 2016) (OpenData.dk, 2016).

Another great example of a city that has deployed sensors in an efficient manner is Santander, Spain. The municipality has been chosen by the EU as a testbed for a pilot installation. Thanks to a team of technicians, researchers and programmers, and the local University of Cantabria, represented by the professor Luis Muñoz, the project has been able to install more than 12,000 sensors. Parking sensors detect where there available places are, and the information is displayed on special panels located at major city intersections, reducing the congestion generated by cars looking for a parking spot. Sensors in the trash bins helped the municipality cutting the cost of gathering it by 20%, as the trucks are sent just when the containers are full. Information about water flowing through parks and in the houses assists an effective management of the resource, ensuring that it is always available where most required.
Sensors monitoring air quality, sound levels, light pollution and traffic are installed in the streetlight of city, and the data are confirmed by mobile sensors positioned on taxicabs and police cars (Newcombe, 2014).

The gateways installed gather the information from the sensors and send it to the city platform, which is completely open-source, meaning that anyone can access it.

The structure of the Santander Smart City is summarized in Figure 39 (Santander).

It exits a web page, called “Santander City Brain”, where citizens can suggest new solutions to developers or ask for new services (Santander City Brain).

In the two examples proposed, the role of the sensors in a Smart City project can be perceived. It is clear that they play a crucial part in the development of solutions. Hence, installing them in FASCOM would increase considerably its value. Not all the sensors can be installed on a streetlight, though. In order to avoid vandalism, sensors have to be installed at more than 2 meters. Ideally, it would be perfect to have the sensors close to the LEDs groups, at a height of 5 m, to keep the device compact and facilitate retrofitting.

The most important sensors will be listed below, with a brief description and a feasibility assessment.

- Weather sensors, as temperature, pressure, humidity. They are by far the most installed sensors in the world; therefore, their intrinsic value is low, as well as their price. Ultraviolet sensors, that measure the intensity of the dangerous portion of sun radiation,
are not so common; hence, they might be useful in some locations, where the sun is particularly strong. They can be installed at 5 m without any drawbacks.

- Air quality sensors. It is a growing category, as the public concern has risen for environmental and health reasons. It is possible to measure the concentration of a particular gas in the atmosphere, to check if it is within the recommended range. In the cities, it is common to refer to fine Particulate Matter (PM) as an indicator of air quality, due to its hazard to human health. It refers to particles with a diameter less than 10 μm (PM 10) or less than 2.5 μm (PM 2.5), produced mainly by car, house heating and power plant. In any case, there are many others pollutants that can be monitored, which also expose the human health to risks, directly or indirectly. Among the latter, greenhouse gases, like CO₂, CH₄, N₂O, and O₃, are the most important. Others type of contaminants are CO, NO, NO₂, NH₃, H₂S, HCl, SO₂.

Ideally, the installation should be at human height, around 2 m, to report exactly the concentration breathed. This is done in indoor applications, while it is not possible outdoor, due to vandalism. Thus, they have to be positioned higher.

Overall, air quality sensors can provide great value, especially to the cities that want to advertise their life quality. The specific sensors, among the proposed ones, depend on the application’s purpose.

- Noise sensors. In the modern society, noise concerns are becoming more and more significant, especially during night. The presence of cars, pubs, disco, outdoors concerts and similar activities is a threat to the tranquillity of the inhabitants. A city that is able to distinguish between the quiet and the noisy neighbourhoods provides a great value to the people. The presence of noise sensors can even inform the police about extreme situations, as it happens in the city of Barcelona (Walt, 2015). They can be installed at 5 meters.

- Light pollution. Related to the previous point, the cities have also become so bright at night that it is impossible to see the sky. New LEDs streetlight can help solve the problem, while light pollution sensors can help detecting where the situation is more dramatic. They can be installed on a streetlight, even if it must be verified that the emitted light does not interfere with the measurement.

- Parking sensors. The commercialized way to detect the availability of a parking spot is positioning it under the asphalt. For this reason, even if they can provide great value to municipalities, they cannot be installed on FASCOM.

- Motion sensors. A motion sensor is already installed in the first prototype; it detects the presence of people to adjust the intensity of the light.
A more advanced solution is to enumerate the number of people passing on a certain area, to have an indication about the most frequented places in the city.

- Wind sensors. Mapping the wind velocity can be of particular interest to show the untapped potential of small-scale wind in cities. It is possible to measure it at 5 m, and then report it to the desired height through calculations, even if it would be preferable to monitor it directly at the chosen elevation.

A list of the sensors that could be useful for FASCOM is provided in the ANNEX.

Additionally to the listed sensors, it is possible to install a video security camera, which presents characteristics extremely different. Indeed, it requires high volume of data and it is energy intensive, and it would be necessary to adapt the prototype consequentially. For these reasons, it will not be considered a priority in the following consideration, even if it will still be possible to equip the device with them if required by the client.

The data collected from a sensor are sent from the board to the cloud. Once received, it is indispensable to make sense of them, as initially they are just long string of numbers, often meaningless.

In fact, the value is not how much data you have, but what you do with it. Big Data require a platform, in which the information is visualized in a human-friendly way (SAS, 2016).

This support system can be made by the sensors manufacturer itself, or can be commissioned to a third party company. The complexity varies depending on the application: some are just visualization tool, and require a human to take action over the situation, while more advanced systems utilize machine leaning to instruct the program to change its behaviour according to the data. The latter is a form of artificial intelligence, as the machine does not only follow explicitly programmed instructions, rather it understands different situations, automates the outcomes and learns from previous decisions. It is a solution more suitable for big-scale applications, where large sets of data are not processable by a human.

As disclosed above, in order for sensors to communicate with a remote platform, a wireless connectivity is required. In the next chapter, the most promising alternatives are presented.
5.2 Connectivity

It has been estimated that there will be between 25 and 50 billion connected devices by 2020. Around a quarter will come from mobile phones, tablets and computers, another quarter from machine-to-machine (M2M) connections, where the connectivity is embedded in commercial products to monitor their performance, and the remaining half will most likely be from sensors that can be connected to the smartphone. IoT devices can be in both the second and in the third category.

As displayed in Figure 40, there will be more than six connected devices per person (Evans, 2011).

To allow such a massive expansion, a stable network technology is required. The following criteria have been individuated as necessary for long-term success.

- **Low Cost.** The large-scale cost of the hardware should be around € 1.
- **Low Data Rates.** IoT device does not need high data pack, as simple data events are sent, usually requiring less than 1 kB each day. In any case, there should be the possibility of increasing it, for special applications.
- **Low Power.** Low data rates should consequently means low energy requirements. Sensors should be able to run off small batteries for 5 – 10 years.
- **Secure.** As the data transmitted might be extremely sensitive, security has to be a priority.

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Figure 40 - Evolution of the Internet of Things (CISCO)
- **Long Range.** In order to keep the infrastructure costs low, base stations should be able to support thousands or tens of thousands of devices. In order words, the infrastructures needed to deploy the connectivity should be as low as possible.

- **Simple, low cost provisioning.** Ideally, the shipped devices should have the ability to connect in plug and play solutions, with low or no fees.

- **Quasi-real time.** The timeframe to report control signals is usually in the order of many seconds or minutes. In case of daily reporting, real-time access is not required.

Cellular networks have always been the main channels for the deployment of connectivity, and the infrastructures have been developed mainly for mobile phones. Nowadays, smartphone are data intensive, in the meaning that a General Packet Radio Service (GPRS) is not enough to transit the information required by the users. Therefore, operators are moving toward third and fourth generation (3G and 4G), which can provide a lot more data, obviously at higher costs and with a higher energy demand.

An important implication is that operators are dismantling their 2G network in order to clear the frequency spectrum for 4G (Hunn, 2015). This operation is necessary to ensure that the growing number of users will get the speed promised by 4G, without any network congestions.

However, for the characteristics listed above, 2G is more suitable for IoT applications than 4G, which have led to an increase interested in long range, low power alternatives that utilize free frequencies. The most promising technologies will be presented below.

Conceived in 1998, ZigBee has been one of the first alternatives. It provides data rate up to 250 kbit/s, utilizing the 2.4 GHz frequency, which is available for unlicensed use anywhere around the world, plus the 868 MHz in Europe. The energy consumption varies approximately between 10 μW in sleeping mode and 30 mW in operation (Power Consumption Analysis of Bluetooth Low Energy, ZigBee and ANT Sensor Nodes in a Cyclic Sleep Scenario). The protocol is also very mature and reliable, and it is secured with an AES-128 encryption.

The main drawback of the technology is the range: considering the presence of many obstacles, the end devices have to be closer than 100 m from the gateway, which make it more suitable for house rather than citywide applications (Zigbee, 2016).

The following generation of communication came just in 2009, from a French company called Sigfox. It is a Low Power Wireless Area Networks (LPWAN) that works completely independent from existing networks, able to connect millions of low-energy objects that need
small amount of data. Sigfox is indeed specifically designed for the purpose, as it is possible to send only up to 140 messages (12 bytes as a maximum size) per object per day, resulting in 1.68 kbit per day. The limitation is justified by the need of keeping consumption and price as low as possible. The device utilizes around 25 mW each time a message is sent, but most of the time it is in idle mode, where the consumption is in the order of micro Watts. The actual energy consumption depends therefore on the number of messages sent each day; in favourable conditions, a single battery can last up to 20 years.

The cost of the hardware is around 10 €, while the annual fee depends on the number of devices connected. For small-scale applications, the price is comparable with GPRS, around 1 € per month, but it rapidly goes down with more devices connected. If a client needs more than 50 thousands things connected, the fee is just of 1 € per year, making Sigfox a lot more competitive than traditional cellular network (Hunn, 2015).

Sigfox also utilizes the same frequencies of ZigBee in Europe, the 868 MHz. The sync time is around 6 seconds, within the requirements of IoT application. The deployed network allows continuous coverage in 18 countries, with the plan of global coverage in the next years. The goal is incredibly ambitious, since no one has been capable of it, despite many mobile operators had tried during the decades. Sigfox is funded by venture capitalists; hence, this strategy exposes the network to immense risks. In the attempt of going global, the danger is running out of cash. Even if the scenario is unlikely, the consequence will be the disappearing of the network overnight, with obvious repercussion on the clients (Hunn, 2015).

Another company employs a completely different approach, in the direction of minimizing the risk of failure. LoRaWAN (Long Range Wide-area network) is a technology owned by a chip company, Semtech, who has formed the LoRa Alliance and developed the protocols that define how the data are transferred. Thereafter, anyone can buy a LoRa base station for a few hundred dollars and set himself up with a network. The deployment strategy is bottom-up, as Semtech does not deal with expanding the network. The created networks are local, and they can even be private-owned. The advantages are the durability, as the structures will endure even if Semtech fails or decides to move towards a more promising technology, and the possibility of privately grow the network even where there is no coverage, while for Sigfox and GRPS it is necessary to wait for the company to deploy it. The main drawback is related to the fragmentation, as private networks cannot talk between each other. However, a roaming framework is under development to allow private LoRaWAN applications to connect on public LoRaWAN networks. Moreover, it is possible to rent an existing network, paying an annual fee. It even exists a crowdfunding campaign with the aim of expanding the technology in every city of the world (The Things Network, 2016).
The technology itself is based on the same free frequency of Sigfox (in Europe), providing higher data range, from 0.3 to 50 kbps. The connection is truly symmetrical, making it suitable for the devices that need to receive instructions, in addition to sending information to the cloud. The distance between sensors and gateway can be as large as 22 km, but it is usually around 2 km. The LoRa technology is indeed very flexible, granting more or less powerful configuration. The high-end layout, with maximum distance and speed, consumes up to 100 mW, which is quite high for an IoT application. Thus, less energy intensive alternatives are offered. Considering the wide span of setups, and the possibility of deploying private networks, it is difficult to make a general cost comparison with the other technologies, and it should be done on a specific application (Hunn, 2015).

The last technology considered is the natural evolution of GPRS. As discussed before, the impending demise of GRPS is caused by the growth of 4G, sometimes also called LTE (Long Term Evolution), even if they are not strictly synonymous. The term LTE refers indeed to the path followed to achieve 4G speed. The connectivity has been developed to provide high symmetric speed, with the theoretical limit of 300 Mbps in download and 150 Mbps in upload (4G, 2016). Obviously, providing these speeds to the IoT is not worth it, as much lower data package are needed (with the only exception of video streaming in security cameras).

The hardware costs around 40 €, plus a minimum monthly fee of 2.5 €, is also far above the limits required to deploy thousands or millions sensors.

In the pursuit of not losing the immense potential of the sector, mobile operators have adapted their offers based on the data requirements. Initially, a Category-1 LTE was released, with a maximum speed of 10 Mbps and a hardware cost around 8 €, but it was still considered too high by the clients. Therefore, a Category-M LTE has been defined, with two different frequencies, depending on the application. At 1.4 Mhz, it is possible to reach a symmetric 1 Mbps speed, while at 200 kHz (Narrow Band) 200 kbps in download and 144 kbps in upload are ensured. The final version of this technology has not yet been release at February 2016, but it is expected between Q1 and Q2 of the current year (Degrasse, 2016).

However, the chips are already in the market, as little modifications have to be done from a standard board: the main difference is related to the power management. A device power saving mode guarantees battery life similar to Sigfox and LoRa, and it consists on a simple timer that determines how long the device remains reachable, limiting the time when the device is actually connected to the network (Nokia, 2015).

The main benefit of LTE-M is that the infrastructure is potentially already there, since most LTE base-stations can be upgraded effortless to support LTE-M.
The coverage is then much higher than the alternatives, but how low the cost can be pushed is still unknown. The market for cellular baseband chips is currently dominated by Qualcomm, which owns an extensive range of patents that have blocked till now a serious competition. In future years, the boom of demand, with billions of IoT devices in the market, might change the situation (Hunn, 2015).

Other interesting contenders are Ingenu, SilverSpring’s Starfish, Cyan’s Cynet, Accellus, Telensa, nwave and Waviot. A soaring number of firms are currently joining the market, as it is in the emerging and growth stage. The exponential rise allows a wide differentiation in the products and in the business models, and profits are made targeting different market niches. Different start-ups are driving innovation, and it still not clear which one will be the dominant design in the future.

However, the four technologies presented appear to have more potential to survive the shakeout, the moment in a market where the growth slows down drastically, causing a tougher competition and the failure of many companies. This point is still not reached for the network protocols for IoT, but it will likely come in the next few years, considering the fast dynamic of the market.

As the technology is consolidated, the innovation shifts to process, delivery, and service, and the margins per unit reduce considerably, compensated by the large volume of sales.

Figure 41 visualizes the above-described life cycle for an industry.
It has been noticed that the technological differences are not so evident from one product to another. Even if speed, consumption and range vary, for a given applications there are many suitable alternatives. The aspect that will determine who will succeed in the market is the business models (Hunn, 2015).

Considering the aim of FASCOM of creating a standard in Smart Cities, it is crucial to choose an alternative suited for the purpose, which can ensure long-term planning with low geographical limitation.

A sim card is already present in the current electronic, to monitor the energy production and consumption. However, the closed nature of the software developed by Faktor3 is a limiting circumstance.

The connection to the sensors would require another equipment; hence, LoRa, Sigfox and LTE-M might all be alternatives, while the range of ZigBee is not appropriate for a streetlight application.

Contacts with LoRa and Sigfox have already started, increasing the possibilities that one of the two will be the connectivity installed. How the connectivity will be used is disclosed in the next section.
5.3 FASCOM in the Smart City Environment

Following the comprehension of the two main technologies that can transform FASCOM in a Smart City device, it has been necessary to understand how to integrate them in the device.

The research into IoT sensor companies has disclosed that, most of the time, each of them has developed its own sensors and network, which cannot communicate to other platforms.

In the Big Data framework, however, the value of the collected data is maximum when a holistic view is available, and information from different sectors intersects each other to create shared benefits for all the stakeholders, from companies to citizen and municipalities.

The main aspect that facilitated the proliferation of fragmentation is the lack of standardization, both from a physical and from a software point of view. Sensors utilize different platforms, and each company has to invest heavily to develop it. The devices are installed wherever there is available space in the cities, from balcony to poles. Even when the sensors are located on streetlight, additional cables have to be set up, with the related costs, because the grid turns off during the day, as it is not needed for lighting. The lack of standards consequently produces an unnecessary waste of resources, which has been estimated that could reach $341 billion by 2025 (Sellebråten, 2016).

For these reasons, FASCOM aims to become the physical infrastructure able to standardize the Smart City environment, providing support for sensors and connectivity protocols. The goal is undoubtedly ambitious, and a clear strategy is required to achieve it.

The first step in the direction has been to identify the different players in the market, and their interaction. The value chain of the IoT sector according to the (IoT Catalan Alliance) is presented in Figure 42.
The chain begins with the *actives*, who facilitate the unfolding of the following processes.

Sensors and actuators (components receiving an instruction to perform actions), are connected to a PCB, creating an embedded device. They both communicate to a platform by means of a gateway. As explained before, IoT products have to be equipped with a low-cost, low-energy connectivity; thus, linking them directly to the internet is not the most effective solution, as it is both expensive and complex.

Gateways solve the challenge, collecting raw data from the nodes and bridging them to the internet. Gateways are similar to routers, since both provide internet access, but gateways regulate traffic between two dissimilar networks, translating two different protocols, for example LoRa and the Internet.

The collected data are then ingested and transformed through a middleware, a bridge software that structures raw data into standard form. The information has then reached the platform (Folkens, 2015).

In order to create value, a data mining approach is taken. Data mining is a set of processes where intelligent methods are applied in order to extract data patterns, which can describe the characteristics of previous information or predict the behaviour of new data sets. Machine learning plays an important role in the technique (Illinois University).
The processed data are then delivered to the service provider, who is directly in contact with the client or the beneficiary. The offered solution can be vertical, where the client does not need to possess specific knowledge to apply the solution, or through an application (Rouse).

Transversal features in the value chain are the data privacy and security. Companies specialized in the purposes can thrive at any point of the process.

Unfolded the series of activities in the IoT sector, it has been discussed where SIARQ and its products could position best.

The first consideration that has to be done is that the programming capabilities required to set up a system made of sensors, an online platform or a machine learning software are not present within the SIARQ’s team.

Therefore, it has been agreed that the active role is the most suitable for the company. Indeed, other companies could utilize the physical support offered by FASCOM to develop their own IoT solutions, producing a Smart City device.

The value proposition for the abovementioned firms had to be studied.

First, IoT devices are installed everywhere in the city, without a standard. They can be on streetlights, poles, balconies or even trees. The fragmentation create confusions before the installation, as it is required to scout the location, look for available space, make deals with the entity responsible for the place, and eventually rent it.

The presence of FASCOM will considerably reduce the effort, considering the available place and the openness of the company to external partners.

Second, the sensors require energy. To solve the challenge, they have been equipped with batteries, solar panels or additional cables, adding complexity to the system and increasing the costs. The sensors installed on FASCOM can utilize the free energy coming from the already present battery and the solar panels, with little modifications to be applied. Considering the limited consumption of these devices (see ANNEX), they would not change deeply the energy balance.

Last but not least, sensors need connectivity to communicate with the cloud. At the moment, FASCOM is equipped with a SIM card, which send the energy readings to the web. The service has been developed by Faktor3, which kept the code closed. Therefore, it would not be possible for the sensors to communicate through SOLVEI. This generated numerous disputes, as SIARQ has stated its open-source and open-data position.
Considering that the connectivity is a crucial aspect in the IoT sector, and the presence of different protocols inside FASCOM would go against the effort of creating a standard, the research for a more open electronic has started.

For the short term, it would be a separate PCB from SOLVEI, because a first device has to be ready for the pilot installation in October. There would not be enough time to find a new electronic, suitable for both solar and Smart City applications, and re-code it with the specification developed by Tecnalia about the MPPT.

Obviously, the plan for the long-term is to have just one electronics, and it will happen most likely in 2017.

Considering the need for not only sending the sensors data to the cloud, but also receiving instructions on how to optimize the LEDs consumption or actuate according to the situation (for example, have an addition light that turns red when the air quality is bad), the most suitable technology is LoRa, thanks to its symmetric connection.

The main benefit from integrating sensors and connectivity is the market expansion. Currently, FASCOM can be sold as a solar streetlight, connected to the grid or stand-alone, with an always-oriented solar panel and a customizable photometry. Adding Smart City capabilities will make the product much more desirable, as the market is booming in these years, while not directly impacting the price of the product. Indeed, the sensors will not be sold by SIARQ, and they will be available just where required.

However, the presented position about sensors and connectivity is not definitive yet. SIARQ has started exploring the Smart City market just recently, and it is far from finalizing its business model in the sector.

An innovative approach has been taken for its development. Instead of presenting to the market a definitive product, an iterative procedure will constantly improve the device, following the design thinking methodology.

Design Thinking is a human-centred approach used to solve complex problem and find desirable solutions for the client. It focuses on building new ideas, questioning every step taken, thinking and brainstorming on it, and eventually starts over if one is not satisfied with the results (Ideo, 2016).

Figure 43 summarizes the most important stages in the process.
Initially, it is important to understand the problem. In the Smart City sector, cities have different needs, and it is important to study in depth the case before jumping to conclusion or providing a solution. Once the needs have been found, it should be checked that the initial problem statement was correct; if not, the process must be repeated.

The idea generation process is made of two parts. At the beginning, diversity can be explored by divergent thinking, producing as much ideas as possible. Thereafter, all the alternatives have to studied, neglecting the not relevant ones and converging through the solution.

A prototype can be built based on the first outcomes. The product can be eventually improved by repeating again the process.

An important part of the methodology is to involve people with diverse backgrounds, and possibly customers. In order to do so, SIARQ will organize a design thinking experience with its partners, starting from the pilot line installation in October. Different players in the ecosystems will be invited: citizens, IoT companies, telecommunication companies, universities, living labs, municipalities and energy service companies. This will help in maximizing the value creation for each actor.

It has been exhibited that the presence of a collaborative process, where the citizen have an active role in the development, is an important advantage in a Smart City project. Examples as the Amsterdam Smart Citizens Lab or the Alcoy Makers Place have already proven the viability of the scheme.

SIARQ has already started scouting the potential participators for the first workshop in October, receiving positive feedbacks about the initiative. Regarding the location, it has already been established that an important telecommunication company in Spain will host the devices, testing both the energy performance and the IoT capabilities.
6. Future plans and cost assessment

The ideal initial market has been identified as of those municipalities that are installing new streetlights, have the need to monitor air quality, noise, or any another feature in order to fulfil a citizens’ need, and are early-adopters consumers. It has been decided to focus on small or medium size cities, as they are more agile and receptive to pilot projects, located in Catalonia or Spain, in order to focus the efforts on a limited geographical region.

Considering the slow nature of municipalities, it could take more than a year before the implementation of a project. SIARQ has already made some initial contacts to anticipate the process; among others, Tarragona and Sant Cugat appear to be most promising. In particular, the latter has pre-ordered a stand-alone device that could display to the citizens the noise level, serving the purpose of increasing its reputation as a quiet city. This case is a perfect example of FASCOM being adapted to the client’s requirements, as it was never been thought before to equip the device with a physical display.

The strategy for 2017 of SIARQ is to deploy around ten pilot installations, made of a restricted number of devices, combined with a design thinking experience, in order to produce a product and a business model that would perfectly fit into the Smart City environment, solving real problems of people and companies in the sector.

The limited number of possible sales is constrained by the lack of an industrialized manufacturing process, which results in a high cost per unit and low production capabilities, reducing therefore the potential clients.

The current price for FASCOM has been estimated by the SIARQ’s team to be around 4000 euro, heavily influenced by the last-minute modifications applied after the thermal analysis. The current base mould has been designed indeed for the previous design, and manual modifications have been necessary to adapt it; machining the holes into the base and into the PV module required 650 euros.

In order to avoid a mould investment on a design still to be tested, the cap has been 3D-printed. The process is still quite expensive for elaborated designs, and 1150 euros have been paid for it.

Once the product will be tested and improved after the test in Cadiz and in Barcelona, a new base and cap moulds will be produced. This would mean that the long-term price for the modification is close to zero, as a new mould was necessary even with the previous design.
The main upcoming challenge for the project is finding the resources to invest for an industrialization plan. In order to produce large quantity of a curved photovoltaic module, a new machine has to be designed and manufactured, with an expected investment not lower than half million euros (estimation by Tecnalia).

The new moulds for the base and the cap will have a total cost between 25 and 100 thousand euros, depending on the equipment chosen by the SIARQ’s team. Indeed, it is currently in discussion the possibility of changing the base’s material to plastic, which would reduce the production cost but increase the initial investment required.

To sum up, the business model and the market strategy appear to be promising for the future, thanks to a holistic view on the product and the willingness to collaborate with relevant entities in order to improve it. At the same time, the short term might be more challenging, as SIARQ needs to find investors and start selling a device that is not yet completed. Even if it is actually an advantage in its value proposition, it produces uncertainties that are not welcomed in the business world.

Therefore, the success of FASCOM in the new Smart City market will depend heavily of the ability of SIARQ to convince its clients and investor in the benefits of the design thinking experience and the open business model.

Lastly, an estimation of the workload devoted to the project is presented. Starting from the end of January till the end of June, 8 hours per day, 5 days per week have been dedicated to the internship (which will continue till the end of July 2016). Therefore, 800 hours can be calculated.

The writing of this report has been carried out during additional hours, which can be estimated between 100 and 150.

Moreover, the thermal analysis has been performed mostly during nights, due to the prolonged time required for the simulation to run. Between 8 and 10 hours per night for 30 non-consecutive nights can be assessed, resulting in 240-300 supplementary hour. Therefore, around 1200 total hours can be allocated to the project.
Conclusions

The innovative solar streetlight FASCOM has been presented. The device is currently at TRL6, and the following steps to reach a market-ready state have been unveiled.

The thermal analysis carried out during this work has considerably improved the situation in respect of the initial prototype. The results are currently being tested in a university environment in Cadiz, through temperature sensors installed on the battery, on the photovoltaics module and on a LEDs heat sink. At the moment of writing, there haven’t been yet confirmations over the outcomes. Once the data of the first weeks will be available, a comparison will be performed to improve the accuracy of the simulations, if required.

As previously mentioned, it is expected that the empirical results would be better than the computed ones, since the worst-case scenario has been examined.

Following the assessment of the temperatures on the device, the behaviour of the lithium battery installed on the prototype will be analysed accordingly. In particular, the results obtained will be compared to the ones claimed by the manufacturer in Table 6. Accordingly to the performance exhibited, it will be evaluated when it is required to install the Ni-Mh technology and when it is still effective to keep the Lithium battery.

In the last section, it has been explained why FASCOM can be much more than a solar streetlight, becoming a playground for sensors and connectivity, which have been described and their installation feasibility has been assessed.

The design thinking methodology has been explained, and it has been shown how SIARQ will implement it to add value to the device. The business model is strongly related to it, and it has been justified why it is still a work in progress.

The pilot line installation in October will be the first demonstration of the Smart City device and its innovative collaborative business model. The next stage of the project is obviously to ensure that five units will be ready, together with the new electronic and the sensors that will be tested.

While many improvements are still to be made to produce a marketable device, the team seems on the right track to transform FASCOM in the Solar Hub for Smart Cities.
References


Energy Star. LIGHTING TECHNOLOGIES: A GUIDE TO ENERGY-EFFICIENT ILLUMINATION. s.l. : Energy Star.


SIARQ. Barcelona : SIARQ.


ANNEX

Reflector-type Spherical Silicon Solar Cell

Structure

- Silicon sphere (1.1 mm)
- Reflectors with n-electrode (2.2–2.7 mm)
- Silicon sphere & Reflector
- (Cross Section)
- p-electrode

Feature

1. Comparable Performance to C-Si Wafer-based Cell
   - Utilize the flat dead space of dark area with reflector.
   - Increase current by utilizing reflection of incident light at the edge of spheres.
   - Increase voltage by utilizing light irradiation to the back of spheres.

2. Use of Silicon less than 1/5
   - Silicon saving by reflector use
   - 0 cut loss for spherical silicon

3. Compatible Feature to the Thin-film
   - Flexible shape and light weight
   - Productivity

CV21 Clean Venture 21 Co., Ltd.
### Cell

**Performance**

<table>
<thead>
<tr>
<th>Pmax</th>
<th>0.83W</th>
<th>0.87W</th>
<th>0.91W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vpm</td>
<td>0.47V</td>
<td>0.47V</td>
<td>0.48V</td>
</tr>
<tr>
<td>Ipmax</td>
<td>1.78A</td>
<td>1.85A</td>
<td>1.88A</td>
</tr>
<tr>
<td>Vcc</td>
<td>0.58V</td>
<td>0.59V</td>
<td>0.6V</td>
</tr>
<tr>
<td>Iscc</td>
<td>1.95A</td>
<td>2.02A</td>
<td>2.05A</td>
</tr>
</tbody>
</table>

*Test conditions: cell temperature (25°C), light radiation (AM1.5 1000W/m²)*

**Dimension**

- **a**
- **b**
- **c**
- **d**
- **g**

**Feature**

- Unbreakable
- Flexible
- Cells connected by ultrasonic welding (no lead, no solder)

<table>
<thead>
<tr>
<th>width(a)</th>
<th>154.9mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>length(electrode)(b)</td>
<td>56.0mm</td>
</tr>
<tr>
<td>length(substrate)(c)</td>
<td>53.5mm</td>
</tr>
<tr>
<td>thickness(d)</td>
<td>1.2mm</td>
</tr>
</tbody>
</table>

| Positive electrode(Al film)(e) | 2.5mm×152.9mm×40µm |
| Negative electrode(Al substrate)(f) | 2mm×154.9mm×0.15mm |
| Electricity generation(g) | 152.9mm×50.2mm |

### Cell Connection

**SSC0515-N**

**Number of cells connected**

**Lead connector (+)**

**Lead connector (-)**

**SSC0515**

#Lead connector material: Al / Cu / solder

Dimension subject to customer's request (width: 9mm)

---

**Clean Venture 21 Co., Ltd.**

Sales & Marketing Department

35 Daimotsuchou, Kamitoba, Minami-ward, Kyoto City 601-8121, Japan  
URL: [http://www.cv21.co.jp](http://www.cv21.co.jp)  
E-mail: sales@cv21.co.jp

*As of October 2007  Please acknowledge that contents of this pamphlet are subject to change without prior notice.*

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**Cell Specifications**
**FASCOM versions**
- Stand Alone
- Grid Connected

**Cap**
- Material: Plastic injection mold
- Manufacturing: ABS

**Base**
- Material: Plastic injection mold/Sand casting mold
- Manufacturing: ABS or Aluminum

**Battery**
- Technology: LiFePO4
- Nominal voltage: 12.8 V
- Nominal energy: 40 Jh
- Nominal current: 512 Wh (aprox)
- Op. temperature: 0.4°C (charge), -20.65°C (discharge)
- Protection rating: IP65
- Lifespan: 8 years

**LED Group**
- Nominal current: 350 mA
- Temperature color: 4500 K
- Color rendering index: 70
- Protection rating: IP65
- Lifespan: 6000 hours
- Luminous Flux: 3000 lm (Stand Alone), 6000 lm (Grid Connected)

**Pole**
- Height: 5 m
- Exterior diameter: ø108 mm
- Material: Galvanized (hot)
- Finish: RAL 9006

**Anchorage plate**
- Dimensions: 300 x 300 x 6 mm
- Material: Galvanized (hot)
- Finish: RAL 9006

**Motion Sensors**
- Technology: Passive Infrared (PIR)
- Nominal voltage: 5 V DC
- Nominal current: 170 μA
- Distance detection: 12 m
- Quantity: 2 (connected in parallel)
- Protection rating: IP65
- Lifespan: 10 years

**PV Module**
- Technology: CIS/CsTe/Si
- Efficiency: 10-16 %
- Peak power: 70 Wp (equiv. c-Si)
- Total area: 1.3 m²
- Lifespan: 20 years

**Electronic system SOLVEI FASCOM**

The electronic system can be managed through the 2G communication module and the web server application.

**PV Panel input:**
- Maximum input current: 5 A
- Maximum PV panel Voc: 10 V
- Maximum PV power: 40 W
- Maximum C.efficiency: >95%
- Maximum O.ripple @ 10kHz: 200 mV
- Operation temperature range: -20...70°C

**LED Driver**
- Maximum output current: 500 mA
- Maximum output voltage: 70 V
- Minimum output voltage: 30 V
- Dimming: 0-100%
- Maximum efficiency: >85%
- Operation temperature range: -20...70°C

**Micro-inverter**
- Output voltage: 230 VAC
- Maximum output current: 250 mA
- Input voltage range: 9.15 V
- Maximum input current: 6 A
- Maximum output power: 60 W
- Maximum conversion efficiency: >80%
- Operation temperature range: -20...70°C
- Isolation voltage: >1500 V

*The information contained in this datasheet and the single components could change in accordance with the technological progress.*

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The content includes various specifications related to FASCOM versions, LED groups, poles, anchorage plates, motion sensors, and PV modules. It also describes electronic systems and their applications, emphasizing the use of 2G communication modules and web servers for management. The data includes details on nominal voltages, current ratings, efficiencies, and lifespans, among other technical specifications.
12v40Ah Lead Crystal Battery Datasheet

**LEAD CRYSTAL BATTERIES**

**SPECIFICATION**

- **Nominal Voltage:** 12V
- **Rated Capacity:** 40 AH
- **Dimensions:**
  - Total Height (top of terminal): 172mm
  - Height: 172mm
  - Length: 196mm
  - Width: 150mm
- **Weight:** Approximately 14.59g / 31.94 lbs
- **Capacity:**
  - 120 hour rate: 40AH
  - 20 hour rate: 42AH
- **Internal Resistance:** Fully charged Battery (25°C)
- **Self-Discharge:**
  - Capacity after 3 month storage: 95%
  - Capacity after 6 month storage: 95%
  - Capacity after 12 month storage: 80%
- **Max Discharge Current:** 4.0A (55)
- **Terminal:** Standard F3
- **Optional Charging:** Cycle: Initial Charging Current 1.2A, 14.7V (25°C)
- **Rated Temperature:** 3.86V (25°C)

**DISCHARGE CURRENT AND END VOLTAGE**

<table>
<thead>
<tr>
<th>Discharge current (Ah)</th>
<th>End voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05C or below or intermittent</td>
<td>11.4</td>
</tr>
<tr>
<td>0.1C of current close to it</td>
<td>11.1</td>
</tr>
<tr>
<td>0.2C of current close to it</td>
<td>10.8</td>
</tr>
<tr>
<td>From 0.2C to 0.5C</td>
<td>10.5</td>
</tr>
<tr>
<td>From 0.5C to 1C</td>
<td>10.3</td>
</tr>
<tr>
<td>From 1C to 3C</td>
<td>9.6</td>
</tr>
<tr>
<td>Current in excess of 3C</td>
<td>9.0</td>
</tr>
</tbody>
</table>

**CHARGE vs TEMPERATURE CHART**

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Cycle Charge</th>
<th>Float Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>-40 to -35</td>
<td>2.66</td>
<td>2.64</td>
</tr>
<tr>
<td>-30 to -25</td>
<td>2.62</td>
<td>2.60</td>
</tr>
<tr>
<td>-20 to -15</td>
<td>2.58</td>
<td>2.56</td>
</tr>
<tr>
<td>-10 to -5</td>
<td>2.54</td>
<td>2.52</td>
</tr>
<tr>
<td>0 to 5</td>
<td>2.47</td>
<td>2.45</td>
</tr>
<tr>
<td>5 to 10</td>
<td>2.45</td>
<td>2.44</td>
</tr>
<tr>
<td>10 to 20</td>
<td>2.42</td>
<td>2.40</td>
</tr>
<tr>
<td>20 to 30</td>
<td>2.38</td>
<td>2.36</td>
</tr>
<tr>
<td>30 to 35</td>
<td>2.34</td>
<td>2.32</td>
</tr>
<tr>
<td>35 to 40</td>
<td>2.30</td>
<td>2.29</td>
</tr>
<tr>
<td>40 to 45</td>
<td>2.27</td>
<td>2.26</td>
</tr>
<tr>
<td>45 to 50</td>
<td>2.24</td>
<td>2.23</td>
</tr>
<tr>
<td>50 to 55</td>
<td>2.22</td>
<td>2.23</td>
</tr>
<tr>
<td>55 to 60</td>
<td>2.21</td>
<td>2.23</td>
</tr>
<tr>
<td>60 to 65</td>
<td>2.20</td>
<td>2.23</td>
</tr>
<tr>
<td>65 to 70</td>
<td>2.20</td>
<td>2.23</td>
</tr>
</tbody>
</table>

**CURRENT CONSTANT DISCHARGE CHARACTERISTICS: UNITS AMPERES (25°C)**

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>5min</th>
<th>15min</th>
<th>30min</th>
<th>45min</th>
<th>1h</th>
<th>2h</th>
<th>3h</th>
<th>4h</th>
<th>5h</th>
<th>6h</th>
<th>8h</th>
<th>10h</th>
<th>12h</th>
<th>20h</th>
<th>24h</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.60V</td>
<td>154.76</td>
<td>77.69</td>
<td>44.94</td>
<td>34.22</td>
<td>27.56</td>
<td>15.79</td>
<td>11.47</td>
<td>8.99</td>
<td>7.67</td>
<td>6.52</td>
<td>4.97</td>
<td>4.14</td>
<td>3.47</td>
<td>2.25</td>
<td>1.84</td>
</tr>
<tr>
<td>1.70V</td>
<td>135.42</td>
<td>75.14</td>
<td>46.24</td>
<td>33.98</td>
<td>27.51</td>
<td>15.72</td>
<td>11.26</td>
<td>8.95</td>
<td>7.56</td>
<td>6.47</td>
<td>4.96</td>
<td>4.09</td>
<td>3.47</td>
<td>2.25</td>
<td>1.84</td>
</tr>
<tr>
<td>1.80V</td>
<td>110.98</td>
<td>67.06</td>
<td>43.46</td>
<td>32.37</td>
<td>26.63</td>
<td>15.05</td>
<td>11.10</td>
<td>8.76</td>
<td>7.38</td>
<td>6.29</td>
<td>4.90</td>
<td>4.00</td>
<td>3.42</td>
<td>2.16</td>
<td>1.83</td>
</tr>
<tr>
<td>1.90V</td>
<td>106.74</td>
<td>61.50</td>
<td>42.78</td>
<td>31.22</td>
<td>24.97</td>
<td>14.91</td>
<td>10.66</td>
<td>8.39</td>
<td>7.12</td>
<td>6.06</td>
<td>4.80</td>
<td>3.84</td>
<td>3.28</td>
<td>2.14</td>
<td>1.81</td>
</tr>
<tr>
<td>2.00V</td>
<td>99.47</td>
<td>59.65</td>
<td>40.00</td>
<td>30.06</td>
<td>24.28</td>
<td>14.31</td>
<td>10.38</td>
<td>8.28</td>
<td>6.94</td>
<td>5.86</td>
<td>4.74</td>
<td>3.79</td>
<td>3.24</td>
<td>2.12</td>
<td>1.79</td>
</tr>
</tbody>
</table>

**DISCHARGE DATA WITH CONSTANT POWER UNITS: WATTS PER CELL (25°C)**

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>5min</th>
<th>15min</th>
<th>30min</th>
<th>45min</th>
<th>1h</th>
<th>2h</th>
<th>3h</th>
<th>4h</th>
<th>5h</th>
<th>6h</th>
<th>8h</th>
<th>10h</th>
<th>12h</th>
<th>20h</th>
<th>24h</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.60V</td>
<td>245.28</td>
<td>136.60</td>
<td>87.85</td>
<td>64.04</td>
<td>51.51</td>
<td>29.82</td>
<td>21.80</td>
<td>17.27</td>
<td>14.59</td>
<td>12.53</td>
<td>9.66</td>
<td>8.00</td>
<td>6.73</td>
<td>4.49</td>
<td>3.68</td>
</tr>
<tr>
<td>1.70V</td>
<td>233.49</td>
<td>134.32</td>
<td>84.30</td>
<td>63.58</td>
<td>51.59</td>
<td>29.82</td>
<td>21.52</td>
<td>17.25</td>
<td>14.59</td>
<td>12.51</td>
<td>9.66</td>
<td>8.00</td>
<td>6.73</td>
<td>4.48</td>
<td>3.68</td>
</tr>
<tr>
<td>1.80V</td>
<td>232.10</td>
<td>133.13</td>
<td>84.26</td>
<td>63.58</td>
<td>51.09</td>
<td>29.59</td>
<td>21.48</td>
<td>17.18</td>
<td>14.36</td>
<td>12.41</td>
<td>9.59</td>
<td>7.91</td>
<td>6.66</td>
<td>4.46</td>
<td>3.68</td>
</tr>
<tr>
<td>1.90V</td>
<td>216.15</td>
<td>131.77</td>
<td>83.35</td>
<td>63.58</td>
<td>50.98</td>
<td>29.36</td>
<td>21.43</td>
<td>17.15</td>
<td>14.31</td>
<td>12.32</td>
<td>9.55</td>
<td>7.85</td>
<td>6.66</td>
<td>4.46</td>
<td>3.65</td>
</tr>
<tr>
<td>2.00V</td>
<td>198.35</td>
<td>125.07</td>
<td>82.53</td>
<td>62.42</td>
<td>50.63</td>
<td>29.36</td>
<td>21.41</td>
<td>17.11</td>
<td>14.22</td>
<td>12.32</td>
<td>9.52</td>
<td>7.81</td>
<td>6.66</td>
<td>4.35</td>
<td>3.65</td>
</tr>
<tr>
<td>2.10V</td>
<td>191.42</td>
<td>114.90</td>
<td>81.84</td>
<td>60.57</td>
<td>48.58</td>
<td>29.13</td>
<td>20.91</td>
<td>16.93</td>
<td>14.06</td>
<td>11.93</td>
<td>9.52</td>
<td>7.58</td>
<td>6.54</td>
<td>4.30</td>
<td>3.63</td>
</tr>
<tr>
<td>2.20V</td>
<td>177.32</td>
<td>112.35</td>
<td>76.66</td>
<td>58.26</td>
<td>47.16</td>
<td>28.44</td>
<td>20.23</td>
<td>16.32</td>
<td>13.66</td>
<td>11.70</td>
<td>9.16</td>
<td>7.51</td>
<td>6.43</td>
<td>4.25</td>
<td>3.61</td>
</tr>
</tbody>
</table>
## 12v40Ah LiFePO4 Battery Datasheet

**HETER ELECTRONICS GROUP**  
Add: Guangming Road, Zaozhuang City, China  
Tel:+86-632-5292977  Fax:+86-632-5199218  
E-mail:markertl9@heter.biz  
Website:www.heterbattery.com

--------------------------------------------------------------------------------------------------------------------------

### QUOTATION SHEET

<table>
<thead>
<tr>
<th>PRICE TERM</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Sample Price</td>
<td>USD 361 / unit</td>
</tr>
<tr>
<td>Battery Order Price (&lt;100pcs)</td>
<td>USD 331/ unit</td>
</tr>
<tr>
<td>Battery Order Price (&gt;100pcs)</td>
<td>USD 327 / unit</td>
</tr>
</tbody>
</table>

### MAIN KIT INCLUDES

- 1 x 12v40Ah LiFePO4 Battery Module;
- 1 x LiFePO4-4S-40A BMS (Reference);
- 1 x PVC Soft Package

### PRODUCT SPECIFICATION

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Voltage</td>
<td>12.8v</td>
</tr>
<tr>
<td>Normal Capacity</td>
<td>41.6Ah (C5)</td>
</tr>
<tr>
<td>Battery Energy</td>
<td>532.48Wh (Approx)</td>
</tr>
<tr>
<td>Cell Assembled Mode</td>
<td>LFP-26650-3.2v-3200mAh-4S13P</td>
</tr>
<tr>
<td>Life Cycle</td>
<td>2000 Times (Approx)</td>
</tr>
<tr>
<td>Battery Continuous Discharge</td>
<td>80A (Max)</td>
</tr>
<tr>
<td>BMS Protection Current</td>
<td>40A (Default)</td>
</tr>
<tr>
<td>BMS Function</td>
<td>Over charge protection; Over discharge protection; Over current protection; Temperature protection; Balanced function, etc.</td>
</tr>
<tr>
<td>Discharge Cut-Off Voltage</td>
<td>10v</td>
</tr>
<tr>
<td>Max. Charge Voltage</td>
<td>14.4v; Charge Mode: CC/CV</td>
</tr>
<tr>
<td>Inner Resistance</td>
<td>&lt; 35mΩ</td>
</tr>
<tr>
<td>Reference Size</td>
<td>(270 ± 2) * (160 ± 2) * (85 ± 2) mm</td>
</tr>
<tr>
<td>Actual Size</td>
<td>Customer Size; Please Inform,</td>
</tr>
<tr>
<td><strong>Total Battery Weight</strong></td>
<td>&lt;=5KG (Approx)</td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td><strong>Charge &amp; Discharge Mode Choice</strong></td>
<td>Same Wires</td>
</tr>
<tr>
<td><strong>Charge Time</strong></td>
<td>Depend on battery charger</td>
</tr>
<tr>
<td><strong>Operation Temperature Range</strong></td>
<td>Charge: 0°C—45°C  Discharge: -20°C—65°C</td>
</tr>
<tr>
<td><strong>Storage Temperature</strong></td>
<td>0°C—40°C (Long Time Storage: 15°C—25°C)</td>
</tr>
<tr>
<td><strong>Battery Logo and Printing</strong></td>
<td>Customer Label / Heter Label / Neutral (Default)</td>
</tr>
<tr>
<td><strong>Battery Box Material</strong></td>
<td>PVC</td>
</tr>
<tr>
<td><strong>Assembled Cell Certificate</strong></td>
<td>CE; UL; UN38.3; MSDS; RoHS; SGS;</td>
</tr>
<tr>
<td><strong>Limited Warranty</strong></td>
<td>24 Month</td>
</tr>
</tbody>
</table>

**PACKAGE**

<table>
<thead>
<tr>
<th><strong>Outside Package</strong></th>
<th>Standard Carton+EPE Cotton</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reference Carton Size:</strong></td>
<td>310<em>165</em>125mm</td>
</tr>
<tr>
<td><strong>Quantity/20'FCL</strong></td>
<td>More than 2000pcs</td>
</tr>
</tbody>
</table>

**TRADE INFORMATION**

<table>
<thead>
<tr>
<th><strong>Sample Lead Time</strong></th>
<th>14——21 Business Days (After Payment Confirmed)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Order Lead Time</strong></td>
<td>21——35 Business Days (After Deposit Confirmed)</td>
</tr>
<tr>
<td><strong>Sample Payment Term</strong></td>
<td>T/T in advance</td>
</tr>
<tr>
<td><strong>Order Payment Term</strong></td>
<td>T/T in advance 30% deposit, the balance paid before delivery</td>
</tr>
<tr>
<td><strong>MOQ</strong></td>
<td>1pce</td>
</tr>
<tr>
<td><strong>Loading Port</strong></td>
<td>Shenzhen, China</td>
</tr>
<tr>
<td><strong>Quotation Validity</strong></td>
<td>30 days</td>
</tr>
</tbody>
</table>

**OPTIONAL ITEM (Charger Price Not Included In Battery Price)**

<table>
<thead>
<tr>
<th><strong>Lithium Battery Charger</strong></th>
<th>14.4v10A (Charge Time: &lt;5 hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FOB Price</strong></td>
<td>USD 48</td>
</tr>
</tbody>
</table>

**SERVICE**

1. CUSTOMIZATION.
2. OEM

**REMARK**

- If customers don’t inform their detailed requirements after checking quotation, We will choose default value.
<table>
<thead>
<tr>
<th>Sensor</th>
<th>Product Name</th>
<th>Company</th>
<th>Dimensions</th>
<th>Max Energy Consumption</th>
<th>Characteristics</th>
<th>Can Be Installed at 5m?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-axis accelerometer</td>
<td>AGF11311</td>
<td>Panasonic / Avnet</td>
<td>58x36.5x33mm</td>
<td>50 mW</td>
<td>Inclination detection</td>
<td>Yes</td>
</tr>
<tr>
<td>2-axis accelerometer</td>
<td>AGS211</td>
<td>Panasonic / Avnet</td>
<td>6.2 x 8.5x1,6 mm</td>
<td>5 V, 2 mA -&gt; 10 mW</td>
<td>Inclination detection</td>
<td>Yes</td>
</tr>
<tr>
<td>CH4 Methane</td>
<td>CH-A3</td>
<td>Libellium</td>
<td>≈18 x 20 x 16 mm</td>
<td>3.3 V, 68mA -&gt; 225 mW</td>
<td>0 to 100% LEL methane</td>
<td>Yes, suggested at 2 m</td>
</tr>
<tr>
<td>CO</td>
<td>4-CO-500</td>
<td>Libellium</td>
<td>18 x 20 x 16 mm</td>
<td>3.3 V, 1mA -&gt; 3.3 mW</td>
<td>0 to 500 ppm, 1 ppm resolution</td>
<td>Yes, suggested at 2 m</td>
</tr>
<tr>
<td>Co2</td>
<td>Telaire® 6613 CO</td>
<td>Avnet</td>
<td>57.15 x 34.67 x 15.24 mm</td>
<td>0.9 W (0.165 W average)</td>
<td>0 to 2000 ppm</td>
<td>Yes, suggested at 2 m</td>
</tr>
<tr>
<td>Co2</td>
<td>INE20-CO2P-NCVSP</td>
<td>Libellium</td>
<td>≈18 x 20 x 16 mm</td>
<td>3.3 V, 80mA -&gt; 264 mW</td>
<td>0 to 5000 ppm, 25 ppm resolution</td>
<td>Yes, suggested at 2 m</td>
</tr>
<tr>
<td>CO2</td>
<td>AirSenseModel 310 CO2 Monitor</td>
<td>GSB</td>
<td>13x8x35 mm</td>
<td>28 V, 20mA -&gt; 0.56 W</td>
<td>0 - 5000 ppm</td>
<td>Yes, suggested at 2 m</td>
</tr>
<tr>
<td>Dust Sensor</td>
<td>GP2Y1010A U0F</td>
<td>Sharp / Libelium</td>
<td>46.0 x 30.0 x 17.6 mm</td>
<td>5 V, 20mA -&gt; 100 mW</td>
<td>0.65 Volt change every 0.1mg/m3</td>
<td>Yes</td>
</tr>
<tr>
<td>GYROSCOPE</td>
<td>ENC03</td>
<td>Murata/Avnet</td>
<td>8x4x2 mm</td>
<td>5 V</td>
<td>measure angular rate or orientation</td>
<td>Yes</td>
</tr>
<tr>
<td>Gyroscope and accelerometer</td>
<td>SCC1300-D02</td>
<td>Murata/Avnet</td>
<td>8.5 x 18.7 x 4.5 mm</td>
<td>5V, 30 mA -&gt; 150 mW</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Sensor</td>
<td>Model</td>
<td>Brand</td>
<td>Dimensions (mm)</td>
<td>Power Supply</td>
<td>Measurement Range</td>
<td>Accuracy</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
<td>-------------</td>
<td>-----------------</td>
<td>--------------</td>
<td>-------------------</td>
<td>----------</td>
</tr>
<tr>
<td>H₂S</td>
<td>4-H₂S-100</td>
<td>Libellium</td>
<td>≈18 x 20 x 16</td>
<td>3.3 V, 1mA → 3.3 mW</td>
<td>0 to 200 ppm</td>
<td>Yes, suggested at 2 m</td>
</tr>
<tr>
<td>HCl</td>
<td>4-HCl-50</td>
<td>Libellium</td>
<td>≈18 x 20 x 16</td>
<td>3.3 V, 1mA → 3.3 mW</td>
<td>0 to 50 ppm</td>
<td>Yes, suggested at 2 m</td>
</tr>
<tr>
<td>Humidity</td>
<td>HSHCAA006</td>
<td>Avnet</td>
<td>2.5×2×1.0</td>
<td>5 V, 0.5 mA → 25 mW</td>
<td>0 to 100%RH</td>
<td>Yes</td>
</tr>
<tr>
<td>Humidity</td>
<td>SENS-808H5V5</td>
<td>Libellium / TME</td>
<td>12.2x8x4mm</td>
<td></td>
<td>Errors ≤ ± 4%</td>
<td>Yes</td>
</tr>
<tr>
<td>Humidity</td>
<td>2381 691 90001</td>
<td>Vishay / Avnet</td>
<td>2.5 mm x 2.5 mm</td>
<td></td>
<td>10 to 90% RH</td>
<td>Yes</td>
</tr>
<tr>
<td>Noise sensor</td>
<td>WM-61A</td>
<td>Panasonic</td>
<td>6 x 3.4 x 3.4</td>
<td>2 V, 0.5 mA → 4 mW</td>
<td>3 dB sensitivity</td>
<td>Yes</td>
</tr>
<tr>
<td>NH₃ - Ammonia</td>
<td>4-NH₃-100</td>
<td>Libellium</td>
<td>≈18 x 20 x 16</td>
<td>3.3 V, 1mA → 3.3 mW</td>
<td>0 to 100 ppm</td>
<td>Yes, suggested at 2 m</td>
</tr>
<tr>
<td>NO</td>
<td>4-NO-250</td>
<td>Libellium</td>
<td>≈18 x 20 x 16</td>
<td>3.3 V, 1mA → 3.3 mW</td>
<td>0 to 250 ppm</td>
<td>Yes, suggested at 2 m</td>
</tr>
<tr>
<td>NO₂</td>
<td>4-NO₂-20</td>
<td>Libellium</td>
<td>≈18 x 20 x 16</td>
<td>3.3 V, 1mA → 3.3 mW</td>
<td>0 to 20 ppm</td>
<td>Yes, suggested at 2 m</td>
</tr>
<tr>
<td>Noise</td>
<td>TA120</td>
<td>CeSvA</td>
<td>395 x 120 x 91</td>
<td>1 W</td>
<td>from 35 to 120 dBA</td>
<td>Yes</td>
</tr>
<tr>
<td>Noise</td>
<td>SC420</td>
<td>CeSvA</td>
<td>292 x 85 x 25</td>
<td>Integrated Battery</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Noise</td>
<td>U-Sound</td>
<td>Urbiotica</td>
<td>340x70x160 mm</td>
<td>Powered by the grid or solar panel</td>
<td>from 40 dB(A) to 110 dB(A) with an accuracy of ±2dB</td>
<td>Yes</td>
</tr>
<tr>
<td>Noise</td>
<td>LM2904</td>
<td>Zolertia / Grove</td>
<td>3.3V to 10 V</td>
<td>48 to 66 dB</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>------------------</td>
<td>--------------</td>
<td>-------------</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>O2</td>
<td>4-OL</td>
<td>Libellium</td>
<td>=18 x 20 x 16 mm</td>
<td>3.3 V, 1mA → 3.3 mW</td>
<td>0 to 30 Vol.%</td>
<td>Yes, suggested at 2 m</td>
</tr>
<tr>
<td>O3</td>
<td>OX-A421</td>
<td>Libellium</td>
<td>=18 x 20 x 16 mm</td>
<td>3.3 V, 1mA → 3.3 mW</td>
<td>0 to 20 ppm</td>
<td>Yes, suggested at 2 m</td>
</tr>
<tr>
<td>Others contaminants</td>
<td></td>
<td>Libellium</td>
<td>Similar...</td>
<td>Similar...</td>
<td>Similar...</td>
<td>Yes, suggested at 2 m</td>
</tr>
<tr>
<td>Parking</td>
<td>U-spot</td>
<td>Urbiotica</td>
<td>95x68x83 mm</td>
<td>10 Years Battery Included</td>
<td>Under the ground installation</td>
<td>No</td>
</tr>
<tr>
<td>Particle Matter (PM1 / PM2.5 / PM10)</td>
<td>OPC-N2</td>
<td>Libellium</td>
<td>75x60x44 mm</td>
<td>5 V, 250 mA → 1,25 W</td>
<td>0.38 to 17 particle range</td>
<td>Yes</td>
</tr>
<tr>
<td>Pressure</td>
<td>NPC-1210</td>
<td>GE/Avnet</td>
<td>15x15x12 mm</td>
<td>3.3 V, 1.5 mA → 5 mW</td>
<td>0,34 - 7 bar</td>
<td>Yes</td>
</tr>
<tr>
<td>Pressure</td>
<td></td>
<td>Libellium</td>
<td></td>
<td>3.3V, 4,2 uA → 13,9 uW</td>
<td>30 to 110 kPa, +0,1 kPa</td>
<td>Yes</td>
</tr>
<tr>
<td>SO2</td>
<td>4-SO2-20</td>
<td>Libellium</td>
<td>=18 x 20 x 16 mm</td>
<td>3.3 V, 1mA → 3.3 mW</td>
<td>0 to 20 ppm</td>
<td>Yes, suggested at 2 m</td>
</tr>
<tr>
<td>Temperature</td>
<td>TDK-EPC 0402</td>
<td>Epcos/Avnet</td>
<td>1x0,5x0,6 mm</td>
<td>150 mW</td>
<td>-55 ° - 250°C</td>
<td>Yes</td>
</tr>
<tr>
<td>Temperature</td>
<td>MCP9700A</td>
<td>Libellium</td>
<td>1,12x3,05x0,5 mm (just chip)</td>
<td>5,5 V, 6 uA → around 33 uW</td>
<td>From -40 to 125°C, 2° C Accuracy</td>
<td>Yes</td>
</tr>
</tbody>
</table>