# Investigation of an autonomous energy system for the ICELABPATAGONIA II in Karukinka Natural Park, Chile


## Maria Paula Alfonso


## Master's in Energy Technologies Final Thesis - MSc ENTECH

Tutor:

- Prof. Ing. Andreas Wagner (FBTA - KIT)

Corrector:

- Prof. Dr. Ing Martin Gabi (ISTM - KIT)
- Dra. Ing. Cecilia Smoglie (ITBA)

Karlsruhe, March 2017

***"The IEA believes that the world needs a clean energy revolution in order to break dependence on fossil fuels. Such a revolution would enhance global energy security, promote enduring economic growth and tackle environmental challenges such as climate change. It would break the long-standing link between economic growth and carbon dioxide ($CO_2$) emissions. But to succeed, it must also be truly global in scope"*.**

International Energy Agency [1]

# Abstract

English

In the ICELABPatagonia project, different laboratories for Karukinka National Park in Chile were designed. The main objective of these laboratories was to provide shelter against the area’s tough weather conditions, specifically intended for small groups of researchers. The goal behind this design was ensuring environmental preservation as a priority. In order to achieve this, the buildings were required to not produce waste during the construction stages and as well as post construction. In a second stage (the project ICELAB II), a design between five possible candidates was selected and later built.

This thesis is meant to provide an in depth review of such design. It has been divided into two stages: The first step consists of taking advantage of natural lighting and reducing energy usage for heating. This was accomplished through the addition of new openings and the installation of insulation materials in walls, roofs, floors and windows. DesignBuilder software was used to simulate the alternate results of installing insulation materials, glazing, air tightness and opening percentages alternatives. As a result, when using fiber glass bats insulation the total heating loss was reduced by 60% from the original design. In addition, electrical demand was reduced by 0.8kWh/day as a result of installing new windows. Natural ventilation was considered as an alternative for cooling the building during summer to avoid overheating. The second step involves the design of an autonomous energy system using photovoltaic cells, consisting of a standalone system which provides the building with electricity without being connected to the grid or requiring a backup system. An 8 module (260kWp) system was selected together with a 4086Ah and 24V battery pack, to supply a 7.26kWh/day demand.

Since the original project did not contemplate winter usage of the laboratory, further analysis was executed resulting in the reduction of batteries required: from 18 batteries+8 modules to 15+4.

Spanish - Español

Para el proyecto ICELAB Patagonia se diseñaron diferentes laboratorios para el Parque Nacional Karukinka en Chile. Estos edificios tenían como objetivo poder alojar entre 5 a 10 días a un número reducido de investigadores proveyéndoles refugio frente a las arduas condiciones climáticas presentes en la región. Al mismo tiempo, es prioritario la conservación del área, ya que se trata de una zona virgen, debido a esto los edificios diseñados no debían generar ningún tipo de desecho durante su construcción y posterior uso. En una segunda fase del proyecto (ICELAB II), se selecciono un diseño entre cinco posibles candidatos para ser posteriormente construido.

El objetivo de esta tesis es trabajar sobre el diseño elegido, en dos etapas. La primera consiste en introducir mejoras en los sistemas de aislación de paredes, techo, piso y ventanas, que aseguren una estancia confortable, y al mismo tiempo una reducción en el consumo de energía debido a la calefacción. Mediante la utilización del software DesignBuilder, diferentes materiales aislantes y

coeficientes de infiltración fueron modelados. La utilización de fibra de vidrio permitió reducir las pérdidas de calor en un 60%. A su vez, el aumento del número de ventanas generó un mayor aprovechamiento de la luz natural, reduciendo el uso de luz artificial en 0.8kWh/día. Por último el uso de ventilación natural fue estudiado como sistema de refrigeración para el verano, de forma de evitar el sobrecalentamiento del edificio durante esta época, dando óptimos resultados. La segunda etapa supone el diseño de un sistema autónomo de energía (basado en energía fotovoltaica) que brinde electricidad al laboratorio. Este sistema debe poder suplir las necesidades de los usuarios (7.26kWh/día) sin contar con integración a la red eléctrica del país o a un sistema auxiliar. Utilizando el software PVsyst junto con cálculos manuales un sistema compuesto por 8 módulos solares de 260kWp, junto con un set de 18 baterías (con una potencia total de 4086Ah y 24V) fue seleccionado como mejor opción para todo el año. Finalmente, se estudió la posibilidad de reducir el sistema ya que el proyecto original no contempla el uso del laboratorio durante invierno. Este caso resultó en un sistema formado por 15 baterías y 4 paneles solares en lugar de 18 y 8 respectivamente.

German - Deutsch

Im ICELABPatagonia-Projekt wurden verschiedene Labore für den Karukinka-Nationalpark in Chile entworfen. Das Hauptziel dieser Laboratorien was es, Schutz vor den schwierigen Witterungsbedingungen des Gebiets für kleine Forschergruppen zu bieten. Das Ziel was die Sicherung der Umweltbewahrung als Priorität. Um dies zu erreichen, mussten die Gebäude während der Bauphasen und des Postaufbaus keine Abfälle produzieren. In einem zweiten Stadium (das Projekt ICELAB II) wurde ein Entwurf zwischen fünf möglichen Kandidaten ausgewählt und später gebaut.

Diese These soll einen Überblick über diese Gestaltung geben. Es wurde in zwei Stufen unterteilt: Der erste Schritt besteht darin, die natürliche Beleuchtung zu nutzen und den Energieverbrauch für die Heizung zu reduzieren. Hinzufügen neuer Öffnungen und die Installation von Dämmstoffen in Wänden, Dächern, Böden und Fenstern wurde dies erreicht. DesignBuilder Software wurde verwendet, um die alternativen Ergebnisse der Installation von Dämmstoffen, Verglasung, Luftdichtigkeit und Eröffnungsprozentsätze Alternativen zu simulieren. Bei der Verwendung von Glasfaser-Isolierungen wurde der gesamte Heizverlust um 60% reduziert. Darüber hinaus wurde die elektrische Nachfrage um 0,8 kWh / Tag reduziert, da neue Fenster installiert wurden. Natürliche Belüftung wurde als Alternative zur Kühlung des Gebäudes im Sommer betrachtet. Der zweite Schritt beinhaltet die Konstruktion eines autonomen Energiesystems mit Photovoltaikzellen. Bestehend aus einem eigenständigen System, das das Gebäude mit Strom versorgt, ohne an das Stromnetz angeschlossen zu sein oder ein Backup-System zu erfordern. Ein 8-Modul (260kWp) System wurde zusammen mit einem 4086Ah und 24V Akku ausgewählt, um eine 7.26kWh / Tag Nachfrage zu liefern. Da das ursprüngliche Projekt die Winternutzung des Labors nicht in Erwägung gezogen hat, wurde eine weitere Analyse durchgeführt, die zu einer Verringerung der benötigten Batterien führte: von 18 Batterien + 8 Modulen bis 15 + 4.

## Declaration of Authorship

I declare that I have developed and written the content of this Master Thesis entirely by myself, and that I have not used unreferenced sources. Any thoughts from other authors or literal quotations are clearly marked. This work has not been used in the same or in a similar version to achieve an academic grading or is being published elsewhere.

# Table of contents

## List of Appendices

# List of figures

## List of tables

# List of appendices' figures



# List of appendices' tables

## List of units

| | | | |
|---|---|---|---|
| Temperature | | K | Kelvin |
| Power | | W | Watts |
| Energy | | Wh or kWh | Watt per hour or kiloWatts per hour |
| Distance | | m or cm or mm | Meters or centimetres or millimetres |
| Weight | | kg | Kilograms |
| Velocity | | m/s | Meters per second |
| Current | | A | Amperes |
| Current flow | | Ah | Ampere hour |
| Voltage | | V | Volt |
| Heat transfer | | W/m K | Watt per meter and Kelvin |
| Resistance heat flow | R-value | $m^2$*K/W | square-meter per Kelvin divided by Watt |
| Thermal transmittance | U-value | W/$m^2$*K | Watt per square-meter and Kelvin |
| Solar heat gain coefficient | g-value | % | Percentage |
| Air flow | | ac/h | Airchange per hour |
| Radiation | | kWh/$m^2$/day | kiloWatts per hour per square-meter and day |
| Altitude | | masl | Meters above sea level |
| Irradiation | $HPS_{crit}$ | W/$m^2$ | Watt per square-meter |
| Daily average energy demand | $L_{md}$ | kWh/day | kiloWatt per hour a day |
| Battery voltage | $V_{bat}$ | V | Volts |
| Daily average current demand | $Q_{Ah}$ | Ah/day | Ampere per hour a day |
| Inverter efficiency | $\eta_{inv}$ | - | - |
| Battery efficiency | $\eta_{bat}$ | - | - |
| Wired efficiency | $\eta_{cond}$ | - | - |

| | | | |
|---|---|---|---|
| Security factor | SC | - | - |
| Total number of panels | $N_T$ | - | - |
| Total number of panels in series | Nserie | - | - |
| Total number of panels in parallel | Nparallel | - | - |
| Module peak power | $P_{MPP}$ | kWp | kiloWatt peak |
| Functioning global factor | PR | - | - |
| Open circuit voltage | $V_{oc}$ | V | Volts |
| Maximum power point voltage | $V_{mpp}$ | V | Volts |
| Maximum power point current | $I_{mpp}$ | A | Amperes |
| Short circuit current | $I_{sc}$ | A | Amperes |
| Module efficiency | $\eta_m$ | - | - |
| State of charge | SOC | - | - |
| Depth of discharged | DOD | - | - |
| Autonomy | N | d | Days |
| Battery nominal capacity | $C_n$ | Wh or Ah | Watt per hour or Ampere per hour |

# Introduction

*This chapter gives an overview of the project ICELAB, in which the current thesis is based. It introduces the concept behind the project and its objective.*

## Introduction

The development of all nations around the world was based mainly on the use of natural resources, leading to the damage of several ecosystems and the loss of both flora and fauna species. Although this growth cannot be stopped, several measures must be taken in order to protect and preserve the natural environment.

Being energy one of the main axes for the development of a country, regulations which promote a shift towards newer non-fossil-fuel-reliant generation methods should be put in place. For construction, autonomous renewable generation systems present a viable alternative.

At the same time, more energy efficient buildings need to be designed in order to ensure demand reduction. To achieve this thermal insulation materials and insulation glazing is used.

## ICELABPatagonia Project

As it is mentioned in the "ICELABPatagonia Dokumentation" paper, Patagonia's landscape is nowadays one of the few places that remains almost virgin. This means that no significant change has been done by the man in the environment. Nowadays it is possible to find the same scenery that was there hundred years ago. Although this presents great economic potential for tourism, it could generate an important change, that will lead to the destruction of the place and the loss of identity.

The concept behind the project arises from the idea to let people know the place without transforming it. *"The Environmental Research Laboratory may be a proposal in order to approach the place with extreme caution and give the scientists the opportunity to have an operational base in the place".*

Due to the location, environmental conditions and climate will play an important role in the building's construction. The design aims to ensure that no waste is generated during the building's construction and use, maintaining conditions of habitability and comfort which are essential for the natural development of the human activity.

The construction will house two people permanently, and have capacity for more during working hours. It will have  water and electric networks. The objective of the construction is to give shelter against outside conditions for short term investigations. For this reason all systems are designed to allow people to remain there between five to ten days Furthermore, it's simple construction based on an easy assembly allows for moving it if it was necessary.

The building will be located in the Chilean Karukinka Park (Appendix A). The park consists of 300,000 hectares of mountains and forest, which makes the park hard to be accessed. It is located in the southern part of Isla Grande de Tierra del Fuego in Chile, limiting with Argentina and nearby Ushuaia. The climate is sub polar oceanic similar to Iceland. There is not great temperature variation between summer and winter, with an average between 9C and 1C. It is characterized by its short summers, strong winds (around 25km/h) and constant amount of precipitations during the entire year, which makes the region inhospitable. During the winter season, the light hours are reduced, with sunrise at around 9.30 and sunset at around 15.00.

# Insulation

*This section presents the state of the art on insulation material and glazing as well as the current regulation around thermal insulation in Chile.*

## Introduction

Although energy from renewable sources is currently widely used, efficiency levels parallel to conventional plants have not been achieved yet as they cannot ensure the same amount of energy production. Furthermore, they are reliant on the weather conditions; therefore being unable to ensure a steady offer across seasons. For this reason, searching for new ways that allow managing and reducing energy demand are necessary to help this renewable systems. In this context, thermal insulation materials and insulation glazing play an important role in a building's energy behaviour which helps the current renewable energy production technology by reducing the energy need (for heating or cooling) inside the building.

People have used thermal insulation in order make buildings more comfortable when energy was less available, and heating-and-cooling devices were not as efficient as they are today. An unsuitable design of building envelope can generate significant heat losses in regions with harsh climatic conditions, requiring an increase in the heating and cooling capacity. The selection of adequate thermal insulation and insulation glazing can lead to reduction in the annual energy cost. They are a key element when building an energy thrifty construction.

## Thermal insulation

"*Thermal insulation is a material or combination of materials, that, when properly applied, retard the rate of heat flow by conduction, convection, and radiation. It retards heat flow into or out of a building due to its high thermal resistance.*" [2]

Heat transfers occur due to temperature difference (which are measured in Kelvin). Conductivity is the rate of steady state heat flow per time unit (measured in Watts) through area thick (measured in meters) in a homogeneous material due to that temperature gap. It is measured in Watts/(meters*Kelvin). There are three different modes of heat transfer [3]:

- **Conduction**: heat transfer due to temperature difference in a solid or fluid stationary medium.
- **Convection:** heat transfer between a surface and the movement of a fluid in contact with it.
- **Radiation:** heat transfer between two surfaces at different temperature and in the absence of an intervening medium caused by the energy that all bodies emit in the form of electromagnetic waves.

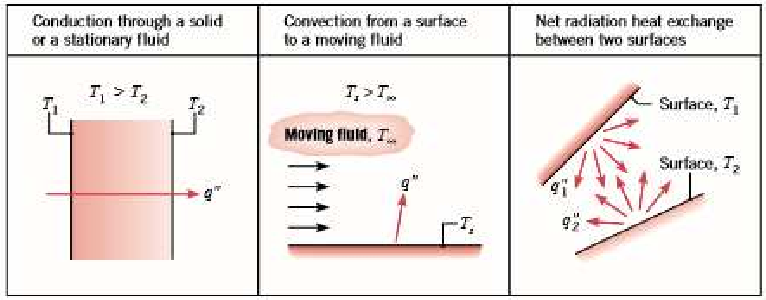



Figure 1: Modes of heat flow. Source: Frank P. Incropera (et al), 2007.

Dr. Mohammad S. Al-Homoud states in his paper that the performance of an insulation material can be determined by its capacity to slow down one or more modes of heat transfer, which is represented by its R-value [4]. The R-value of a material is the resistance of the material to heat flow. It is a function of the material conductivity, thickness and density. It is expressed in square-meters*Kelvin/Watt (as it is the inverse of conductivity).

Another way to compare various materials is through their thermal conductance. Thermal conductance is similar to thermal conductivity but it refers to a particular thickness and unit area. It is inversely proportional to the sum of resistance without the inner and outer air film resistance layers. Thermal transmittance, or U-value, takes into consideration these layers, making it a more common unit of comparison between materials. It is expressed in Watt/square-meter*Kelvin.

Installation of the material is also important when evaluating its effectiveness. How and where it is placed affects the performance of the insulation. Arranging several layers of a specific material may increase the R-value of the total surface in a non-linear manner. For example, when compressing insulation into a cavity it does not provide its full rated R-value because it losses some of the air trapped inside. Also the total area will not have the same R-value of the one calculated with the insulation, as there are thermal bridges, such as studs, joints and other building materials, through which heat flows more readily. Finally, infiltrations are taken into consideration to account for the several materials that can reduce heat flow and act against infiltration.

Several considerations must be taken when choosing the appropriate insulation for a building. The amount and type of insulation will depend on the area's climate, which part of the building it is insulated, regulations of the specific country, etc. Other considerations to also account for are: fire retardants, moisture and mechanical properties.

## State of the art in thermal insulation

The many existing insulation materials can be grouped according their chemical and physical structure. The U.S. Department of Energy provides a table with the most usual insulation materials classified by form, the type of material that can be found under that form, most common places of appliance and some advantages for each group:

| Type | Insulation Materials | Where Applicable | Installation Method(s) | Advantages |
|---|---|---|---|---|
| Blanket: batts and rolls | •Fiberglas<br><br>•Mineral (rock or slag) wool<br><br>•Plastic fibbers<br><br>•Natural fibbers | •Unfinished walls, including foundation walls<br><br>•Floors and ceilings | Fitted between studs, joists, and beams. | Do-it-yourself.<br><br>Suited for standard stud and joist spacing that is relatively free from obstructions. Relatively inexpensive. |
| Concrete block insulation<br><br>and insulating concrete blocks | Foam board, to be placed on outside of wall (usually new construction) or inside of wall (existing homes):<br><br>Some manufacturers incorporate foam beads or air into the concrete mix to increase R-values | •Unfinished walls, including foundation walls,<br><br>for new construction or major renovations<br><br>•Walls (insulating concrete blocks) | Require specialized skills<br><br>Insulating concrete blocks are sometimes stacked without mortar (dry-stacked) and surface bonded. | Insulating cores increase wall R-value.<br><br>Insulating outside of concrete block wall places mass inside conditioned space, which can moderate indoor temperatures.<br><br>Autoclaved aerated concrete and autoclaved cellular concrete masonry units have 10 times the insulating value of conventional concrete. |
| Foam board or rigid foam | •Polystyrene<br><br>•Polyisocyanurate<br><br>•Polyurethane | •Unfinished walls, including foundation walls<br><br>•Floors and ceilings<br><br>•Unvented low-slope roofs | Interior applications: must be covered with 1/2-inch gypsum board or other building-code approved material for fire safety.<br><br>Exterior applications: must be covered with weatherproof facing. | High insulating value for relatively little thickness.<br><br>Can block thermal short circuits when installed continuously over frames or joists. |
| Insulating concrete forms (ICFs) | •Foam boards or foam blocks | •Unfinished walls, including foundation walls for new construction | Installed as part of the building structure. | Insulation is built into the home's walls, creating high thermal resistance. |

| Type | Insulation Materials | Where Applicable | Installation Method(s) | Advantages |
|---|---|---|---|---|
| Loose-fill and blown-in | •Cellulose<br>•Fiberglas<br>•Mineral (rock or slag) wool | •Enclosed existing wall or open new wall cavities<br>•Unfinished attic floors<br>•Other hard-to-reach places | Blown into place using special equipment, sometimes poured in. | Good for adding insulation to existing finished areas, irregularly shaped areas, and around obstructions. |
| Reflective system | •Foil-faced kraft paper, plastic film, polyethylene bubbles, or cardboard | •Unfinished walls, ceilings, and floors | Foils, films, or papers fitted between wood-frame studs, joists, rafters, and beams. | Do-it-yourself.<br>Suitable for framing at standard spacing.<br>Bubble-form suitable if framing is irregular or if obstructions are present.<br>Most effective at preventing downward heat flow, effectiveness depends on spacing. |
| Rigid fibrous or fibber insulation | •Fiberglas<br>•Mineral (rock or slag) wool | •Ducts in unconditioned spaces<br>•Other places requiring insulation that can withstand high temperatures | HVAC contractors fabricate the insulation into ducts either at their shops or at the job sites. | Can withstand high temperatures. |
| Sprayed foam and foamed-in-place | •Cementitious<br>•Phenolic<br>•Polyisocyanurate<br>•Polyurethane | •Enclosed existing wall<br>•Open new wall cavities<br>•Unfinished attic floors | Applied using small spray containers or in larger quantities as a pressure sprayed (foamed-in-place) product. | Good for adding insulation to existing finished areas, irregularly shaped areas, and around obstructions. |

| Type | Insulation Materials | Where Applicable | Installation Method(s) | Advantages |
|---|---|---|---|---|
| Structural insulated panels (SIPs) | •Foam board or liquid foam insulation core<br>•Straw core insulation | •Unfinished walls, ceilings, floors, and roofs for new construction | Construction workers fit SIPs together to form walls and roof of a house. | SIP-built houses provide superior and uniform insulation compared to more traditional construction methods; they also take less time to build. |

Table 1: Most Usual insulation materials. [5]

## Insulated Glazing

Windows are necessary in every construction as they provide natural light, ventilation and passive solar gains. Moreover, they are part of the visual comfort of the users as they allow to see the outside. However, windows are responsible for more than half of the energy losses in a building, mainly due to the poor U-value of the glass. Jelle BP et al. state in their work that almost 60% of the total losses in a construction are caused by the windows [6]. However, many factors influence in the selection of this openings. Heat exchange through windows occurs by conduction, convection and radiation. Through the years different developments have been carried out in order to improve their insulations properties. The following figure shows different alternatives in the number and type of glazing.

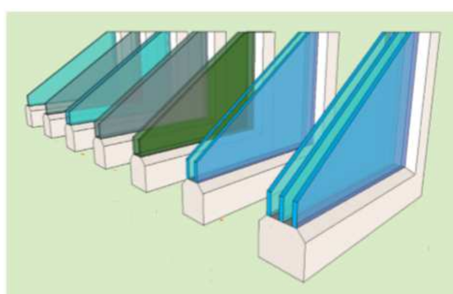


Figure 2: Glazing types. [7]. [1]

However, the total U-value of the window depends not only on the glass but on the whole device. The total U-value is affected by the type of glazing, the number of glasses, the size of the cavity between glasses, the gas that fills the cavity, the type of frame, the tightness, etc. The following figure shows a schematic heat flow through a double glazing window.

[1] From left to right: single clear glass, single glazing with gray tint, double clear glass, double glazing with gray tint, double glazing with selective tint, double glazing with low-e and triple glazing with low-e

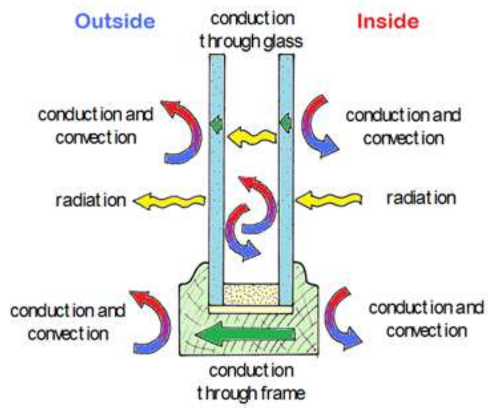



**Figure 3: Heat transfer through a double glaze window. [8]**

In windows, radiation has a more significant role than in the rest of the building due to the glass properties. Solar heat gains through glass are an important part of the energy flows in a building design, particularly in areas of large seasonal temperature variations where they can be beneficial during winter season while generating an overheating in summer. Erdem Cuce [7] differentiate three heat exchange forms within windows and occupants:

- Long wave heat exchange due to radiation between an object and the window inside surface (length between 3-50 microns).
- Short wave solar radiation which penetrates through window (0.3 - 2.5 microns range).
- Drafts introduced by cold air drainage off the window.

When the irradiation interacts with semitransparent solid or liquid bodies radiation occurs in several possible ways. This leads to four basics properties, which are taken into consideration in glazing technologies [9]:

- Transmittance
- Reflectance
- Absorption
- Emittance

The fraction of incident solar radiation that enters the building is known as g-value (or solar heat gain coefficient in U.S.A, SHGC). It is a measure of the total radiation that is transmitted through the window, and calculated as the ratio of the amount of radiation that is absorbed and transmitted inside the building, over the total solar radiation that impacts the surface. A higher g-value is beneficial in cooler climates, while a lower g-value is used in warmer areas. The following figure shows the solar spectrum, and two alternatives of glazing with different spectral transmittance. The first one is designed to reduce solar gains; it allows visible light to go through while solar infrared radiation is reflected. Long-wave radiation is reflected to the interior. The second alternative is designed to enhance solar gains: the infrared radiation is transmitted through the glass and long-wave radiation is also reflected to the interior. This second kind of glass is more commonly used in cold climates.

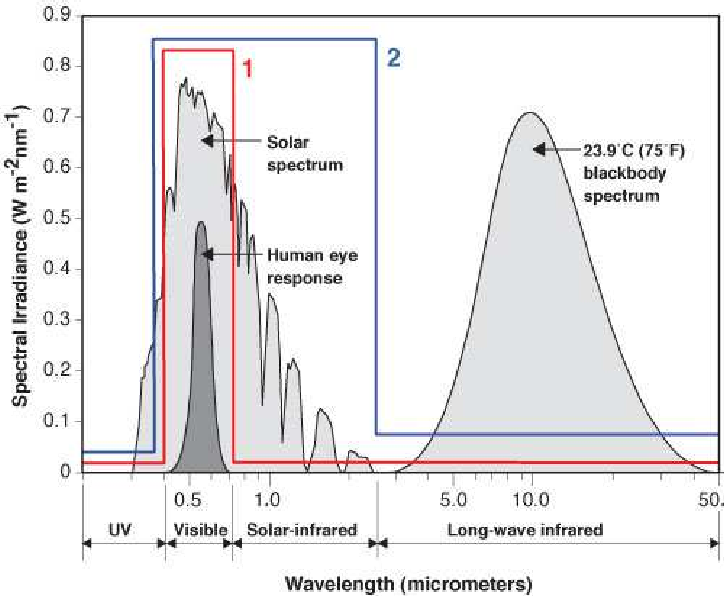



Figure 4: Ideal spectral transmittance for glazing in different climates. [9]

## State of the art in insulated glazing

Erdem Cuce et al. [7] in their paper evaluate different advanced glazing technologies based on their main performance parameter. The most significant alternatives are:

- Multilayer glazing: is the combination of two or more glass layers with a gap between them. This gap can be filled with air or other gas (most typical gases used are Argon or Krypton). The number of layers and the type of gas affects the window performance.
- Suspended film: is placed between the outer and the inner panes, and acts like an additional glass pane, but it is thinner and has less weight than a common glass panel.
- Vacuum glazing: it is similar to multilayer glazing but the gas in the gap in between the panels is removed, generating a vacuum space. Support pillars are needed to prevent the panels from collapsing.
- Low emittance coating: are made of metal or metallic oxides; they allow the transmission of the visible light spectrum while they reflect much of the other wavelengths, reducing the solar gain.
- Smart glazing: allows for variations on the thermal and visible characteristics of the glazing by means of voltage, heat or light application.
- Photovoltaic glazing: used of PV panels as shading. This also provides electricity generation.
- Aerogel glazing: based on silicium dioxide, this material has a high percentage of air in its structure which gives great thermal insulation properties.
- PCM (phase change material) glazing: they work by changing from solid to liquid as absorbing energy (during the day), and changing again from liquid to solid when release it (as temperature drops). The most common use material is paraffin.
- Gas filled glazing: as described in the multilayer glazing, the gap between the panels is filled with a gas. The most common gas is air, but Argon or Krypton may be also used.

The paper also focuses on innovating solutions through a combination of different glazing technologies:

- Solar absorbing windows: uses water to remove the heat in between the glass panels. This will lead to less cooling needs.
- Reversible windows: uses a highly reflective coating. During the summer period it avoid overheating, while during winter it is possible to reverse it, in order to avoid heat losses.
- Switchable electro chromic window: uses a nano-thick switchable coating in order to change the tint without loss of the view.
- Transparent insulation material filled window: filled with glass or plastic capillaries or honeycomb structures.
- Ventilated double glazed window: consists of two parallels windows with a air flow in between. This concept can be used as a ventilation system with a preheat of the air.

Finally, the dissertation also mentions three alternatives for hot climates areas. This glazing panels are based on a reflective coating that prevents solar gains to penetrate inside the building:

- Tinted glazing.
- Reflective glazing.
- Anti-reflective coating glazing.

Further research is carried out in this topic as it is responsible of an important part of the heat losses affecting the total energy demand in the buildings. Frames are considered in the window selection as different materials present different heat flows resistance. The different technologies properties are detailed in the table below.

| Window | Glazing type | Frame type | *U*-value ($W/m^2 K$) |
|---|---|---|---|
| A | Double, low solar gain, low-e | Aluminum | 0.59 |
| B | Double, low solar gain, low-e | Aluminum break | 0.47 |
| C | Double, low solar gain, low-e | Wood/wood clad | 0.34 |
| D | Double, low solar gain, low-e | Vinyl | 0.34 |
| E | Double, low solar gain, low-e | Insulated fiberglass | 0.26 |

**Table 2: Frames technology properties [7]**

## Thermal Regulation in Chile

Thermal Regulation Manual from Chile [10] introduces new directions regarding thermal insulation material need in constructions along the country. Chile is one of the first Latin America country to introduced this ordinances, following regulations regarding the energetic demand in buildings done by developing countries for almost thirty years. "*In several countries private and public initiatives have emerged that not only reduce the energy demand, but also have leaded nowadays to buildings that generate (using renewable technologies) their own electricity and disposed the surplus to the network*". [10]

The report separates the country in fifteen different regions and seven zones taking into consideration the climate conditions. It defines for each one of the zones the minimum insulation requirement (giving by the total U-value) for roofs, walls and floors. It also respecifies the maximum glazing surface. The regulation is based on three objectives:

- Improve the population live quality through better thermal comfort and the benefits that it reports: greater habitability, health improvement, less pollution and greater durability of the housing.
- Optimized and reduce the consumption of fuel fossil used to heat the building.
- Promote and stimulate the productive, industrial academic activities and research.

To achieve these objectives several directions have been drafted based on three consecutive actions:

- Maximum reduction of the energy demand.
- Use and optimization of the energy gains inside and outside the house.
- In the case of heating and cooling use, use systems that do not run on fossil fuels, and at the same time efficient and have low cost.

The first article establishes that all dwellings (for the roof, walls, and floor) must comply with the requirements of thermal insulation. The total thermal transmittance (U-value) must be equal or less (or the total thermal resistance (R-value) equal or greater) than the one that is indicated in the following table, for the zone that corresponds to the location of the construction.

| ZO | ROOF | | WALL | | FLOOR | |
|---|---|---|---|---|---|---|
| | U W/m²K | Rt m²K/W | U W/m²K | Rt m²K/W | U W/m²K | Rt m²K/W |
| 1 | 0,84 | 1,19 | 4,0 | 0,25 | 3,60 | 0,28 |
| 2 | 0,60 | 1,67 | 3,0 | 0,33 | 0,87 | 1,15 |
| 3 | 0,47 | 2,13 | 1,9 | 0,53 | 0,70 | 1,43 |
| 4 | 0,38 | 2,63 | 1,7 | 0,59 | 0,60 | 1,67 |
| 5 | 0,33 | 3,03 | 1,6 | 0,63 | 0,50 | 2,00 |
| 6 | 0,28 | 3,57 | 1,1 | 0,91 | 0,39 | 2,56 |
| 7 | 0,25 | 4,00 | 0,6 | 1,67 | 0,32 | 3,13 |

Table 3: U-value and R-value allowed [10]

Regarding the maximum possible quantity of glazing in the building, the following table establishes the values that must be used due to the type of glass.

| WINDOWS | | | |
|---|---|---|---|
| ZO | % Maximum of glass surface | | |
| | Monolitic Glass | Doble Hermetic Glass | |
| | | 3.6 W/m²K ≥ U> 2.4 W/m²K (a) | U ≤ 2.4 W/m²K |
| 1 | 50% | 60% | 80% |
| 2 | 40% | 60% | 80% |
| 3 | 25% | 60% | 80% |
| 4 | 21% | 60% | 75% |
| 5 | 18% | 51% | 70% |
| 6 | 14% | 37% | 55% |
| 7 | 12% | 28% | 37% |

**Table 4: Maximum glazing allowed [10]**

The project corresponds to the region twelve and the zone seven with a shore limit.

# Photovoltaic systems

*This section presents the state of the art on photovoltaic systems. It explain the component parts and the functioning.*

## Introduction

"*Modern societies are becoming increasing dependent on reliable and secure electricity supplies to underpin economic growth and community prosperity. This reliance is set to grow as more efficient and less carbon-intensive forms of power are developed and deployed to help decarbonise economies. Maintaining reliable and secure electricity services while seeking to rapidly decarbonise power systems is a key challenge for countries throughout the world."* [1].

Currently most daily human's activities depend on electrical energy to develop properly. In the last 20 years there have been a fast advancement in Information Technologies, which has changed daily life tasks, making them easier to perform [11]. Technologies represents an important part in the social and economical development of the countries. For that reason, electrical energy to all constructions must be ensure to achieve comfortable and proper progression of everyday activities. However, access to commercial energy is not always possible. In many countries electric grid cannot supply the growing demand due to several reason (such as distance, installed capacity, resources, etc). In this context stand alone systems represents an alternative for constructions without grid connection. Stand alone system includes some method of electricity generation (photovoltaic system using solar panels, wind turbine, diesel generator, geothermal source, etc) with a energy storage system (batteries, capacitor, fuel cells, others) and regulation (controllers, MPPT, inverter, etc). [12]

On the other hand, increasing clean energy's used is one of the world challenges in order to achieve decarbonisation's world targets [1]. According to the International Energy Agency (IEA), currently 40% of the energy-related $CO_2$ emissions is from electricity generation [1]. Using renewable sources has became a relevant area of study in the last years. New development in this technologies has made possible increasing its used. The IEA states that it is feasible to supply 30% of the global demand using only wind and photovoltaic systems [1].

As it was mention before, there are several alternatives to supply electricity to a off-grid building. Generation depending on both, fossil fuels and renewable energies technologies, can be used. But in order to reduce the environmental degradation it is necessary to stop the dependency on fossil fuels. It is aim of the ICELAB project (on which this project is based) to design a building that does not change the surrounding environment but gives shelter to researchers for to develop their activities. As a result an autonomous energy system based on solar panels will be implemented.

## Stand alone photovoltaic systems

The sun is the most abundant energy source. Directly (solar radiation) or indirectly (wind, biomass, hydro, etc) it sources nearly all energy on Earth. About 60% of the energy generated by the sun reaches the Earth surface (around $1.08x10^{14}$kW) [11][2]. According to the World Energy Council if 0.1% of

[2] The sun emits $3.08x10^{23}$kW per second. From this approximately $1.8x11^{14}$ kW intercepted the earth. [11]

this energy is used, it would be enough to produce four times the actual world generating capacity (3.000GigaWatt) [11].

Photovoltaic (PV) systems convert sunlight directly into electricity by meaning of a solar cell. A solar cell is a electricity-producing devise made of a semi conductor material. An individual cell produces around 1 to 2 watts power. But as greater power is needed to supply demand, they are connected together forming a chain. This chain is known as a module or panel [5]. An array is the interconnection between the modules (this can be done in series or parallel).

The array can be placed directly to meet the demand or to charge a storage system (battery pack). Since they have a fluctuating production, as its depends on the radiation from the sun, the second alternative is more appropriated to fulfil the demand when the building has not grid connection or backup system. In both cases control systems are needed to ensure the correct functioning. The following figure shows a schematic design of a PV system. The PV panel output is direct current (DC) electricity; this can be connected directly to DC loads. When alternating current (AC) loads are used an inverter need to be placed between the modules and the appliances. An inverter transforms DC to AC current and vice versa. As it was explained before a storage system need to be add in order to supply the demand when there is no solar radiation (during night) or when it is not enough. For this a battery pack is used. Like the solar panels, the battery's output is DC current, because of that this must be placed before the inverter. A charge control must be placed between the array and the storage system. This is used to protect the battery for overcharging and limiting discharge levels.

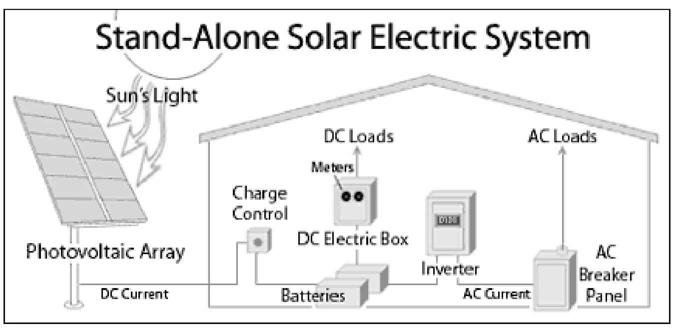



**Figure 5: Schematic design of a PV system [13]**

Like every system PV generation is not perfect. As it depends on the sun, it has a great variation in the energy produced along the year (different radiation through the seasons). Also, location is an important parameter because solar energy does not reach the earth surface evenly. Placing the panels with an inclination angle or using solar tracker[3] are some alternatives to improve the system performance. The following table shows some advantages and disadvantages described by the IEA.

[3] A solar tracker is a device that orients a payload toward the Sun [45]

| Benefits | Drawbacks |
|---|---|
| High reliability, no moving parts | Intermittency |
| Quick installation and dismantling | Grid connection challenges |
| Suitable solution for remote areas | Use of toxic materials |

Figure 6: Advantages and Disadvantages of photovoltaic energy systems

## Photovoltaic solar cells

A solar cell is an electronic device that uses solar energy (photons[4]) to produce electric power. They are made of semiconductor materials[5] . When solar irradiance impacts the cell it can be absorbed, reflected or transmitted. Reflected and transmitted energy are considered losses. The absorbed photons transfer their energy to the electrons located in the atoms' bonded. If this energy is big enough they are set free to move through the material, leaving behind a "hole"[6]. The following picture shows a schematic cross section of a solar cell.

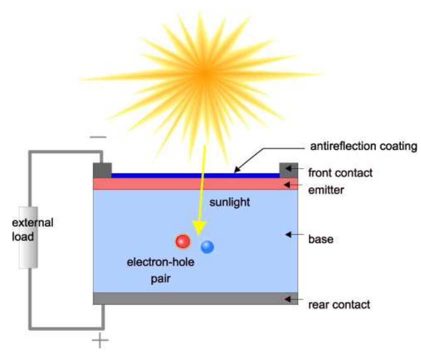



Figure 7: Cross section of a solar cell [14]

There are several characteristics that affects the incident solar energy reaching solar cells. The main ones are:

- ***"the radiant power density from the sun":*** the total energy emitted by the sun. The available energy in the photon has an inverse dependency on its wave length. This means that for blue light energy is bigger than for red light or infrared. The photon flux is the number of photon that impacts a surface per second; depending on the content of the light (the photon's wave length in the flux) its radiant power varies. The spectral irradiance is a measure of the power density

[4] "A photon is an elementary particle, the quantum of the electromagnetic field including electromagnetic such as light, and the force carrier for the electromagnetic force (even when static via virtual photons). The photon has zero rest mass and is always moving at the speed of light. Like all elementary particles, photons are currently best explained by quantum mechanics and exhibit wave-particle duality, exhibiting properties of both waves and particles". [46]

[5] Group IV and combination if group III-V in the periodic table materials

[6] A "hole" is the blonde's position that was previously occupied by the electron that now is free for other electron (it makes the atom to have a positive charge) [14]

for a certain wavelength and flux. The spectral irradiance integration along all the wavelengths available in a source emission gives the total power density [14]

- ***"the spectral content of the incident light":*** the wavelength that form the source emission. Only a fraction of the total power emitted by the sun reaches the Earth atmosphere, because it depends on the distance between the objects. And even a smaller part reaches the Earth surface due to different atmospherics effects (absorption, scattering, and reflection in the atmosphere and changes in gases concentration and clouds, etc). All these phenomenon affects the overall power received and the spectral content of light. [14]
- ***"the angle at which the incident solar radiation strikes a photovoltaic module":*** the rotation of the earth causes the idea that the sun moves along the day. The position of the sun depends on the location in the earth, the time of the day and time of the year. Only when the irradiance is perpendicular to the module's surface the power density on it is equal the incident power density. With any other position it must be correct by the angle's cosine[7]. [14]
- ***the radiant energy from the sun throughout a year or day for a particular surface*:** the angle between the sun and a fix location on Earth varies due to the location's longitude, time of the year and time if the day. This happens because the Earth surface is a sphere and it rotates around the sun with a tilt along its axes. The declination angle is the angle formed between the equator and a line drawn from the Earth's centre to the sun's centre (it changes with the seasons). The elevation angle is the angular high of the sun in the sky measured from the horizontal (it varies during the day, being zero at sunset and sunrise and maximum at solar noon[8]). The azimuth angle is the compass direction from which the sunlight is coming (at solar noon it is south for the northern hemisphere and north for the southern hemisphere). The following figure shows all three angles [15].

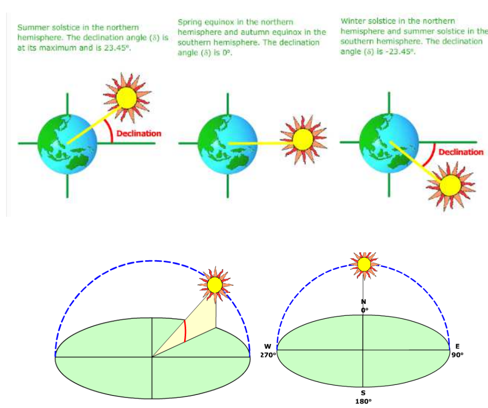



**Figure 8: Declination angle through the year, elevation angle and azimuth [14]**

Cells are formed by two types of semiconductor materials, p-type and n-type. A p-type material has a high concentration of electrons, while a n-type material has holes concentration. In a p-n junction electrons diffuse from the p-type side to the n-type side leaving an electric charge behind which creates

[7] It is the angle between the sun rays and the module normal.
[8] "*Solar noon is the time when the sun is highest in sky".* It is not necessary the same as the local time [15].

a electric field (depletion region). On the other hand "holes" diffuse from the n-type side to the p-type side, also contributing to the electric field generation. Thanks to that electric field free electrons (due to photons absorption energy) are most likely to move to the n-type site while free "holes" are attracted by the p-type site. Conductive material in the outer side of the cell allows the electrons movement through the electrical circuit. [16]

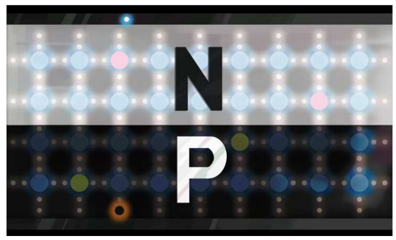



Figure 9: p-n junction electric flow [16]

The electrical current generated in the cells depends on many factors (cells losses, light spectrum, irradiance power, etc). To be able to calculate the power generated by a solar cells several parameters and a full knowledge of semiconductor materials and light properties need to be achieved. It is not aim of this project to explained this, but to give a general idea as an introduction, in order to understand future design needs.

## State of the art on solar cells

Different semiconductor materials can be used for the construction of solar cells. Nowadays silicon is the most common used material, representing the 90% of the market modules [17]. Because of that, it will be the one used in the design.

### *Silicon solar cells*

It is the second more abundant material on Earth  and the most common for electronic uses [17]. The are different ways to obtained silicon (monocrystalline silicon, polycristalline silicon, silicon ribbon, amorphous silicon, microcrystalline silicon, HIT solar cell); depending on the selected technique the efficiency of the cell vary.

This material has a low optical absorption coefficient, but this can be compensated using a higher thickness. The purity needed for solar cells is lower than the one used for semiconductor grade, which allows to used material that is rejected in that industry [18].

Currently it has most of the market share because it provides a good combination if high efficiency, low cost and long lifetime (25 years). The commercial efficiency for this cells is between 15% and 20%. [17]

### *III-V solar cells*

Compound like gallium arsenide(GaAs), indium phosphide (InP) and gallium antimonide (GaSb) form this cells. They have a good optical absorption coefficient which gives them high efficiency levels with low thickness. They high production costs represent a disadvantage for this materials. Also it is difficult to obtained a good purity quality and low crystal imperfections. [18]

### *Thin film solar cells*

They are made of cadmium telluride (CdTe) or indium gallium diselenide (CIGS). They are produced by depositing thin layers (a few microns) of these materials on a supporting structure (glass, plastic or metal) [17]. Like III-V solar cells they have good optical absorption coefficient (and a nearly optimums energy bandgap). However, they are not as efficient as III-V solar cells [18].

### *Organic solar cells*

This cells are made of carbon-rich polymers. They are less expensive than silicon solar cells but also half efficiency and have shorter lifetime [17].

### *Efficiency*

The following picture shows the efficiency of various PV technologies studied by the National Renewable energy laboratory. The highest efficiency reached is around 46% for multijunction solar cells investigation designs (no commercial cells) in Frauhofer ISE (Germany). This cells are made of different materials p-n junction. Each material absorbs a different wave length improving the electrical energy production. Silicon solar cells has a maximum efficiency of 27%. While organic cells have still low values.

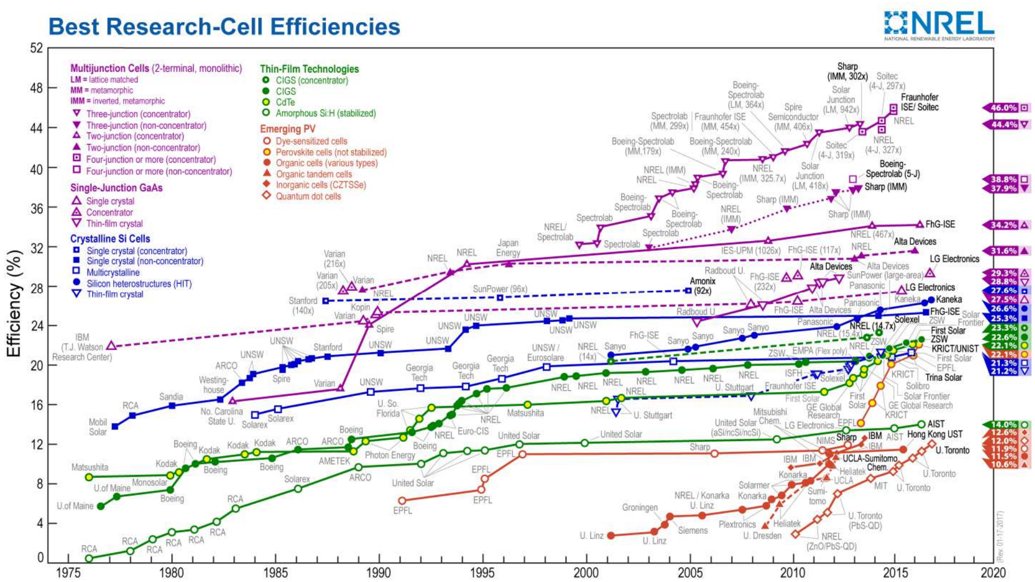



Figure 10: World record efficiency of solar cells [19]

## Modules and Arrays

*"A PV module consists of a number of interconnected solar cells (typically 36 connected in series) encapsulated into a single, long-lasting, stable unit. The key purpose of encapsulating a set of electrically connected solar cells is to protect them and their interconnecting wires from the typically harsh environment in which they are used"* [15]

There are different types of modules; depending on the material and application of the solar cell different covers, encapsulant, rear layer (Tedlar), grid connectors metals and frames need to be used.

- **The cover or front surface**: usually glass with a high transmission coefficient and low reflection. An antireflection coating or a texture surface can be used to improve its efficiency. This surface needs to ensure also protection against dust, dirt and water. It should have a high impact resistance and low thermal resistivity. In most cases it provides a rigid structure for the cells. Other materials like acrylic and polymers can be used [15].
- **Encapsulant:** usually athyl vinyl acetate (EVA). It is used to glue the solar cells to the top surface and the rear layers. It needs to be transparent in order to allow light to go through. Like the cover, it needs to have a low thermal resistance, be stable at high temperatures and high UV exposure [15].
- **Rear Surface:** commonly Tedlar (polymer sheet). It is used to prevent water vapor to get in [15].
- **Frame:** typically made from aluminum. This is used to maintain the structure together [15].

Modules can then be connected in series or parallel in order to increase their output depending on the load. The addition of other materials introduces new losses in the system reducing the overall efficiency when referring to an array. These losses need to be study separately because in most cases they depends on the location site weather conditions.

## Batteries

Batteries convert chemical energy into electrical energy by reduction (oxygen loss, gaining electrons) and oxidation (oxygen gain, losing electrons) reactions. A cells is the smallest part of the battery that generates a voltage. They are connected in series or parallel to form a module with higher voltage or current. Modules can be connected again in series or parallel to increases the voltage or current. The whole system is considered as a battery. Several definitions are used when describing the battery's performance, this terms need to be understand when comparing different technologies [20].

A battery consist of two terminals; the positive one or cathode and the negative one, the anode (where the electrons are realise). In between the two terminals there is a solution (electrolyte), that gives the right environment for the ions (positive charges due to the loss of electrons) to move in the opposite direction from the electrons [21]. For rechargeable batteries cathode and anode invert. For the common used they are considered as positive or negative for the discharging face.

### State of the art

Different materials can be used to produced batteries. Here the most common materials for rechargeable batteries are described.

#### *Lead-acid batteries*

They are the oldest rechargeable technology. They have a low energy density (per weight and volume). They are made of toxic materials which creates environmental hazards. Both plates are made of lead sulfate ($PbSO_4$) in a solution of sulfuric acid ($H_2SO_4$). [22]

Currently they are the more common batteries used with PV array for autonomous systems [22] because of their known technology and efficiency in long discharge periods.

### *Lithium-ion batteries*

They are the most common technology used in portable consumer electronics. Currently they are making a transition to electric vehicle applications; but lower maintenance and operating costs. Also better state of charge and lifetime need to be achieved for this batteries. They have a high energy density and low memory effect. [22]

They used an intercalated lithium compound for the anode (the most common is graphite); the cathode is made of an metal oxide. The solution is a lithium salt in an organic solvent. [22]

This batteries are expensive but represents a new alternative for solar systems. They are more efficient than lead-acid batteries when low discharged and long unused periods are needed [23]. Because of that an alternative using this batteries is developed in Appendix H.

### *Nickel cadmium batteries*

Sealed nickel cadmium batteries are used commonly for commercial electronic products where light weight is needed. Vented nickel cadmium batteries are used where large energy per weight and volume are critical. They can stand high temperatures which make them useful for solar systems. On the other hand, they do not perform well in peak applications. Moreover they are highly toxic. [22]

They are also known as alkaline batteries as they used an alkaline electrolyte (more common potassium hydroxide). The cathode is made of nickel oxide hydroxide; and it has a cadmium anode. The plates need to be separated by a nylon divider. [22]

### *Sodium sulfur batteries*

They have a high energy density and high efficiency of charge and discharge. However, the do not perform well at high temperatures. They are made from sodium and sulfur with a solid electrolyte in between [22].

## Charge controllers

Charge controller protects the battery in a PV system. They regulate the voltage (or current) that comes from the PV panels into the battery pack, keeping it from overcharging. As it was mentioned before, panels output depend on the radiation of the sun, this means that voltage is not always constant which can damage the battery. Standard controllers down it to the battery's need. However, there can occur some energy loss [23].

Maximum power point tracking (MPPT) controllers optimizes the match between the PV panels and the batteries. They are inverters (DC to AC converter) that compares the panels output energy with the battery pack voltage and calculates the best modules output to charge the batteries by changing the voltage to obtain the best current. They take DC current, change it to high frequency AC current and convert it back to DC with a different voltage [24] .

# Insulation and daylight utilization design

*This section present the improvements made in the ICELAB II building regarding insulation materials and daylight utilization. The software DesignBuilder was used to simulate different possible situations.*

## Introduction

The aim of this chapter is to present different alternatives to reduce the energy demand of the building. Two characteristics were assessed: amount of energy for heating and day light utilization. The performance of different thermal insulation materials and glazing was evaluated in order to bring down heating need but securing a comfortable temperature during summer. Adequate orientation and glazing percentage were studied to exploit day light. Other parameters like natural ventilation, possible infiltration (due to a poor construction), heat loads due to people and equipment were also considered for the final temperature calculation. The selected construction from the ICELAB II project was used as base model for designing the building. Improvements were evaluated through simulations done using DesignBuilder software.

## Building design (ICELAB II)

A second project (ICELAB II) was carried out after the first one (ICELABPatagonia project) consisting on the design and following selection of five suitable buildings. The candidates needed to fulfil the objectives established during the first stage (described in the introduction).

The winning construction consists of a rectangular wood structure which allows an easy construction and removal. It lies on two stilts to not have direct contact with the ground. The main structure consists on U form timber frames (design by the students) running along the building. Supported beans are placed in the upper part to give the construction its final form. Oriented Strand Board (OSB) panels are placed in between the frames cavities to form the walls, floor and ceiling. The images bellows show pictures of the building constructed at KIT.

Figure 11: Pictures of the ICELAB II building

The building has a rectangular shape (outer measures: 717cm long, 340cm width, 375cm high). The work space, kitchen, bathroom and tank deposit are on the ground floor. While in the first floor are located the bedrooms. The work area covers the total high and length of the building. Next to it lies the kitchen. There are no physical separation (walls) between this two zones. On the other hand, the tank deposit and the bathroom have internals walls that keep them apart from the main area. The first one is located next to the kitchen, followed by the bathroom. The following figure shows the ground floor plan of the building.

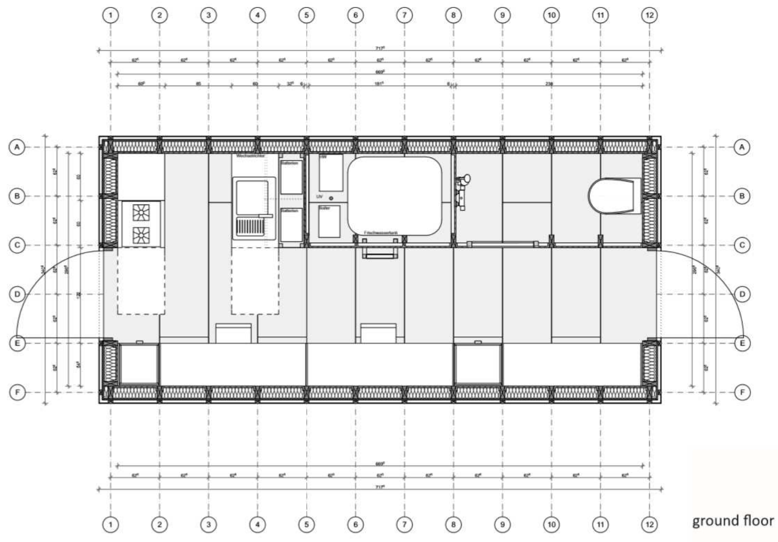



**Figure 12: ICELAB II ground floor plan**

The left part of the construction does not run for the total high of the building; on top of it is the first floor. It consist of two rectangular spaces (each one placed on the corner of the building) where the bedrooms lie. There are two openings located on opposite sides of the construction, they act as a door and a window. The next figure shows an exploded view. (Full plans are in Appendix B)

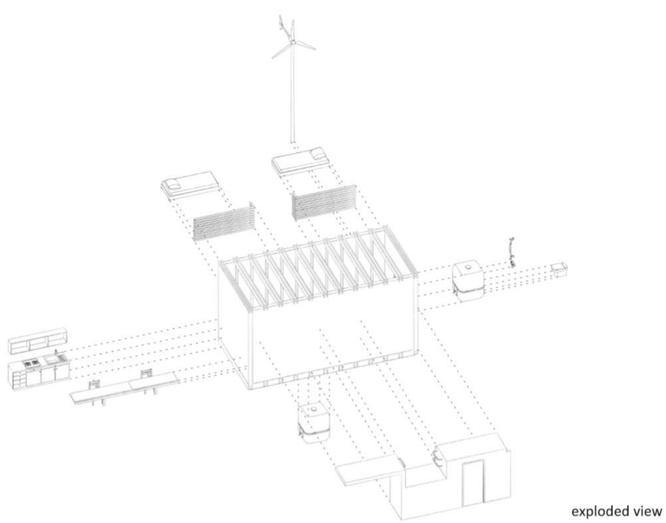



**Figure 13: ICELAB II exploded view**

# Base model (simulation parameters)

## DesignBuilder

"*DesignBuilder provides advanced modelling tools in an easy-to-use interface. This enables the whole design team to use the same software to develop comfortable and energy-efficient building designs from concept through to completion.*" [25]

The software has an modular structure [26]. Each module represents a different analysis platform and they all interact through a nucleus, this allows the user to have a whole analysis of the building regarding, HVAC, illumination, computational fluids dynamics (CFD), construction costs, optimizations, and others. As a result, the total environmental and energetic performance of the building can be obtained. Numerous analysis can be carry out in the different modules, some of them are:

- energetic need and CO2 emissions calculation (simulation with real weather data).
- comfort levels in passive buildings evaluation.
- heating and cooling capacity need calculation.
- insulation materials performance comparison .
- glazing and shading systems comparison.
- day light impact analysis.
- optimization analysis, among others.

## Location

In DesignBuilder the building is located in Ushuaia (Argentina), as it was not possible to do it in Karukinka since it does not exist in the software data base. Ushuaia is located near to the park, shearing similar climate.

Weather conditions provided by the software and information from Argentina National Meteorological Service were compared. Both data have not significant difference, so not additional information is needed. The graphs bellow show the temperature (min, max and average), and the precipitations for the region during the whole year. The table contains the information in the software

| Month | 2002 | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Outside Dry-Bulb Temperature (°C) | 10.42 | 10.57 | 8.73 | 6.26 | 4.37 | 2.16 | 1.66 | 2.32 | 4.18 | 6.68 | 8.70 | 9.74 |
| Outside Dew-Point Temperature (°C) | 6.45 | 5.77 | 5.39 | 3.98 | 2.73 | 0.30 | -0.76 | 0.71 | 1.18 | 4.01 | 4.31 | 5.19 |
| Wind Speed (m/s) | 7.68 | 6.66 | 6.03 | 6.16 | 6.83 | 4.47 | 6.59 | 7.48 | 7.02 | 8.45 | 6.10 | 8.09 |
| Direct Normal Solar (kWh) | 134.14 | 95.54 | 88.80 | 52.11 | 37.22 | 32.06 | 44.78 | 72.09 | 93.05 | 139.33 | 144.21 | 125.11 |
| Diffuse Horizontal Solar (kWh) | 101.24 | 72.70 | 53.99 | 33.74 | 19.52 | 11.23 | 14.23 | 24.26 | 42.04 | 62.57 | 83.85 | 112.31 |

**Table 5: DesignBuilder Ushuaia weather conditions data**

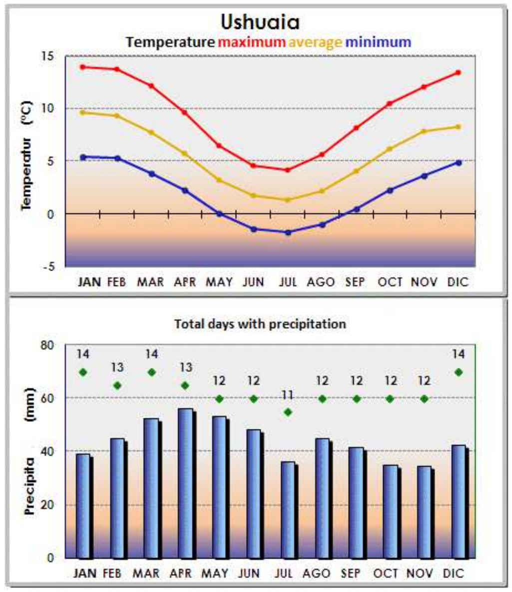



**Figure 14: Ushuaia temperature and precipitation along the year. [27]**

Although the site does not present high temperature variations among the seasons, the total solar radiation decreases considerably during winter affecting solar gains inside the building (increasing heating need). The region stands out for the strong wins which improves natural ventilation during summer decreasing heat loads. However, it represents a problem during winter because it also increases infiltrations. Rainfall remains in similar amounts throughout the year, with a slight increase during autumn.

## Layout

The building was drawn using two different building blocks[9], one for the ground floor and one for the first floor. The two blocks were then connected through "holes" (all internal walls were erased) obtaining only one region. Because of that, the working zone, kitchen and bedrooms share the same characteristics regarding occupation, equipment loads, heating system and natural ventilation behaviour. In the ground block two zones were created by drawing internal walls allowing to set different properties; they correspond to the tank deposit and bathroom. The following figure shows a draw of the ground floor. The colours represent each area where different parameters can be set. The down left arrow in the picture indicates north. A window is placed in the north wall, while the door occupies the opposite side.

[9] "*A building block represents the outer shell of the model or part of the model. A finished block comprises a set of building elements, which may include external walls, roofs and floor slabs.*" [25]

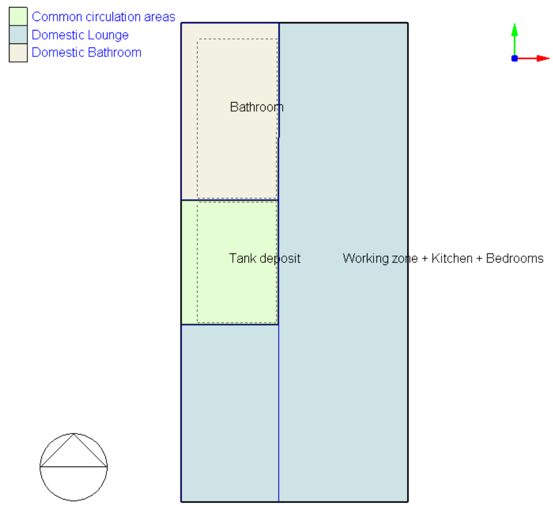



Figure 15: DesignBuilder building draw

The two stilts, where the building lies, have ground properties (they behave like ground) since they do not take part during the simulation; they are only used to obtain a semi exposed floor (a floor without a direct ground contact).

## Internal loads

The person's metabolic activity and the use of equipment and appliances are constantly generating heat. Heat gains are an important factor when defining temperature, together with solar gains through windows influence the total latent load inside the building; hence the comfort, causing possible overheating during summer and reducing the needed heating energy in winter. Because of this they must be considered during the building simulation. In DesignBuilder metabolic activity, computer and office equipment and kitchen appliances (catering) are loaded as internal gains (no other internal energy source was used). Their change along the day is set by a schedule[10] (Appendix C shows all the schedules for the construction). To establish the period of time an ending date period (31 Dec) and ending time (for example until: 08:00) are set. Applicable periods are selected (Weekdays, Weekends, SummerDesignDay, etc). They are used for the simulations conditions; they are explained later in this chapter. For the laboratory no Holiday period was used, because only occupancy periods were studied and no the performance of the whole year.

For the metabolic activity, the total building area is 24.38m$^2$ with five people during work hours (between 8:00-18:00) and less for the rest of the time occupancy. The occupancy value (0.205people/m$^2$) is multiplied by the schedule's values (0 for no occupancy and 1 for all occupied). The activity inside the house is thought to be only drinking and eating so a factor of 0.90 is set for the action.

Heat gains due to computers (16.10W/m$^2$), office equipment (3.90W/m$^2$) and cooking (80W/m$^2$) are contemplated [2]. All this gains are regulated by different schedules (Appendix C). For the

[10] "Schedules are used in DesignBuilder to define: occupancy times, equipment lighting HVAC operation, heating and cooling temperature set points and transparency component block". [25]

bathroom and tank storage room there is not heat gain, as not equipment was set there. Although the presence of a electric water heater introduces heat gains; it is not sure that this technology will be used, so the worst condition is examined. Moreover, this part of the building do not have heating system. For the bathroom heat gain are not added as heating energy is low due to inconstant use.

### Construction materials and glazing

For the base model no insulation is used. The construction consists on a wood frame with 15mm oriented strand board (OSB) panels for the wall, roof and floor inner layer. For the floor not further material was placed. The external wall outer layer is made of 60mm high density hardboard panels, like in the original planes (Appendix B). Also, the total 220mm width from the original design was respected. On top of the roof asphalt was placed as rain protection. The gaps between layers for the walls and roof are filled with air. The corresponding U-values and R-values for each part are calculated automatically by the software based on the component materials. This values are used in the heating design simulation to measure the heat losses. The following figure shows the walls and roof cross section layout with the corresponding measures.

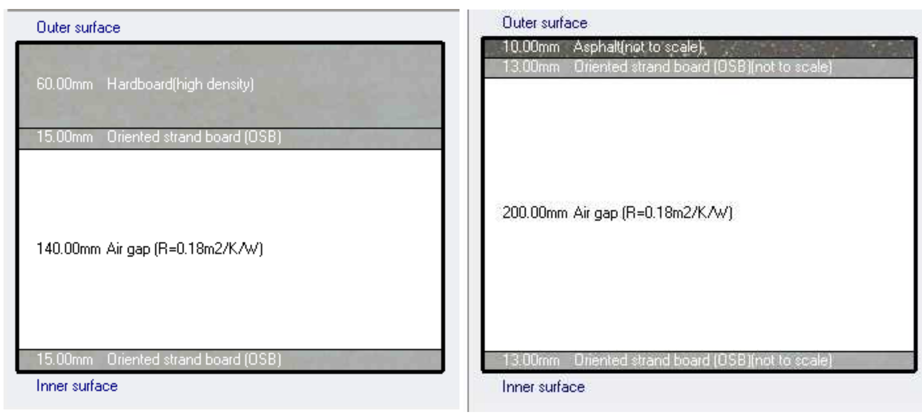



**Figure 16: Roof and wall cross section (base model)**

Linear thermal bridging are only placed at junctions. Not thermal bridging surface is considered in the construction material for the walls, roof and floor. The software default Psi values are used. The following picture shows them.

| Linear Thermal Bridging at Junctions | |
|---|---|
| ☑ Specify Psi Values | |
| **Psi Values Involving Metal Cladding** | |
| Roof-Wall (W/m-K) | 0.420 |
| Wall-Ground floor (W/m-K) | 1.730 |
| Wall-Wall (corner) (W/m-K) | 0.380 |
| Wall-Floor (Int - not ground floor) (W/... | 0.040 |
| Wall-Floor (Ext - not ground floor) (W/... | 1.730 |
| Lintel above window or door (W/m-K) | 1.910 |
| Sill below window (W/m-K) | 1.910 |
| Jamb at window or door (W/m-K) | 1.910 |
| **Psi Values NOT Involving Metal Cladding** | |
| Roof-Wall (W/m-K) | 0.180 |
| Wall-Ground floor (W/m-K) | 0.240 |
| Wall-Wall (corner) (W/m-K) | 0.140 |
| Wall-Floor (Int - not ground floor) (W/... | 0.110 |
| Wall-Floor (Ext - not ground floor) (W/... | 0.240 |
| Lintel above window or door (W/m-K) | 0.450 |
| Sill below window (W/m-K) | 0.080 |
| Jamb at window or door (W/m-K) | 0.090 |

**Figure 17: Psi values for thermal bridging at junctions**

The internal partitions are made of gypsum plasterboard with air gap. They are considered adiabatic[11], so they do not affect heat flow inside the building. However, they are barriers for the natural light distribution. For the air tightness the worst allowed value is used as first scenario (5 airchange/hour) and a schedule of 24-7 is considered. This has a significant relevance in the heat losses. Not other internal thermal mass is used in the building.

For the openings a single (1500x2000mm) window is placed in the north face of the building following the project design. It consists of a double 3mm generic glazing panel with 13mm air gap in between. There is no other ventilation mean, internal doors or windows.

## HVAC and lighting selection

The lighting tab in the software is used to select the artificial light equipment. The project focuses on the performance of natural light distribution due to windows percentage and how to improve it. It does not account the needs of artificial light. However, an approximate value is then used to calculate the demand of the building.  For this part default data is used.

For summer there is no cooling equipment in the building. However, natural ventilation is used. A constant rate of 18 air changes per hour by zone is considered as definition method [28][12] (similar value was obtained when calculating it with the program (it can be seen in Appendix C). For opening minimum temperature value of 15°C, and 20°C for closing the system are needed. For heating electric convectors were chosen.

As it is with the artificial lighting system, the HVAC part is used to size the heating and cooling equipments. It is not aim of this project to work on those designs but to understand the building's heat losses and how to reduce them using the adequate insulation. Because of that, obtained values are used as a reference for comparison and comfort evaluation only.

---

[11] There is no heat exchange through the wall.
[12] The publication gives a reference value of 37ach/h for a full opened 1.5x2m$^2$ window and a full opened 1x2m$^2$ door for a 126m$^3$ room.

## Calculation and results

For the project three different calculations are done (heating design calculation, cooling design calculation and daylighting calculation) .

### *Heating design calculation*

"*Heating design calculations are carried out to determine the size of the heating equipment required to meet the coldest winter design weather conditions likely to be at the site location*" [25]. As it is mentioned previously, it is not aim of this work to design such system. The results are used to compare the performance of different insulation materials and thicknesses in the building.

For the HVAC design the software uses steady state[13] condition for winter external temperature (set in -4.8°C), while wind speed and direction are set to design values. Because of that, design margin coefficient must be introduced to simulate the ramp up until the desire temperature is reached (a value of 1.8 is used). The control for the system is done through the comfort air temperature; 20°C was set as desire inside temperature for winter season. Zones are heated constantly to achieved the temperature set point using a convective system. The simulation continues until temperature/heat flow converged [25]. The worst condition is used, for that, heat recovery is excluded from the simulation, also internal heat gains and solar gains are not considered as part of the heat flow inside the house. Schedules are not used here (it is based on a steady state analysis). The available outputs are [25]:

- **Air Temperature**: calculated average temperature of the air.
- **Radiant Temperature:** (area*emissivity) inside surface temperatures weighted average.
- **Operative Temperature** : internal air and radiant temperatures mean.
- **Outside Dry-Bulb Temperature.**
- **Glazing:** heat loss through all glazing.
- **Walls**: heat loss through all external walls.
- **Ceilings (int):** heat loss through internal ceilings (e.g. zone above is colder).
- **Floors (int):** heat loss through internal floors (e.g. zone below is colder).
- **Floors (ext):** heat loss through external floors.
- **Ground Floors:** heat loss through ground floors.
- **Doors and Vents**: conduction heat loss through doors and vents.
- **Partitions (int):** heat loss through all internal partitions (e.g. adjacent zone is colder).
- **External Infiltration:** heat loss through air infiltration (unintentional air entry through cracks and holes in building fabric).
- **External Mechanical Ventilation:** heat loss due to the entry of outside air through the air distribution system.
- **Internal Natural Ventilation**: heat loss due to air exchange through open internal windows, doors, vents, holes and virtual partitions to adjacent spaces.
- **Zone Sensible Heating:** heat delivered to maintain the internal heating design temperature. [25]

[13] The condition remains constant as time change. [42]

For the calculation the default design algorithms of the software is used (TARP for the inside convection algorithm and DOE-2 for the outside convection algorithm) as it is not aim of this work to focus on the final numbers, but to do the proper comparison among different situations. The following figure shows the results obtained for this simulation. This displays the total heat losses broken down as glazing, walls, roof, floor and infiltrations and the total heat need.

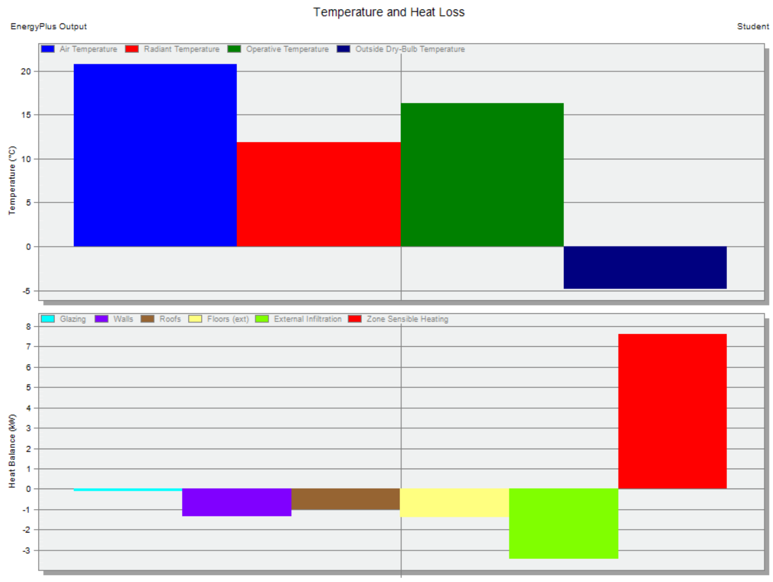



Figure 18: heat losses through glazing, walls, roof, floor and infiltrations and total heat need (base model)

The total heat energy need for the HVAC system for the non insulated model is 7.6kW for winter season. Although glazing is said to be the most relevant heat loss surface, in this case the material selected is insulated while the rest of the building is not. For that reason only 0.11kW are loss through window. On the other hand, the higher losses are due to infiltration (around 3.41kW). As it was mention before, the worst case possible was considered regarding building tightness. This can be improved when insulation materials are installed. For the walls, floor and roof losses are similar (around 1.3kW each).

### *Cooling design calculation and simulation*

*"The cooling system design calculation are carried out to determine the capacity of mechanical cooling equipment required to meet the hottest summer design weather conditions likely to be encountered at the site location"* [25]. The building does not have a cooling equipment, but the values obtained are employed to understand how insulation materials, glazing percentage, natural ventilation and orientation affect the temperature during summer. This is used to ensure that there is not overheating during warmer periods (for southern hemisphere 15th January is used). It has the following characteristics:

- Periodic steady-state external temperatures calculated using maximum and minimum design summer weather conditions.

- No wind.
- Includes solar gains through windows and scheduled natural ventilation.
- Includes internal gains from occupants, lighting and other equipment.
- Includes consideration of heat conduction and convection between zones of different temperatures. [25]

Heat recovery is excluded but natural and mechanical ventilation are consider influencing the final temperature. As it was mentioned before, it is not aim of this work to focus on the final numbers but to do the proper comparison among different situations. Because of that, for the calculation the software's default design algorithms were used (TARP for the inside convection algorithm and DOE-2 for the outside convection algorithm) and all parameters are default DesignBuilder'a defect values. The available results for this part are:

- **Air Temperature**: calculated average temperature of the air.
- **Radiant Temperature:** (area*emissivity) inside surface temperatures weighted average.
- **Operative Temperature** : internal air and radiant temperatures mean.
- **Outside Dry-Bulb Temperature.**
- **Glazing:** total heat flow to the zone from the glazing, frame and divider of exterior glazing excluding transmitted short-wave solar radiation (which is accounted for in **Solar Gains Exterior Windows**).
- **Walls:** heat gain due to conduction through all external walls, including the effect of solar radiation and long wave radiation to the sky.
- **Roofs:** heat gain due to conduction through all external roofs, including the effect of solar radiation and long wave radiation to the sky.
- **Ceilings (int)**: heat /conduction gain through internal ceilings (e.g. zone above is colder).
- **Floors (int)**: heat conduction gain through internal floors (e.g. zone below is colder).
- **Floors (ext):** heat conduction gain through external floors (not ground floor).
- **Ground floors**: heat conduction gain through ground floors.
- **Partitions (int)**: heat conduction gain due to heat conduction through all internal partitions from adjacent zones at different temperatures.
- **Doors and vents**: conduction heat gain through doors and vents.
- **External Infiltration:** heat gain through air infiltration (unintentional air entry through cracks and holes in building fabric).
- **External Vent:** heat gain due to the entry of outside air through natural and mechanical ventilation.
- **Internal Natural Ventilation**: heat gain from other zones due to air exchange through open internal windows, doors, vents, holes and virtual partitions.
- **Task Lighting:** heat gain due to task lighting.
- **General Lighting:** heat gain due to general lighting.
- **Miscellaneous:** heat gain due to miscellaneous equipment.
- **Process:** heat gain due to process equipment.

- **Catering** - heat gain due to cooking.
- **Computer and Equipment:** heat gain due to computer and other IT-related equipment.
- **Occupancy:** sensible gain due to occupants.
- **Solar Gains Exterior Windows**: Short-wave solar radiation transmission through external windows. For a bare window, this transmitted radiation consists of solar radiation passing through the glass and diffuse radiation from solar reflected from the outside window reveal, if present. For windows with a shade, this transmitted radiation is totally diffuse (shades are assumed to be perfect diffusers). For windows with a blind, this transmitted radiation consists of beam + diffuse radiation that passes between the slats and diffuse radiation from beam-to-diffuse reflection from the slats. *Solar re-reflected back out of the external window and transmitted through interior windows is not subtracted*.
- **Solar Gains Interior Windows**: Total beam + diffuse solar radiation transmission through *interior* windows.
- **Zone Sensible Cooling**: sensible cooling effect *on the zone* of any air introduced into the zone through the HVAC system. It includes any 'free cooling' due to introduction of relatively cool outside air. Cooling always shows as a negative heat gain in the results. [25]

When running the simulation it is observed that around 14:00 outside temperature reaches its maximum (18.2°C). However, the maximum temperature in the building is between 15:00 and 17:00pm. The operative temperature in the building goes up to 25.10°C, and the air temperature to 22.3°C. The difference is due to the radiant temperature. Infiltration maintains air change rate constant at a minimum of 5ach/h through the day, while natural ventilation is activated when cooling down the building is needed.

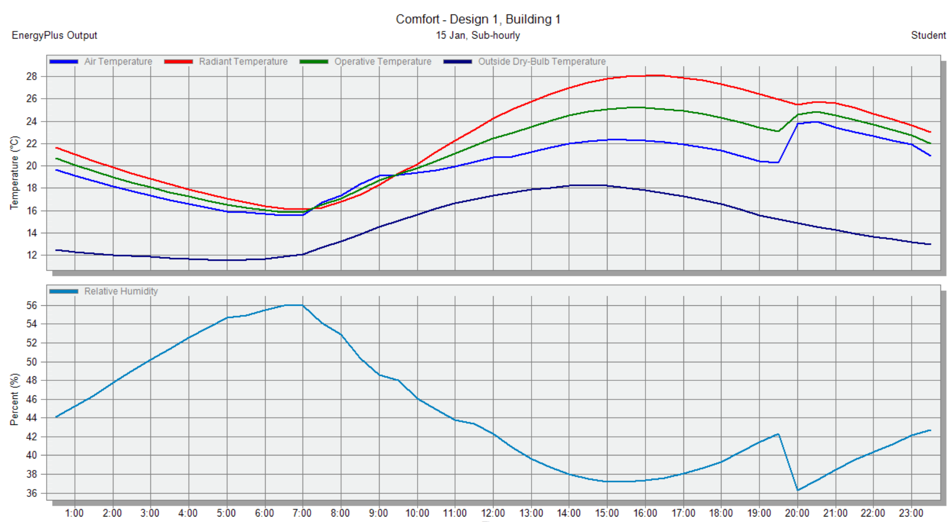



Figure 19: Comfort design results (Base Model)

Internal gains play an important part in heating the building. As it is shown in the next figure, solar gain due to exterior windows reaches a maximum value of 35.2W/$m^2$. Heat load due to computer equipment is in second place, it maintains almost constant through the day. The total latent load reaches its peak around midday, when also the higher cooking loads are added. As a result, a total value of 17.5 $W/m^2$ must be considered during the summer period due to external loads.

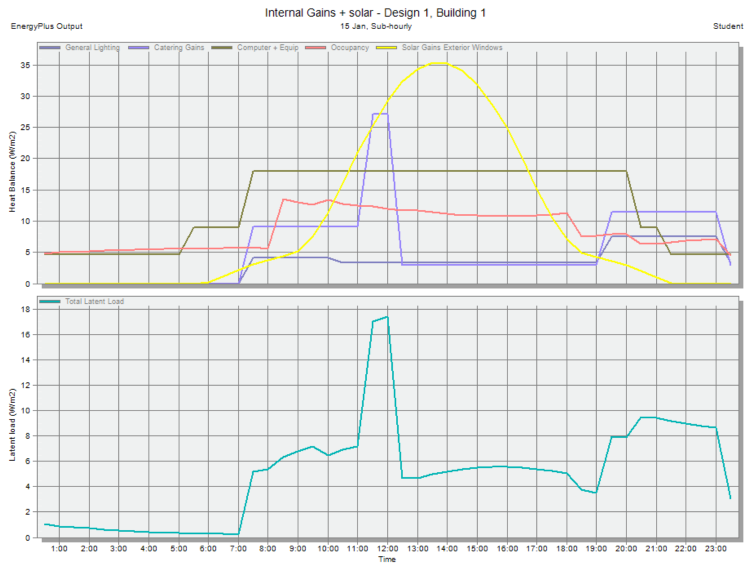



Figure 20: Internal gains (Base Model)

In order to reduce this window shading are included in the building. Blinds with high reflective slats are placed and set to be used when inside temperature goes over 20 degrees Celsius. The next figure shows that the solar gains go down to an average of 7.6$W/m^2$, with a pick at 11:00am of 25$W/m^2$ .

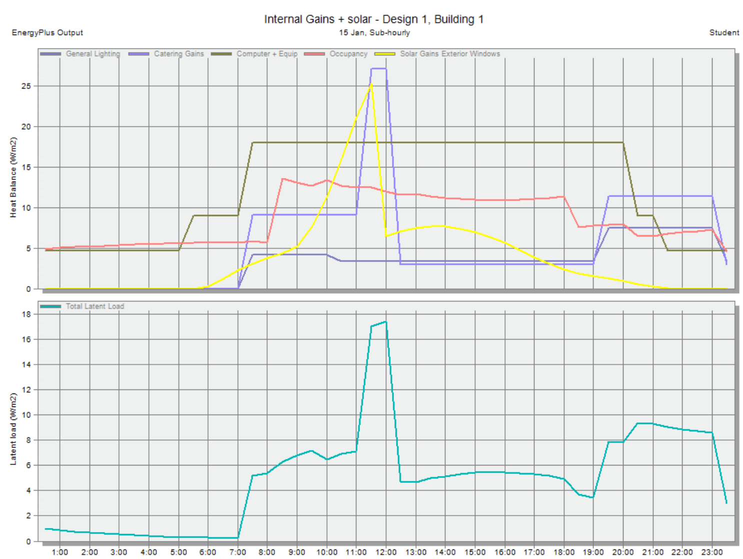



Figure 21: Internal gains when adding shading (Base Model)

Finally, fabric and ventilation are simulated. Between 9:00 and 20:00 there is heat gain through roof and glazing due to radiation. On the other hand, there are heat losses through walls, floor and due to natural ventilation and infiltration. This is because inside temperature is higher than outside temperature in the building due to the internal gains showed before. However, during night there is heat gain through walls and floor as there are no solar gain and internal loads (due to set schedules).

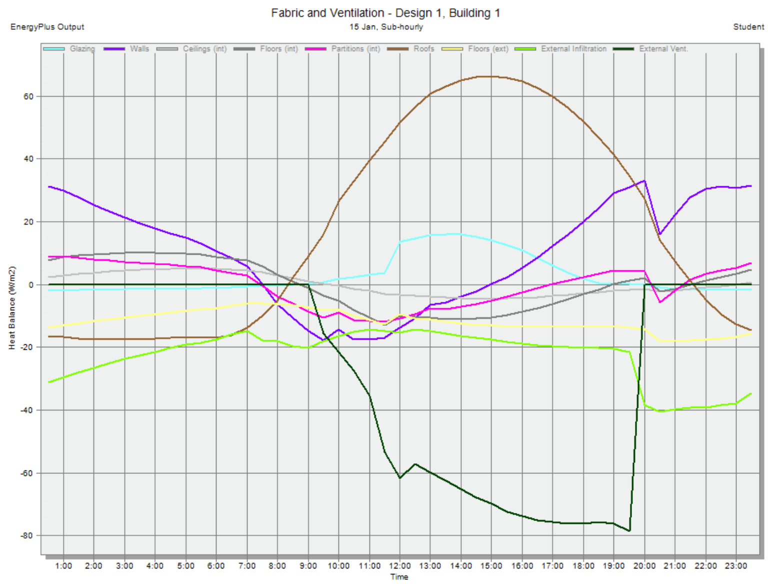



**Figure 22: Fabric and ventilation results (Base Model)**

"*The simulation manager allows to run and control multiple simulations and view their results. Simulations can be run in parallel and over the network*" [25]. A total simulation can be performed to evaluate different parameters and control their results in a period of time (annual, monthly, daily, hourly or sub-hourly). Also optimization techniques can be analysed in this option. The following data can be obtained:

- **1-All**: fabric and ventilation heat gains/losses, internal gains (not Heating Design), temperatures and outside dry-bulb air temperature.
- **2-Site data**: all site data (site temperature, wind speed, wind direction, pressure and solar radiation).
- **3-Comfort:** inside air, the radiant and comfort temperatures, relative humidity, ASHRAE 55 and various comfort indices.
- **4-Internal gains** : internal gains including equipment, lighting, occupancy, solar and HVAC heating/cooling delivery.
- **5-Fabric and ventilation**: heat gains to the space from the surface element (walls, floors, ceilings etc.) and ventilation. Negative values indicate heat loss from the space. [25]

When running a simulation for a typical summer week, (5th to 11th March) it is observed that inside temperature does not goes above 20° C. As it was explained before, cooling design meets the hottest design weather. On the other hand, summer typical week simulation uses weather data translate as typical temperatures during summer period. While heat loss due to infiltration remains almost constant, natural ventilation is not needed because inside temperature does not go over 20° C.

As it was seen in cooling design calculation heat gain due to solar radiation through windows is the principal source of heat.

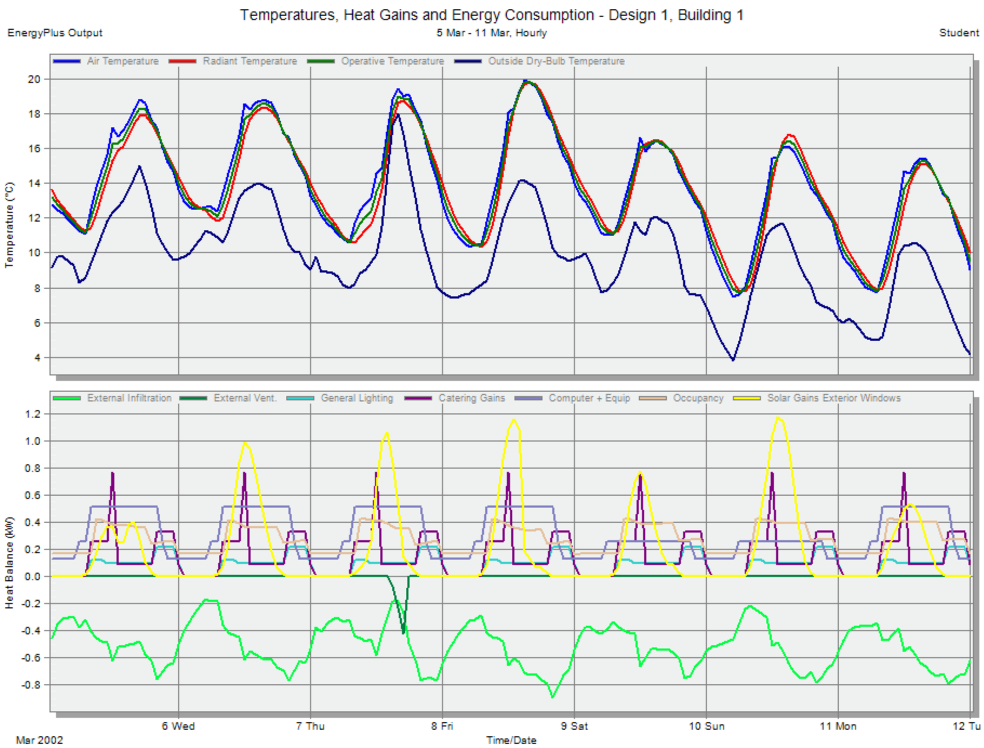



**Figure 23: Simulation results for a typical summer week (Base Model)**

Running the same simulation for a summer design week ( in February as it is the hottest week in the year) temperature goes up to 23°C and heat losses due to natural ventilation also increases. However, the total temperature for the week remains into a comfortable range during the day (between 15°C and 25°C).

Natural ventilation represents an important source of heat loss because outside temperature stays always lower than inside temperature. The software gives the alternative to calculate this value when introducing information regarding windows' opening percentage and size, among others. For the simulation results this value is constant, but dynamic opening was performed to compare the numbers (results are shown in Appendix C) and set proper information.

For a typical winter week (1st to 7th July) a constant heating is needed to maintain inside temperature around 20°C. Internal gains do not reach a sufficient value in order to heat the building while infiltration is the main cause of heat loss. The following picture show winter results.

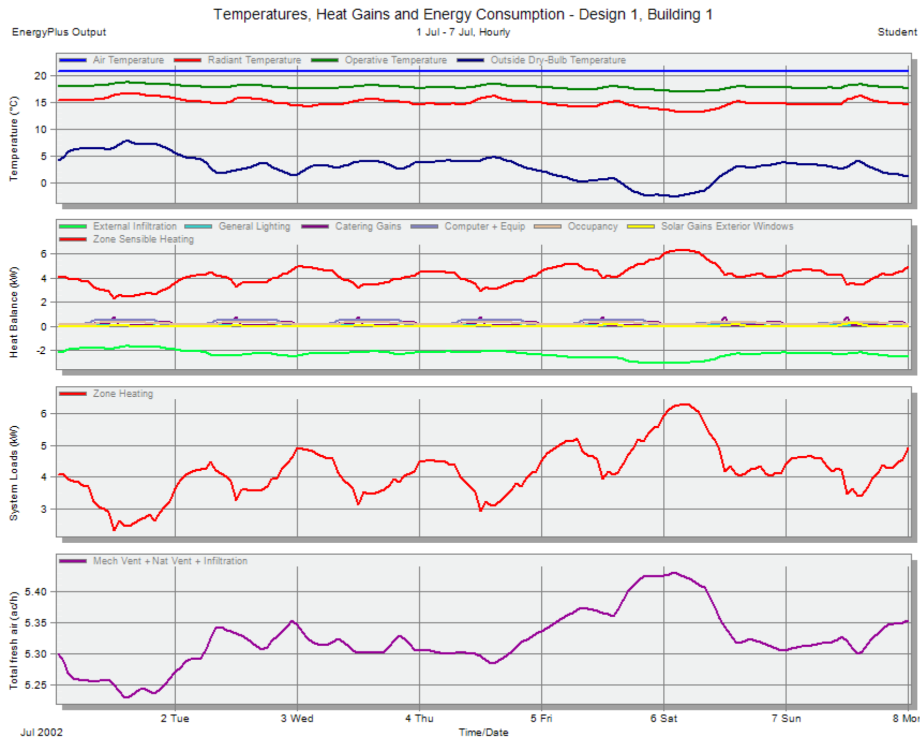



**Figure 24: Simulation results for a typical winter week (Base Model)**

## *Daylighting simulation calculation*

"*Daylight illuminance contour plots and average daylight factor and uniformity are generated for each zone calculated using the Radiance ray-tracing simulation engine*" [25]. This is used to take advantage of natural lighting through windows in the building in order to reduce artificial lighting.

Although, the software produces several reports (such as: *"LEED v2. Credit EQ 8.1"* and *"Green Star Credit IEQ4"*), for daylight calculation a distribution contour map was selected as output because no specific report is needed. All parameters were set to default for the accurate detailed template. For a better performance the grid size was established between 0.05m and 0.2m and not margin in the building was considered. The working plane high is set in 0.75m. For the sky model several options can be taken to provide different values to the external daylight iluminance. CIE overcast day (scaled)[14] is used, as it is the standard traditional [25].

Because the only window designed for this first model is relative small, compare to the construction, most part of the building presets daylight factor[15] less than 2% (shown by the dark area of the figure), which is the lower value for a room to be considered daylight. However, in order to ensure

[14] Overcast day represent the luminance distribution observed for overcast skies. Adopted as a standard by the CIE in 1955, this description is the one most frequently used for illuminance modelling. This option is scaled using a standard sky illuminance at the zenith. By default the zenith illuminance is set to 10,000 lux so that daylight factors can be calculated simply as working plane illuminance values divided by 100. This option is frequently used for daylight factor calculations. Other zenith illuminance values can be entered though.

[15] It is the relation between the daylight illuminance at a point inside the building over the outdoor simultaneous illuminance on a horizontal plane of overcast sky.

not artificial lighting use the factor should be over 5%. The following figure shows the daylight distribution in the working zone where the window is located. Areas over 4% are coloured between pink and green; only a small zone near the windows has this colours. This means that electric lighting is needed in most of the place during the day (dark area) and supplementary light maybe used in the blue and light blue areas. The only zone over 1000Lux[16] is near the glazing, this value is recommended as good illumination for working areas . There is not natural light illumination in the tank deposit, bathroom and bedrooms areas due to the lack of windows. which indicates that artificial light is needed during the whole day. Improvements regarding this need to be done in order to reduce electricity demand in the building.

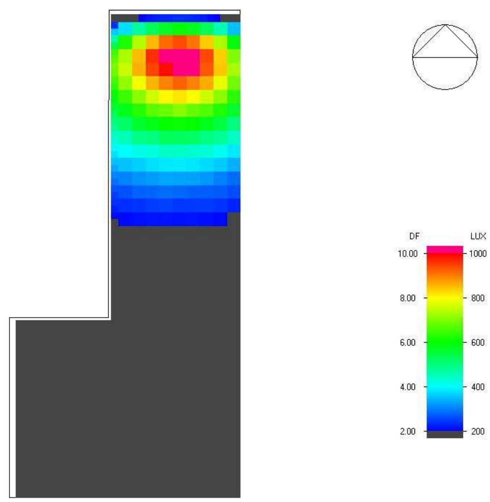



Figure 25: Daylight distribution in the working zone (Base Model)

## Improvements

As it is explained before, day light was not being exploited totally. For that reason new windows were placed on the east wall of the house in order to improve day lighting on the work area, because it is consider to be the zone with more occupation during the day. At first, the bedrooms' area did not received natural illumination. Because of that, two additional windows were drawn in the west wall, at the first floor high. The same glazing as the original window is used for all the new openings (double panel with air gap). Changing the glazing will be evaluated in later analysis. No openings were placed in the bathroom and storage room. Those spaces does not have a continuous occupation so the total electrical demand due to artificial light is not high. However, a ventilation system was incorporated on the west wall at the bathroom level to improve natural air circulation. A large, dark slats grille was placed for ventilation.

Although this improvement represents a saving regarding the energy used in artificial illumination, it rises the losses through glazing and the solar gains, resulting in increasing of heating during winter and possible overheating during summer period. The table bellow shows for different percentage of wall glazing changes in the heating energy and sola gain.

[16] 1000Lux are recommended as good value for working areas. 500Lux can be also used as the lowest limit [49].

| % glazing | | | Heat | | | Max solar gain (Jan) | | | |
|---|---|---|---|---|---|---|---|---|---|
| north wall | east wall | west wall | losses (kW) | need (kW) | % heat energy need increase | gain (kW) | % gain increase | Area above threshold (%) | Avg dayfactor (%) |
| 41% | 0% | 0% | 0.11 | 7.06 | | 0.92 | | | |
| 41% | 11% | 0% | 0.23 | 7.93 | 12% | 1.38 | 50% | 69 | 3.01 |
| 41% | 22% | 10% | 0.42 | 8.07 | 2% | 2.49 | 80% | 80 | 5.11 |
| 48% | 36% | 16% | 0.62 | 8.20 | 2% | 4.04 | 62% | 99.95 | 7.71 |
| 48% | 48% | 22% | 0.78 | 8.28 | 1% | 5.09 | 26% | 99.95 | 11.13 |

**Table 6: different percentage of wall glazing, heating need and sola gain**

The total opening in each wall stays under 50%, which is the maximum value allowed in the area regarding Chile's regulations (for a glazing U-value lower than 2.4W/$m^2$ K). After a while the total area above threshold stop increasing. Meanwhile, it is the average day factor which continues improving. Losses through the glazing growth in the same proportion as the window area. However, it does not impact in the same way the total heating need, as it only increases between 1% and 2% after its initial pick. On the other hand, solar gain remains heightening achieving a final value 4.53 time bigger than the first model. Increasing in solar gain not only depends on the size of the opening, but also in the window location. It is a problem during summer because it represents one of the main factors enhancing inside temperature.

Because the building will depend only on an autonomous electrical generation system the total energy used for heating needs to be reduced. Hence, thermal insulation in walls, roof and floor was placed. In order to accomplish a proper alternative Chile's regulations were followed when selecting the corresponding insulation materials. The most common alternatives used in the country are glass fibber batt insulation and mineral fibber/wool batt insulation. These materials must have a minimum R100[17] equivalent factor of 376 for roofs, 154 for walls and 295 for ventilated floors [10]. When fulfilling this values a thickness of 160mm for roofs, 80mm for walls and 140mm for ventilated floor (or over) must be used. The following figure show the new cross sections of the different building parts using glass fibber batt (compressed). The other layers remain equal the original design.

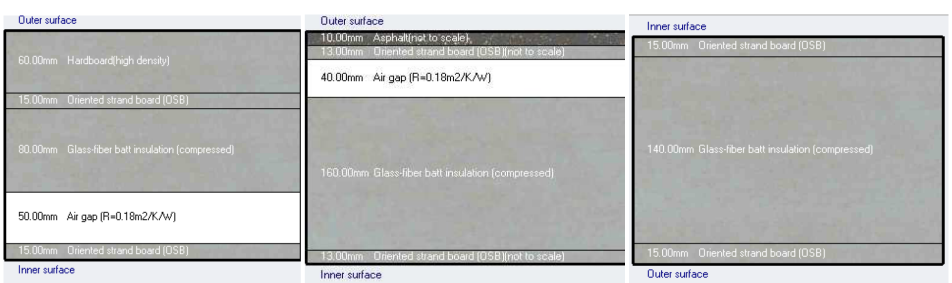



**Table 7: external wall, roof and floor cross section with insulation**

[17] The R100 equivalent factor corresponds to the thermal resistance value ($m^2$K/W) multiply by 100 *(Chile's regulation NCh 2251)* [10]

Although losses increase due to added glazing and external ventilation, when adding insulation structural they reduce by 75%. Hence, the heating energy needed falls by 33%. The following table shows losses values through glazing, walls, roof and because of external ventilation and infiltration for three different models. The first one corresponds to the base design (ICELAB II). The second model is the one with new openings, but not insulation material. There losses through glazing increase and due two external ventilation (slats in the bathroom). Model 3 represents the building with new windows and insulation material (minimum required values of fibber glass bat).

| kW | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| **Glazing** | 0.11 | 0.42 | 0.42 |
| **Walls** | 1.36 | 1.28 | 0.61 |
| **Roof** | 0.97 | 0.97 | 0.13 |
| **Floor** | 1.37 | 1.37 | 0.13 |
| **Ext Inf** | 3.41 | 3.41 | 3.41 |
| **Ext Vent** | - | 0.14 | 0.14 |
| **Sensible Heating** | 7.6 | 8.07 | 5.39 |

Table 8: Losses values through glazing, walls, roof and because of external ventilation and infiltration improvements

The table also shows a chance of improvement when reducing external infiltration losses. For the base model the worst possible scenario was used ( setting a the value in 5 ach/h), if that value is changed to 3.5 ach/h the total heating need decreases to 4.36kW. This progression is linear. The following graphic presents the relationship among the air changes per hour due to infiltration (values between 5 and 0.5) and the heat losses and sensible heating. As a result, when bringing the value from 5 ach/h to 0.5 ach/h a total saving greater than 70% can be achieved.

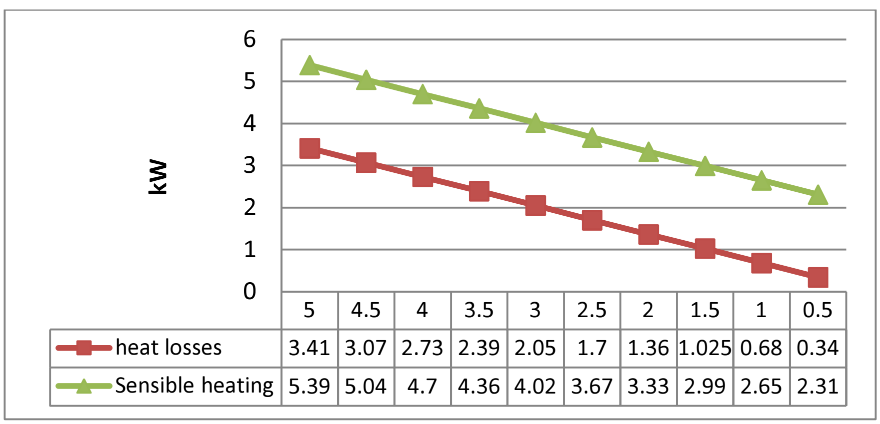
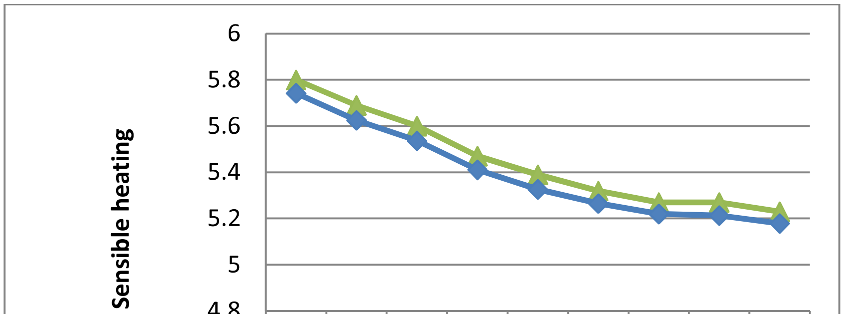



Figure 26: Infiltration rate

Nonetheless, the same result is not observed when referring to insulating materials. Since the losses do not decrease linearly when increasing their thickness. The graph bellow shows the relationship between the material added in the wall and the heating need (the rest of the parameters stay constant). Also mineral wool perform slightly better than the fibber glass (around 1%). Consequently any of both materials can be used indistinctly.




| | 20 | 30 | 40 | 60 | 80 | 100 | 120 | 130 | 150 |
|---|---|---|---|---|---|---|---|---|---|
| Glass fiber | 5.8 | 5.69 | 5.6 | 5.47 | 5.39 | 5.32 | 5.27 | 5.27 | 5.23 |
| Mineral wool | 5.74 | 5.62 | 5.54 | 5.41 | 5.33 | 5.26 | 5.22 | 5.21 | 5.18 |

Figure 27: Insulation material vs. sensible heating

The only cooling system in the building is natural ventilation, because of that it is necessary to ensure that during summer inside temperature stays in a comfortable range. When increasing the opening also increase the air change per hour. Natural ventilation values were calculated for a new design with four new windows (22% opening in the east wall and 10% on the west wall); insulation material located in walls, roof and floor (minimum required batt fibber glass). Infiltration is not considered so the value only stays for natural ventilation. The windows can be opened 5% the whole day between September and March. The door is not opened. Results shows that the temperature reaches a pick if 26° Celsius and 25ac/h can be reached with this openings.

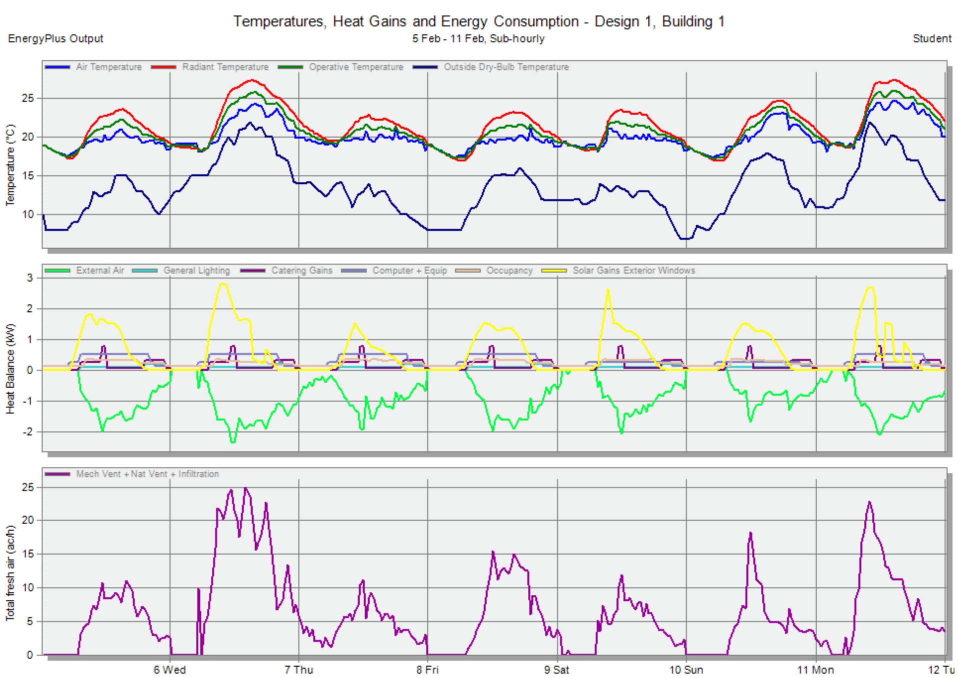



Figure 28: Simulation results for a design summer week increasing openings (natural ventilation calculated)

When reducing the number of windows that can be opened also decreases the ac/h rate. Recalculating the values for only three windows the total fresh air goes to 17ac/h peak and inside temperature stills stays under 26° C. If now the natural ventilation is set to a constant value of 10ac/h (and not calculated) and the outside temperature opening set point reduced to 10°C, inside temperature is still in 26°C. This indicates that natural ventilation has a great potential in the area. New windows are located for natural light improvement, as a result natural ventilation increases ensuring enough heat loss in summer to avoid overheating.

## Selection

For the final model a fibber glass insulated building (160mm for roofs, 80mm for walls and 140mm for ventilated floor) with double panel glazing. Natural ventilation (18ac/h) is used in summer period and infiltration value is 2ac/h. Heating is only used during autumn and winter. Five openings are present in the building. Two of them are placed on the east wall at 2000mm high from the floor and have a total size of 1500x2000mm (as the original window). Other two 550mmx1500mm windows were placed on the west wall at 3000m high from the floor. The last one is the original window on the north wall.

The previous values were selected in order be able to design the autonomous energy system and evaluate the building as a whole. Different combination of various alternatives can be done to obtained distinct results. During the chapter this choices were presented.

# Autonomous energy generation system design

*This section presents the design of the autonomous energy generation system based on solar energy using photovoltaic panels. Various tools like Chile's solar energy explorer and PVsyst software were used for sizing it.*

## Introduction

The objective of this chapter is to present different alternatives PV systems to supply the building demand. The performance of different PV system arrays is evaluated in order to obtained an alternative that fit the user's needs. Weather conditions (like solar radiation, cloudy sky, rain, etc) are an important factor when designing the system as they define the total number of modules. Moreover, the available space needed to placed the panels is also a decisive factor; as it is intended to do it on the roof of the building in order to reduce the impact in the area. As the whole building only depends on this system, demand needs to be divided into seasons because it is not constant through the year.

Demand and equipment system (PV array, batteries and controllers) calculations are detailed bellow.

## Demand

In order to design the autonomous energy generation system first it is necessary to know the total demand for the building. Lighting system, heating, kitchen appliances and working equipment loads are considered.

According to Chile's Ministry of housing and urban planning the average residential electric consumption in the country is 220kWh/month. This gives a value around 7.3kWh/day [29]. A similar number can be found in the World Energy Council [30].

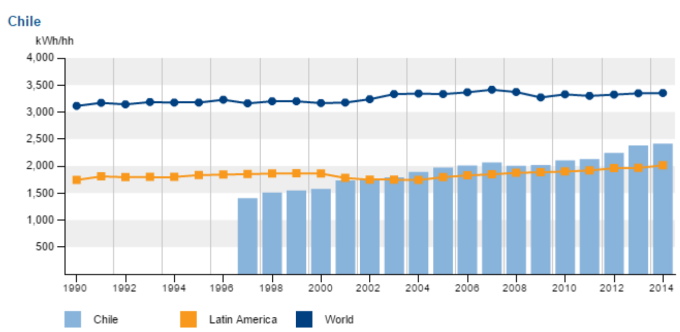



Figure 29: Average residential electric consumption in Chile [30]

Although this values can be taken as reference, they do not represent the real demand of the Lab. As the only available source of energy is electricity all systems may really on it. Objects like stoves and electric heating systems demand a great amount of electricity in order to work which can increase the final number. The table bellow shows a list of common appliances and their power consumption, also the regular time of use in a house. To calculate the final demand the appliances' power need to be multiply by the amount of hours the object is used. Not all the following objects are considered for the building.

| Equipment | Power (Watts) | Average daily use | Total monthly energy (kWh) |
|---|---|---|---|
| **Lighting** | | | |
| 10 Compact fluorescent lamp 20W | 200 | 8 | 48 |
| 10 Compact fluorescent lamp 15W | 150 | 8 | 36 |
| **Big appliances** | | | |
| Refrigerator (300liters) | 150 | 24 | 54 |
| Microwave oven | 800 | 1 | 19.2 |
| Washing machine (5kg) | 2500 | 1 | 26.25 |
| Freezer (350 liters) | 250 | 24 | 81 |
| **Air conditioning** | | | |
| Air conditioning unit | 1350 | 2 | 60.75 |
| Air conditioning unit | 2150 | 2 | 96.75 |
| Air conditioning unit central | 6000 | 3 | 432 |
| Fan | 90 | 2 | 5.4 |
| **Small appliances** | | | |
| Coffee machine | 900 | 1 | 21.6 |
| Iron | 1000 | 1 | 30 |
| Hair dryer | 500 | 0.5 | 6 |
| Food processor | 500 | 0.5 | 6 |
| **Electronic equipment** | | | |
| Personal computer | 90 | 4 | 10.8 |
| Ink printer | 50 | 0.5 | 0.75 |
| Laser printer | 400 | 0.5 | 6 |
| Computer monitor | 120 | 4 | 14.4 |
| TV | 100 | 4 | 12 |

Table 9: Common appliances and their power consumption [31]

Approximate values were taken to define the building's daily demand profile for each season. Finally the days per month the building is occupied was established to obtained a similar demand profile through the year and respecting the occupancy between 5 to 10 days established in the original project. For this a total of 13 days in summer, 7 days in autumn and spring and 6 days in winter was used. The table bellow shows the daily demand values (in kWh) for each season and the graph the monthly total demand.

| Season | Summer | Autumn | Winter | Spring |
|---|---|---|---|---|
| Daily demand | 4.10 | 7.09 | 7.26 | 7.09 |

Table 10: Daily calculated demand

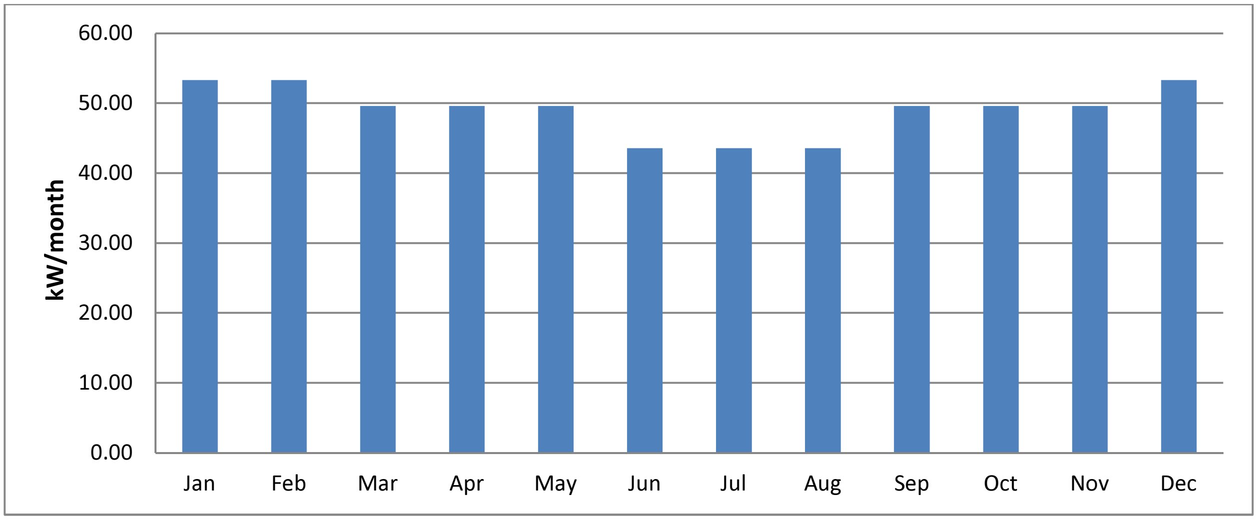



Figure 30: Monthly calculated demand

The design is done on the total daily value. An hourly file was created breaking up these numbers through the day and placing them in the hour when the consumption is most probably to be generated (Appendix D). Because user's needs are not constant along the day, it is necessary to separate the values to ensure enough power to supply the peak demand. For example, during office hours computers and laboratory equipment need to be used; increasing the demand when comparing to night hours (when users are sleeping). The following table shows the selected equipment, their power and consumption hours. These values are reference numbers. Using more efficient appliances or replacing the one selected for more suitable ones to supply the user's needs is possible as long as the demand does not go over 7.26kWh and the peak can be supplied with 24V.

| Equipment | Power (Watts) | Average daily use | Total daily energy (kWh) |
|---|---|---|---|
| LED lamp laboratory (500lux) [32] | 70 | 7 h | 0.49 |
| LED lamp other (350 lux) [32] | 25 | 4 h | 0.10 |
| Coffee machine [31] | 900 | 10 min | 0.15 |
| Microwaves oven [31] | 800 | 20 min | 0.27 |
| 2 Portable computers 65W [33] | 130 | 5 h | 0.65 |
| Laboratory equipment [34] | | 4 h | 1.14 |
| Electric Heating system [35] | 700 | 4 h | 2.80 |
| Water heating system [34] | | 24h | 1.33 |
| Refrigerator [36] | | 24 h | 0.32 |

Table 11: Selected equipment

## Solar energy (Solar Explorer calculation)

A first prototype for the autonomous energy generation system was design using the Solar Energy Explorer tool provided by Chile's Energy Ministry[18]. This tool allows to perform a estimation of a solar electrical generating system. It provides information regarding solar radiation and some basic aspects for PV panels selection [37]

For the country southern part around 3kWh/m$^2$/day of radiation energy reaches the earth. The system does not have the exact information for Karukinka Park (GPS: -57.03° latitude; -69.00° longitude; 400masl elevation) because of that GPS coordinates: -54.18° latitude; -68.70° longitude; 334meters above sea level elevation (masl) are used instead. For the zone, the annual radiation with 42° inclination goes up to 3.65 kWh/m$^2$/day. The direct normal radiation is about 3.69kWh/m$^2$/day and 1.33 kWh/m$^2$/day is diffuse radiation. The following graph shows the daily radiation for fixed, 42° inclined panel array and the monthly radiation for the horizontal plane (in kiloWatts/square-meter/day). The inclination optimizes the system performance in autumn, winter and spring when comparing to an horizontal fix position. Only during December and January the horizontal position performs better than having an angle.

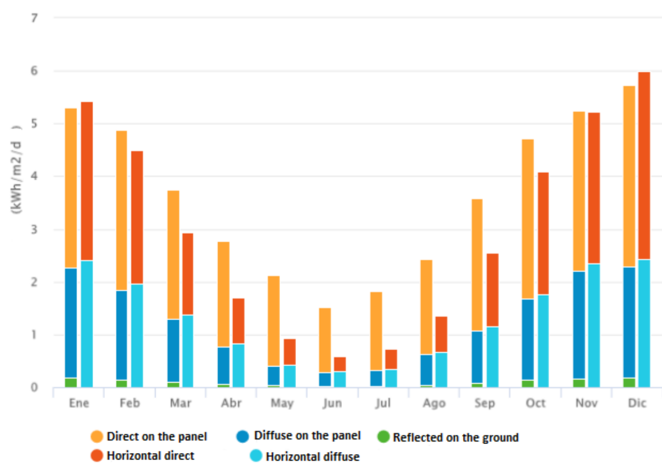



Figure 31: Daily radiation for fixed, 42° inclined panels array and horizontal plane

Only the 4% of the time the place has shadows. The cloudy sky affects Earth irradiance; because clouds scatter radiation of the sun the PV system's efficiency decreases. However, during winter (when there is less radiation) the sky stays clearer, while probability of cloudy sky increases during summer when light exposure hours are longer during the day. The following figure shows cloudy sky concurrency frequency along the year.

[18] The solar energy explorer was developed by the Physics Science and Math faculty from Chile University and it can be acceded through the link "*http://walker.dgf.uchile.cl/Explorador/Solar3/*".


Figure 32: cloudy sky occurrence frequency through the year

Temperature and wind velocity affects also the system. The selected place does not count with information regarding this parameters. For the calculation a constant temperature of 10°C and a wind speed of 2m/s is set.

The PV array consists of 42° tilt and -5° azimuth angle fixed panels. The assembly is "parallel to the roof" with a correction factor due to the reduction of ventilation under the panel (panels efficiency depends strongly on working temperature). Generic panels are used; the table bellow resume the modules' characteristics.

| | |
|---|---|
| Temperature coefficient | -0.45 |
| Loss factor | 14% |
| Cover | Glass |
| Current inverter efficiency | 96% |
| PV module efficiency | 15% |

Table 12: Solar energy explorer panels' characteristics

A total surface of 25m$^2$ is the available area for the installation (it is considered to be located on the roof of the building). Results show that a capacity of 3.7kW can be installed (this changes with the selected modules). The graph bellow show the monthly electric generation for this system and the annual variation. There is a remarkable difference in the total production between summer (dic-jan-feb) and winter (jun-jul-aug); being the last one 62% less. This values cannot supply the daily demand considered previously (for winter: 7.26kWh/day) but the monthly total generation is greater than the monthly demand. Installing a storage systems (batteries) will solve the daily problem. Also it will give the system enough autonomy when weather conditions are not optimal (cloudy days) and allow energy supply during night.

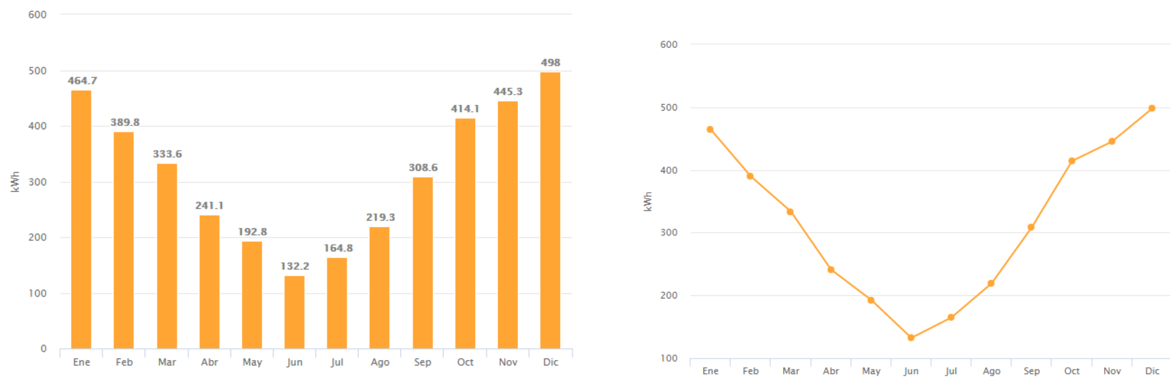



Figure 33: Solar energy explorer monthly electric generation and annual variation

In conclusion, there is enough radiation in the area to set a PV system (plus batteries) to supply the lab's demand. In this tool generic panels were used. The panel's material, type of cover, loss factor and temperature coefficient affect the production; when choosing the panels this characteristics need to be considered. A more detailed evaluation was done using PVsyst software.

## Pre-calculations

Previous the utilization of the software the PV array was estimated manually to use as reference. Calculation is done based on the calculation's manual for autonomous photovoltaic systems written by Europe SunFields [38] following this steps:

- Demand calculation.
- PV panels array sizing (using weather data of the place obtained from the Solar Energy Explorer).
- Battery sizing.
- Charge controller sizing and power inverter sizing.

### Demand calculation

For calculating the demand data exposed before is used. The daily demand during winter was selected as it is the higher value (7.26kWh/day). This number must be divided by the power inverter efficiency (0.95), the battery efficiency (0.9) and the conductors (wires) efficiency (1.00). A security coefficient (SC) of 20% is applied to the final result. The total value obtained is 10.19kWh/day. The resulting equation is:

$$L_{md} = \frac{L_{mdw}}{\eta_{inv} * \eta_{bat} * \eta_{cond}} * SC = 10.19kWh/day$$

The system voltage needs to match the loads. As a general rule 24Volt battery systems can be used for loads under 3-4kWh. While 12Volt systems are used for 1kWh loads or less [39]. The calculated demand does not go over 0.8kWh. However, some appliances use three to four times their nominal power when starting generating a peak. For safety reasons, 24V battery system is used. Using this voltage the total demand in Ah/day is:

$$Q_{Ah} = \frac{L_{md}}{V_{bat}} = 424.79 Ah/day$$

## PV panels array sizing

For the PV array calculation it is necessary to ensure the energy supply using weather data (radiation). In order to calculate the number of panels needed the lowest radiation value in the area is selected. For the park area this value corresponds to the one in June (1.51 $kWh/m^2/day$). The value is calculated dividing the energy consumption obtained before ($L_{md}$) by the chosen module peak power ($P_{MPP}$), the lowest irradiation ($HPS_{crit}$) and a functioning global factor recommended value 0.9 [38] (PR).

$$N_T = \frac{L_{md}}{P_{MPP} * HPS_{crit} * PR}$$

The following table presents the daily, horizontal radiation that reaches the park near zone per month, obtained from Chile's Solar Energy Explorer and the one at 42° (which was the explorer optimization angle). During December the total radiation is 5.72$kWh/m^2/day$ which is the higher value. While the lowest value is in June (1.51 $kWh/m^2/day$) when there is a bigger demand due to heating system. The difference between this two periods is 74%. With a constant demand profile along the year (as it was designed) there will be a surplus in the generation during sunnier periods when calculating the panels with the lowest irradiation. Hence different options were carried out.

| $kWh/m^2/day$ | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Daily Radiation** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
| **Direct** | 3.01 | 2.53 | 1.55 | 0.87 | 0.51 | 0.28 | 0.4 | 0.71 | 1.41 | 2.32 | 2.87 | 3.58 |
| **Diffuse** | 2.42 | 1.95 | 1.38 | 0.83 | 0.42 | 0.29 | 0.34 | 0.65 | 1.15 | 1.76 | 2.36 | 2.44 |
| **Global** | 5.43 | 4.48 | 2.93 | 1.7 | 0.93 | 0.57 | 0.74 | 1.36 | 2.56 | 4.08 | 5.23 | 6.02 |
| | | | | | | | | | | | | |
| **Daily Radiation on the panel** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
| **Direct** | 3.02 | 3.04 | 2.45 | 2 | 1.74 | 1.24 | 1.5 | 1.83 | 2.51 | 3.06 | 3.02 | 3.42 |
| **Diffuse** | 2.11 | 1.7 | 1.21 | 0.72 | 0.37 | 0.25 | 0.3 | 0.57 | 1 | 1.54 | 2.06 | 2.12 |
| **Ground** | 0.17 | 0.14 | 0.09 | 0.05 | 0.03 | 0.02 | 0.02 | 0.04 | 0.08 | 0.13 | 0.16 | 0.18 |
| **Global** | 5.3 | 4.88 | 3.75 | 2.77 | 2.14 | 1.51 | 1.82 | 2.44 | 3.59 | 4.73 | 5.24 | 5.72 |

Table 13: Daily radiation

From the German company SolarWorld the Sunmodule SW Plus 260 Si-poly panel is used for the PV system (Specifications are in Appendix E). This module have a maximum power of 260Wp[19] ($P_{MPP}$); 38.4V of maximum open circuit voltage ($V_{oc}$)[20] and 31.4V for maximum power point voltage ($V_{mpp}$)[21]. The maximum power point current is 8.37A ($I_{mpp}$)[22] and the short circuit current is 8.94A ($I_{sc}$)[23]. The module efficiency is 15.51% ($\eta_m$).This panel was chosen due the company excellent functioning modules' performance and their yield in the PV+Test 2.0[24] [38]. The following pictures shows a rank of the best company in the market done by the Italian company SunReport in April 2016. SolarWorld stays in second place only surpassed by SANYO.

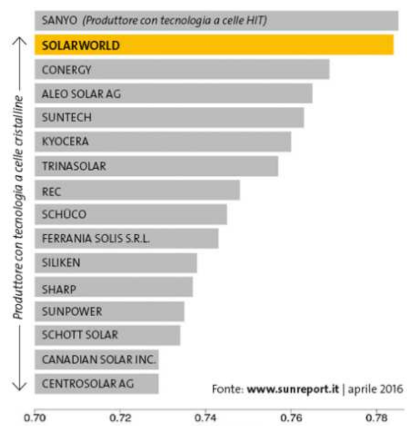



**Figure 34: Photovoltaic Systems Performance grouped by modules market. April 2016 [40]**

Three calculations are done using different HPS values in order to reduce losses due to variation in irradiation. For the first one the worst HPS value is selected (June: 1.51W/m$^2$), giving a total modules' number of 29. For the second one, an intermediate value is used (April:2.77W/m$^2$) resulting in 16 modules. Finally, the best scenery possible is chosen (December: 5.72 W/m$^2$) with 8 modules. The total modules' number can be connected in series or parallel. To defined the number of elements in series the battery voltage (24V) must be divided by the modules' maximum power point voltage (31.4V); resulting in 1 module. The number of modules in parallel is obtained dividing the total number of modules by the number of modules in series. As the previous result is 1 for each alternative the parallel modules will correspond to the total modules. (This equation can be used only when a maximum power point tracker converter is used). For this the following equations are used:

[19] Wp stands for Watt peak. "It is the standard used in the photovoltaic industry to measure the technical capacity of solar modules; it expresses the nominal output of the module under standard test conditions" [47]. Standard test conditions are 25°C and light intensity of 1000W/m$^2$.
[20] It is the voltage at zero current. [48]
[21] *"It is the voltage at which maximum power is produced by a solar panel"* [48]
[22] *"It is the current at which maximum power is produced by a solar panel"*
[23] It is the current at zero voltage (zero resistance). It is the maximum possible current. [48]
[24] The PV+Test is quality test performed by the German company TÜV.

$$N_{serie} = \frac{V_{bat}}{V_{MPP}}$$

$$N_{parallel} = \frac{N_T}{N_{serie}}$$

### Battery sizing

For the battery selection a maximum stationary SOC[25] ($DOD_{max,s}$) of 30% is used and a maximum daily depth of discharged ($DOD_{max,d}$) of 15% (reference values taken from the manual [38]). A total autonomy (N) of 6 days is set to ensure the operation of the building for a week in case modules do not produce enough electricity due to inappropriate weather conditions. To size the storage system the necessary nominal capacity ($C_n$) regarding the stationary and daily SOC needs to be calculated. Then the higher value is chosen. When using the daily DOD the total demand ($L_{md}$) is divided by this value in order to obtained the nominal capacity. On the other hand, when the stationary SOC is used the total demand is first multiply by the autonomies days and then divided by the corresponding DOD. The obtained values are divided by the battery voltage to have the result in Amperes per hour (Ah).

$$C_{nd}(Wh) = \frac{L_{md}}{DOD_{max,d}} = 67966Wh$$

$$C_{nd}(Ah) = \frac{C_{nd}(Wh)}{V_{bat}} = 2832Ah$$

$$C_{ns}(Wh) = \frac{L_{md} * N}{DOD_{max,s}} = 87385Wh$$

$$C_{ns}(Ah) = \frac{C_{ns}(Wh)}{V_{bat}} = 3641Ah$$

A minimum nominal capacity C100[26]=3641Ah is needed for the battery pack. When changing the demanded autonomy the battery changes. The following table shows the different battery size needed

---

[25] State of charge: "An expression of the present battery capacity as a percentage of maximum capacity" [20]. The depth of discharge is the complement of the SOC.

[26] "*A C-rate is a measure of the rate at which a battery is discharged relative to its maximum capacity. A 1C rate means that the discharge current will discharge the entire battery in 1 hour. For a battery with a capacity of 100 Amp-hrs, this equates to a discharge current of 100 Amps. A 5C rate for this battery would be 500 Amps, and a C/2 rate would be 50 Amps*." [20]

for an autonomy between 2 and 6 days. Before 5 days 2532Ah is needed, as it is the biggest value between the daily and stationary SOC.

| Autonomy | $C_n$ daily | $C_n$ stationary |
|---|---|---|
| 2 | 2832 | 1214 |
| 3 | 2832 | 1821 |
| 4 | 2832 | 2427 |
| 5 | 2832 | 3034 |
| 6 | 2832 | 3641 |

Table 14: Battery size needed for different autonomies

### Charge controller and power inverter sizing

The in and out maximum allowed current in the charge controller need to be calculated. The in current of the controller must be able to stand de short circuit current in the modules (as it is the maximum current possible). The calculation is done by multiplying this value per the parallel modules and a security factor (1.25). The result is 89A. For the out current, the total loads power needs to be divided by the efficiency of the inverter and the battery voltage. The result is 238A. For the charger controller a MPPT system will be used.

The inverter's power is calculated multiplying the AC the total loads power by a security margin of 20%. The same value for the loads as before is used. The result is 5140W. The inverter is not the simulated in the PVsyst software. The proper calculation needs to be done if the total load is changed.

Both the inverter and the charger are not selected on this work, as it is considered that nowadays these technologies are constantly improving and a detailed analysis on the subject needs to be performed in order to ensure the best choices.

## PVsyst calculation

### PVsyst software

"*The PVsyst software is a tool that allows its user to accurately analyse different configurations (grid-connected, stand alone, pumping and DC-grid) and to evaluate the results and identify the best possible solution*" [41]. The program has two different stages: preliminary design and project design. All configurations can be found in both parts.

- The preliminary design is the pre sizing step of a project. "*In this mode the system yield evaluations are performed very quickly in monthly values, using only a very few general system characteristics or parameters, without specifying actual system components. A rough estimation of the system cost is also available*" [41]. For the stand alone system this step sizes the required PV power and battery capacity using the load profile and the required autonomy (time without enough sun for generation).
- The project design is used for detailed hourly simulation. "*Within the framework of a "project", the user can perform different system simulation runs and compare them. He has to define the plane orientation (with the possibility of tracking planes or shed*

*mounting), and to choose the specific system components. He is assisted in designing the PV array (number of PV modules in series and parallel), given a chosen inverter model, battery pack or pump. In a second step, the user can specify more detailed parameters and analyse fine effects like thermal behaviour, wiring, module quality, mismatch and incidence angle losses, horizon (far shading), or partial shadings of near objects on the array, and so on*" [41].

## Preliminary design

A preliminary design using PVsyst software was done to obtained a pre-sizing of the PV array and battery pack needed to supply the demand. Before starting with the project the park's weather data is uploaded in the software. The data is from the NASA-SSE satellite data based (existing in the software) for the GPS coordinates: -54.18° latitude; -68.70° longitude; 334meters above sea level elevation (the same as in Chile's Solar Energy Explorer). This values is used because of its proximity with the park and to compare with the explorer results. The following table presents both radiation data. The values in PVsyst software are around 20% lower than the ones given by the country. This will be considered when analysing the results.

| $kWh/m^2/day$ | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Chile's Explorer** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
| **Direct** | 3.0 | 2.5 | 1.6 | 0.9 | 0.5 | 0.3 | 0.4 | 0.7 | 1.4 | 2.3 | 2.9 | 3.6 |
| **Diffuse** | 2.4 | 2.0 | 1.4 | 0.8 | 0.4 | 0.3 | 0.3 | 0.7 | 1.2 | 1.8 | 2.4 | 2.4 |
| **Global** | 5.4 | 4.5 | 2.9 | 1.7 | 0.9 | 0.6 | 0.7 | 1.4 | 2.6 | 4.1 | 5.2 | 6.0 |

| **Pvsyst** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Monthly global** | 135 | 102 | 77 | 42 | 24 | 16 | 19 | 35 | 61 | 102 | 122 | 144 |
| **Days per month** | 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 |
| **Daily global** | 4.3 | 3.6 | 2.5 | 1.4 | 0.8 | 0.5 | 0.6 | 1.1 | 2.0 | 3.3 | 4.1 | 4.6 |

**Table 15: Chile's solar explorer and PVsyst software radiation data**

Once the site and meteo are defined the user's needs are uploaded. For this part of the software the hourly file cannot be used. A daily household consumption profile need to be set. This is done by adding the number, power and daily used hours in a existing appliances list and defining their hourly used distribution. This can be done for the whole year, using a season profile or per month. For the project a season profile is used, and a total load similar to the one used in the hourly files is set. A battery voltage of 24V (the same as in the pre-calculations) and an autonomy of 6 days are the storage system's needs. The panels have 42° inclination.

The software proposes a battery system capacity of 2006Ah with a 3657 Wp nominal power PV array with nominal current of 117A. With this system the user's need are supplied in most part of the year. Between April and June a backup system need to be used. The following pictures shows the PV energy yield and the user's needs. The table bellow details the values for the incident radiation, PV available energy, the demand, excess and missing energy among others. During summer the PV available energy is four times bigger than in winter due to the difference in the incident radiation (as it was described before). For that reason there is an important energy surplus during summer (less than the PV available energy is used) that generate losses. For the total year the available energy is greater than the demand.

| | Incid. | PV avail. | Demand | Excess | Missing | SOC | Pr. LOL | Fuel |
|---|---|---|---|---|---|---|---|---|
| | kWh/m².day | kWh | kWh | kWh | kWh | % | % | liter |
| Jan. | 4.2 | 378.1 | 224.6 | 131.2 | 0.0 | 95 | 0.0 | 0.0 |
| Feb. | 3.9 | 320.1 | 202.9 | 107.1 | 0.0 | 94 | 0.0 | 0.0 |
| Mar. | 3.1 | 283.7 | 219.0 | 33.7 | 0.0 | 90 | 0.0 | 0.0 |
| Apr. | 2.2 | 194.7 | 211.9 | 0.0 | 0.7 | 58 | 0.3 | 0.4 |
| May | 1.7 | 154.8 | 219.0 | 0.0 | 80.2 | 17 | 36.6 | 53.5 |
| June | 1.5 | 127.6 | 123.0 | 0.0 | 17.2 | 20 | 14.5 | 11.4 |
| July | 1.5 | 134.2 | 127.1 | 0.0 | 10.0 | 21 | 7.9 | 6.7 |
| Aug. | 2.1 | 188.4 | 127.1 | 0.0 | 0.0 | 44 | 0.0 | 0.0 |
| Sep. | 2.8 | 248.0 | 211.9 | 8.6 | 0.0 | 84 | 0.0 | 0.0 |
| Oct. | 3.8 | 342.5 | 219.0 | 93.8 | 0.0 | 97 | 0.0 | 0.0 |
| Nov. | 4.0 | 351.3 | 211.9 | 114.4 | 0.0 | 97 | 0.0 | 0.0 |
| Dec. | 4.3 | 392.6 | 224.6 | 141.8 | 0.0 | 93 | 0.0 | 0.0 |
| Year | 2.9 | 3116.1 | 2322.1 | 630.7 | 108.1 | 67 | 5.0 | 72.1 |

Table 16: PVsyst pre-sizing report

The obtained values are taken as reference but they will not be considered as the final design because a backup system is needed. The objective of the project is design an autonomous system that can supply the total demand of the building. In case that this system is not possible due to some restriction (space, availability, etc) the use of a fuel powered backup system will be considered.

## Project design

### *Project's designation*

Like in the pre-sizing the site and meteo need to be defined. For this the same data uploaded in the previous step is used. Albedo's coefficient must be considered[27]. When there is no inclination the corresponding value is cero; while it increases with the angle's increased. It also depends on the materials in the surrounding area (where the radiation is reflected). The default value (0.2) is used for summer, autumn and spring. It is recommended by the program for urban environment and areas with grass. Other materials like aluminium, copper or fresh snow have a higher coefficient; while wet asphalt or very dirty galvanized have lower values. Because of that, during winter period it is used 0.5 to represent the snow's impact. In this part are also set other design parameters like the site dependent design parameters, the array maximum voltage, the muVoc value and the transposition model (Perez-Ineichen model, sophisticated). The site dependent design parameters are the reference operational temperatures. They are used for the design and can changed with the selected area. All the parameters correspond to usual European countries which is the best practice rule; they are:

- Maximum cell temperature in operating conditions (60°C).
- Summer usual operating condition (50°C).

[27] "*It is the fraction of global incident irradiation reflected by the ground in front of a titled plane*" [41].

- Winter minimum cell temperature in operating conditions (20°C).
- Absolute Cell lower temperature (-10°C).

The International Electrotechnical Commission standard (1000V [41]) is used for the maximum admissible array voltage. One-diode model[28] calculation is used to defined the muVoc value.

### *Orientation and user's needs*

For the orientation 42° is used and -5 azimuth (maintaining to Chile's Solar Explorer optimization options). For the user's needs an hourly file was uploaded (as described before).

### *System*

For the PV array the 260Wp Sunmodule Plus SW panels by SolarWorld are used (as in the pre-calculation). The regulation (battery charging controller) is done by a MPPT converter. The selection of the converter is done automatically by the program (universal controller is used).

For the storage system 8V and 681Ah batteries by Rolls (Surrete)[29] company are used (8-CS-25PS) because they adjust the best among the program's alternatives. For this battery there were no specifications found in Rolls' official site, but a similar alternative was selected. Changes needed and specifications are shown in Appendix F. The software selected technology is lead-acid, sealed, plates battery with 97% efficiency. It has 210mm width, 464mm depth, 718mm height and weights 134kg. The following picture shows the charge/discharge vs. SOC behavior.

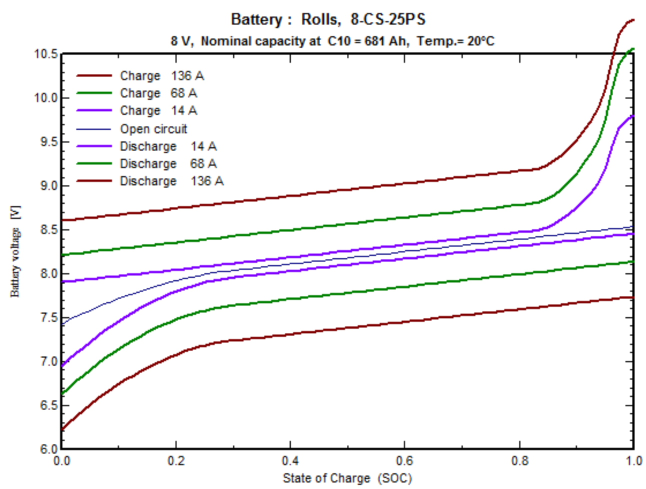



Figure 35: Rolls battery charge/discharge vs. SOC

No backup equipment is used in the system as it was explained before. The following picture shows typical layout of a stand-alone system used by the program. It consist of the PV array system, the battery pack, the regulator and the loads. The regulator connects and disconnects the loads and the PV

[28] The one diode model is Shockley's simple one diode model used to described a single cell operation and can be generalized for the whole module. [43]

[29] . Rolls is a battery manufacturer located in Springhill, Nova Scotia. They produced a wide range of deep cycle lead-acid batteries for use in Renewable Energy [44]

array to the battery. Here the charger controller need to be located in order to protect the battery. Loads can be also connected directly to the PV array if it is needed.

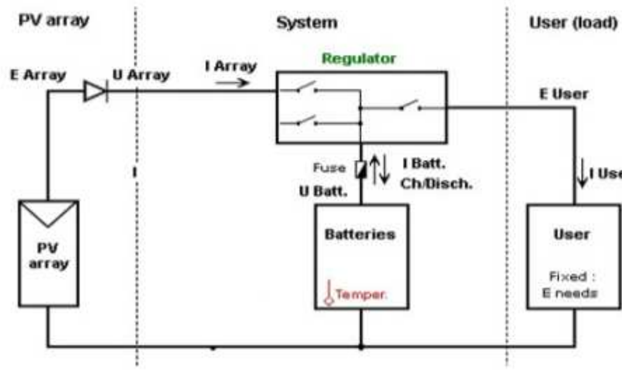



Figure 36: Typical stand alone layout [41]

### *Detailed losses*

Several detailed losses parameters can be carefully defined according to the designed PV system. PVsyst sets this losses to reasonable general values as default but a further analysis on each one can be done. Each case deserves a detailed study as they depend on several variants (like weather conditions, selected modules, array layout, etc). For this work the values were left as default since no adequate bibliography was found on the selected array that allows a proper definition of the coefficients. It will be the objective of further works to carry out a detailed analysis of the area that allows to define the losses' parameters. The losses' parameters are:

- **Thermal parameters**: field thermal loss factor definition (U) due to constant heat loss and due to wind. This coefficients depends on the mounting type (free mounted modules with air circulation, semi-integrated with air duct behind, integration with fully insulated back). The module efficiency depends on the working temperature. Increasing the operating temperature reduces the PV module voltage which lowers the output power [14]. Heat losses to the environment are due to conduction, convection and radiation. *"These loss mechanisms depend on the thermal resistance of the module materials, the emissive properties of the PV module, and the ambient conditions (particularly wind speed) in which the module is mounted*" [15].
- **Ohmic Losses**: losses due to wiring resistance. The software has a tool that allows the calculation of the losses when introducing the wire length. [41]
- **Module quality**: self consideration of the deviation of the average effective module efficiency by respect to manufacturer specifications. [41]
- **Mismatch losses:** losses caused by the interconnection of solar cells with different properties [15]. PV array output is defined by the module with the worst condition (lowest current). PVsyst has an statistic tool that creates a model (using a Gaussian or square distribution) to estimate this loss [41].

- **Soiling losses:** losses due to dirt accumulation on the panel's surface. This value depends strongly on the environment because different factors (as rainfalls, type of dust, wind, etc) can change its value. Snow must be also considered but it is not available in the program. [41]
- **Incident angle modifier (IAM) losses:** losses due to reflexion increase with the incident angle. Fresnel's laws is used to described it (concerning transmition and reflection) [41].
- **Module degradation:** loss of efficiency due to decrease in the PV yield. [41]

The following pictures shows a graphic of the previous detailed losses that are used in the simulation.

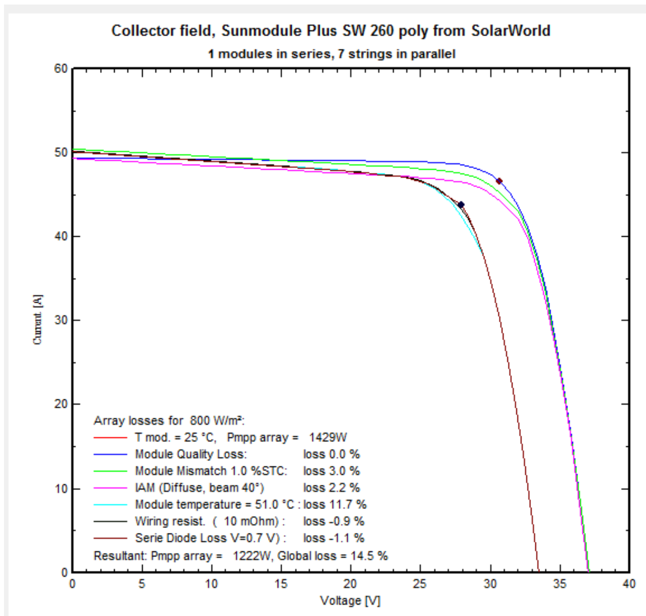



Figure 37; Losses' graph

### *Horizon and Near Shadings*

The horizon set allows to define far shadings (like mountains). According to PVsyst helper this shades need to be at least 10 times bigger than the PV field size [41]. Because of the selected placed, only 4% of the time there is shading [37]. Because of that, no far away shading were considered.

The near shading tool allows to create a 3D scene of the site placing near objects (trees, other buildings, etc) than may create shadow on part (or the total) PV array. The building should be placed in order it has no shadings, this need to be considered when doing the construction. For the PV array selection not near shadings are set.

### PV arrays' simulation

Different configuration were simulated in order to obtained a system that best adjusts to the building needs regarding demand, available space and losses. The different alternatives were done following the pre-calculations results and the PVsyst recommendations. In all of them the previous described PV modules and batteries are used. Also the losses and project's designation are maintained constant. The changes are in the number of PV modules and battery size. The MPPT is adjusted for each case. The following table summarizes the calculations made.

| | PV array | | | Battery | | |
|---|---|---|---|---|---|---|
| **Alternative** | $N_{serie}$ | $N_{parallel}$ | **Nom power (kWp)** | $B_{serie}$ | $B_{parallel}$ | **Global capacity (Ah)** |
| **1** | 1 | 29 | 7.5 | 3 | 6 | 4086 |
| **2** | 1 | 16 | 4.1 | 3 | 6 | 4086 |
| **3** | 1 | 8 | 2.1 | 3 | 6 | 4086 |
| **4** | 1 | 5 | 1.3 | 3 | 6 | 4086 |
| **5** | 1 | 4 | 1.0 | 2 | 1 | 681 |

Table 17: PV array and Battery sizing resume

The first alternative takes the modules' quantity calculated for the June radiation (worst scenario). The total available energy produces by the system is 6460kWh/year, but only 430kWh/year are used. This gives a surplus of 5700kWh/year unused (this energy is lost). It represents 88.2% in losses. The solar fraction is 100% which means that the system is big enough to supply the demand also during winter. For this array a total available space of 48.6m$^2$ is needed. This is bigger than the roof area. The performance ratio is 7.58%

For the second simulation a better HPS was used giving a total of 16 modules. Here the space needed is 26.8m$^2$ so it can be placed on the roof of the building. The total available energy is 3540kWh/year resulting in 2776kWh/year in excess (unused). This represents 78.5% in losses. The solar fraction is still 100%, indicating that not backup equipment is needed. The performance ratio goes up to 13.73%.

The following choice used a total of 8 panels corresponding to December HPS value. Here the performance ratio increases to 27.47% and the solar fraction is still 100%. The total available energy is 1731kWh/year, and the unused energy losses are 56.2% (974kWh/year). However, the unused energy in June is only 10.1kWh (enough energy to supply one and a half days' demand).

The fourth alternative is simulated using PVsyst recommendation regarding the panels' quantity but keeping the battery size that was manually calculated. The total energy available is 1061kWh/year and the excess only 306kWh/year. The total available energy is used in May and August. The performance ratio increase to 43.95% and the full battery loss decreases to 28.8%. Here the demand during June and July is bigger than the energy available. A deeper study need to be carried out to ensure that the battery will be able to supply this missing energy.

The last alternative takes into consideration the PVsyst recommendation regarding modules and battery size. The solar fraction is 49.70% which means that there is not enough available energy to supply the building demand. For that reason this alternative will not be longer considered.

## Selection

The best observed choices are the third and fourth alternatives described before. They both ensure the supply for the total demand for the whole year, but at the same time, losses due to unused energy are not so high. Further studies need to be done to ensure that the total energy available in the free period is enough to charge the battery to ensure an 6 days autonomy. For that period the total demand is 61.16kWh (this is calculated multiplying the winter daily demand of 7.26kWh per the 6 days autonomy and adding a 20% as security factor and equipment efficiency). The battery depth of discharged is 70%; the previous result must be divided by this number (although the battery has a 30% remained energy, it will be considered that the total energy is needed). The result is 87.38kWh. The total energy generated is obtained multiplying the array's total current (one module current multiplies per the total modules in parallel) per the total voltage (one module voltage multiplies by the total modules in parallel) and the irradiation (a 15% is reduced due to losses).

It is important to highlight that although the values calculated are the monthly demand, it is concentrated only in a week; while the array produces the entire month. So it is necessary to ensure that during the unused period the array generated enough electricity to load the battery when the daily demand is higher than the daily PV production. For the fourth alternative (4 modules) in May and August the following table shows that the energy is just enough to supply the total demand without considering the 20% safety factor. And for June and July the produced energy is lower than the demand, not being able to charge the battery in its totality. The following table shows the main results for the fourth alternative. Unlike fifth alternative, here no backup system is needed as the battery is big enough to supply the missing energy. This is under perfect conditions of radiation (the data uploaded in the program). This values are not constant along the years which can lead to not sufficient capacity.

| | GlobHor kWh/m² | GlobEff kWh/m² | E Avail kWh | EUnused kWh | E Miss kWh | E User kWh | E Load kWh | SolFrac |
|---|---|---|---|---|---|---|---|---|
| **January** | 134.8 | 118.9 | 129.1 | 19.30 | 0.000 | 53.25 | 53.25 | 1.000 |
| **February** | 101.6 | 99.6 | 109.3 | 44.28 | 0.000 | 53.25 | 53.25 | 1.000 |
| **March** | 76.9 | 87.5 | 97.7 | 36.95 | 0.000 | 49.59 | 49.59 | 1.000 |
| **April** | 41.7 | 58.6 | 65.3 | 3.97 | 0.000 | 49.59 | 49.59 | 1.000 |
| **May** | 24.2 | 43.7 | 50.1 | 0.01 | 0.000 | 49.59 | 49.59 | 1.000 |
| **June** | 15.6 | 33.5 | 39.1 | 0.00 | 0.000 | 43.55 | 43.55 | 1.000 |
| **July** | 18.6 | 35.5 | 41.7 | 0.00 | 0.000 | 43.55 | 43.55 | 1.000 |
| **August** | 34.7 | 54.9 | 62.9 | 0.00 | 0.000 | 43.55 | 43.55 | 1.000 |
| **September** | 60.6 | 74.5 | 83.5 | 7.91 | 0.000 | 49.59 | 49.59 | 1.000 |
| **October** | 101.7 | 106.2 | 120.4 | 59.39 | 0.000 | 49.59 | 49.59 | 1.000 |
| **November** | 121.5 | 109.4 | 122.5 | 61.65 | 0.000 | 49.59 | 49.59 | 1.000 |
| **December** | 143.8 | 123.8 | 139.0 | 72.75 | 0.000 | 53.25 | 53.25 | 1.000 |
| Year | 875.8 | 946.0 | 1060.5 | 306.19 | 0.000 | 587.93 | 587.93 | 1.000 |

Table 18: 4 modules array main results

As it was said before, this kind of generation has a strongly dependency on weather conditions using limit values will not ensure the supply. For this reason it is considered that the best option would be to oversize the array in order to guarantee it but at the same time not introducing big losses due to unused energy. The best equilibrium between enough energy and low losses is obtained with the third alternative. This option guarantees a total supply using the array and at the same time a surplus energy that will allow to totally charge the battery during unused periods. The following table summarizes the daily, used period (days when the building is occupied) and monthly production of the 8 and 5 panels array. It shows the remaining energy produced in the month (unused period energy) and the energy needed to load the battery (unused energy in used period). The last row shows the losses due to unused energy when the battery is full (this energy can be load to the grid is there were a grid connection). As it was mentioned before PVsyst uses 20% less radiation values than the one obtained in Chile's data based. For that reason PVsyst values are considered (all energy is in kWh).

In the calculations, it is seen that for the 5 modules array the available energy is not enough to ensure charging the battery between May and July (unlike the previous PVsyst results that it was only for June and July). A different building's monthly used can be evaluated and more analysis can be done on the alternatives but this will restricted the user's need. For that reason using 8 modules array is considered to be the best option.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Days per month** | 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 |
| **Used period** | 13 | 13 | 7 | 7 | 7 | 6 | 6 | 6 | 7 | 7 | 7 | 13 |

| $I_{PV\ array}$ | 66.96 | | 8 modules array | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{PV\ array}$ | 31.4 | | | | | | | | | | | |
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| kWh/d | 7 | 6 | 5 | 4 | 3 | 2 | 2 | 3 | 4 | 6 | 7 | 7 |
| kWh/used period | 90 | 83 | 36 | 25 | 18 | 12 | 12 | 19 | 31 | 43 | 46 | 93 |
| kWh/month | 214 | 179 | 157 | 105 | 79 | 60 | 64 | 99 | 134 | 191 | 197 | 223 |
| | | | | | | | | | | | | |
| Daily demand | 4 | 4 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 4 |
| Unused daily energy | 3 | 2 | -2 | -4 | -5 | -5 | -5 | -4 | -3 | -1 | -1 | 3 |
| | | | | | | | | | | | | |
| User period demand | 53 | 53 | 50 | 50 | 50 | 44 | 44 | 44 | 50 | 50 | 50 | 53 |
| Unused ener in used period | 36 | 30 | -14 | -25 | -32 | -32 | -31 | -24 | -18 | -7 | -4 | 40 |
| Unused period energy | 124 | 96 | 122 | 81 | 61 | 48 | 51 | 80 | 103 | 148 | 151 | 129 |
| | | | | | | | | | | | | |
| Monthly demand | 53 | 53 | 50 | 50 | 50 | 44 | 44 | 44 | 50 | 50 | 50 | 53 |
| Unused monthly energy | 160 | 126 | 108 | 56 | 29 | 17 | 20 | 55 | 84 | 141 | 147 | 169 |
| | | | | | | | | | | | | |
| Losses due to unused energy | 160 | 126 | 108 | 56 | 29 | 17 | 20 | 55 | 84 | 141 | 147 | 169 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $I_{PV\ array}$ | 42 | | 5 modules array | | | | | | | | | |
| $V_{PV\ array}$ | 31 | | | | | | | | | | | |
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| kWh/d | 4 | 4 | 3 | 2 | 2 | 1 | 1 | 2 | 3 | 4 | 4 | 4 |
| kWh/used period | 56 | 52 | 22 | 15 | 11 | 8 | 8 | 12 | 20 | 27 | 29 | 58 |
| kWh/month | 134 | 112 | 98 | 66 | 49 | 38 | 40 | 62 | 84 | 119 | 123 | 139 |
| | | | | | | | | | | | | |
| Daily demand | 4 | 4 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 4 |
| Unused daily energy | 0 | 0 | -4 | -5 | -6 | -6 | -6 | -5 | -4 | -3 | -3 | 0 |
| | | | | | | | | | | | | |
| User period demand | 53 | 53 | 50 | 50 | 50 | 44 | 44 | 44 | 50 | 50 | 50 | 53 |
| Unused ener in used period | 3 | -1 | -27 | -34 | -39 | -36 | -36 | -32 | -30 | -23 | -21 | 5 |
| Unused period energy | 78 | 60 | 76 | 50 | 38 | 30 | 32 | 50 | 64 | 92 | 94 | 81 |
| | | | | | | | | | | | | |
| Monthly demand | 53 | 53 | 50 | 50 | 50 | 44 | 44 | 44 | 50 | 50 | 50 | 53 |
| Unused monthly energy | 80 | 59 | 49 | 16 | -1 | -6 | -4 | 18 | 34 | 70 | 73 | 86 |
| | | | | | | | | | | | | |
| Losses due to unused energy | 80 | 59 | 49 | 16 | -1 | -6 | -4 | 18 | 34 | 70 | 73 | 86 |

Table 19: 8 and 5 modules PV array resume

The previous table's numbers does not match exactly the values obtained in the PVsyst software (table 18); as it works with simulation and can change the parameters for the different periods. But they can be considered as an approximation of the real results and be used to evaluate the system's capacity as a whole. The following figures show the PVsyst losses graph for the two arrays.

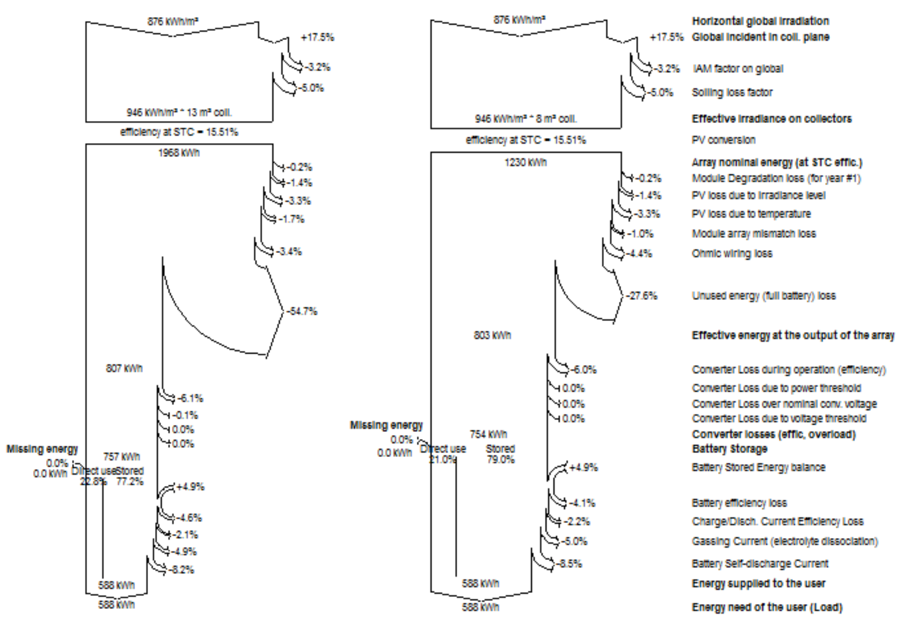



Figure 38: 8 and 5 modules array losses' graph

Further study on a 6 module array system was done (Appendix G). Although this value was not first considered, this is the minimum quantity of panels that can be used if the total demand want to be supply along the year and the battery wants to be fully charged every month. Although this new alternative is presented the 8 modules system is selected. This is because several parameters were used as default values due to lack of bibliography regarding those topics. Because of that it is considered that using more panels is a secure option without being excessive. After knowing the real performance of the system this can be recalculated and the total number of modules adjusted.

# Results and discussions

This chapter present the recommended choices' results using the softwares.

The objective of this thesis is to design an autonomous system that can supply the demand generated in the ICELAB Patagonia II. For this the user's needs were studied and several improvements were introduced to reduced the demand. Then an energy generation system based on photovoltaic technology was calculated. The performance of the different options were exposed in the previous chapters. In this section the final performance of the whole building using the chosen options is presented.

Insulation materials are an essential factor to ensure a comfortable space without increasing the energy demand due to heating or cooling. Based on Chile's regulations adequate thermal insulation and glazing was selected for the building which decreases heat loss. A better performance was obtained by reducing the heating needs but at the same time ensuring an adequate inside temperature during summer. The following results correspond to the building selected in the corresponding chapter. Because solar panels are placed with 42°tilt, one of the longer walls need to face north (-5° azimuth was despised), the building was rotated so the east wall now faces north.

The daylight illumination inside the building improved substantially. Most of the working area in the ground floor has a natural illumination between 400 and 800 lux. The average daylight factor stays in 5,11%, and the 80% of the area stays above the 2% threshold. While in the first floor a mayor area is still under the inferior daylight factor limits (2%) there is some daylight utilization.

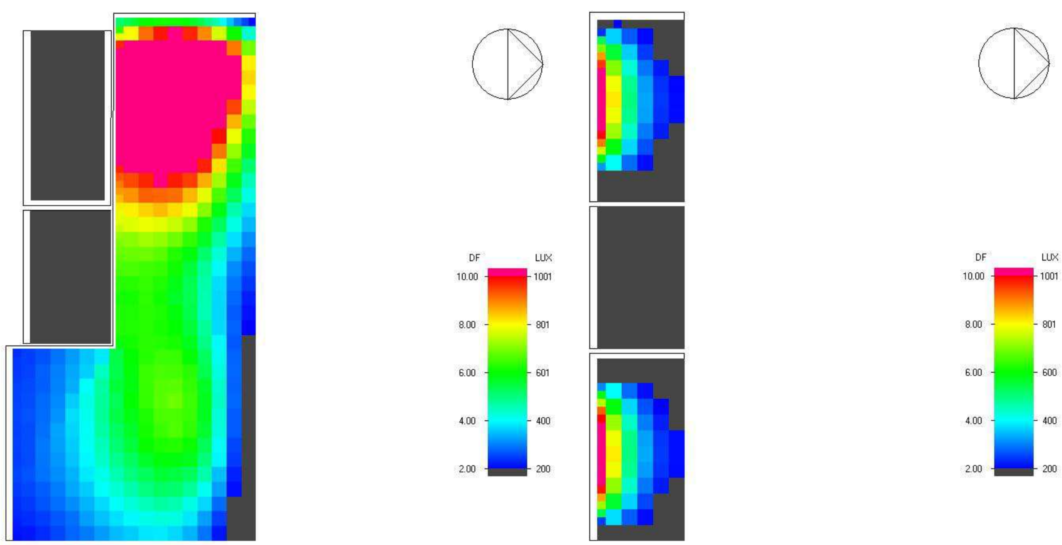



Figure 39: Ground and first floor daylight map (Final Model)

The total energy needed to heat the house is 3.2kW. The following pictures shows a typical design summer week (during March). Natural ventilation affects inside temperature (as outside temperature is always bellow inside temperature), this ensure cooling due to natural air. Solar gains are still the most important heat source. For the program natural ventilation is activated with set parameters while in reality it is the user's behaviour respond. That is why it is does not show the real performance of this system but can be used to evaluate the cooling capacity of the area weather conditions. The results show a good performance of the building during summer with comfortable temperatures.

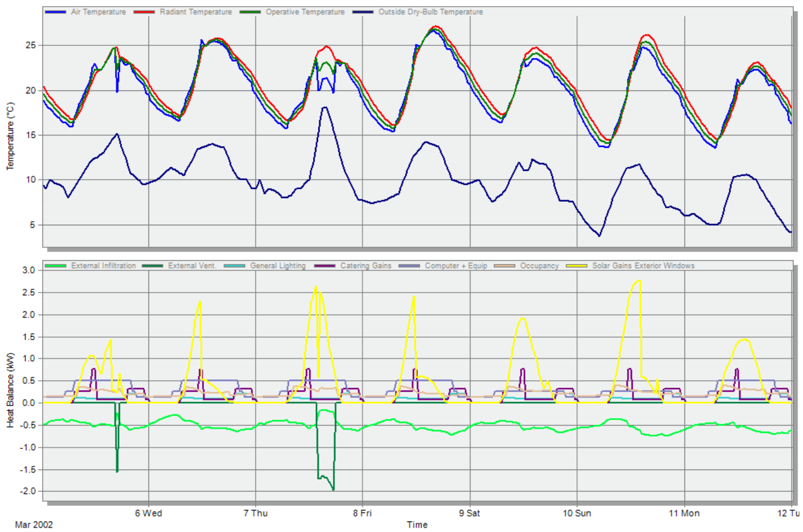



Figure 40: Summer typical week building performance (Final Model)

During winter heating maintains a constant temperature of 20°C inside the building. Although the total heating energy needed (worst scenario) is 3.1kW when considering internal loads this values goes down to 2.5kW. The pick of demand occurs during night when there is no solar gain and temperatures gets lower. For the demand the selected heating does not respond to this needs as it was explained before electric heating has a high electric consumption. Appropriated winter clothing need to be worn in to ensure a comfortable stay. Once built, the real performance of the building can be analysed and further adjustments can be done.

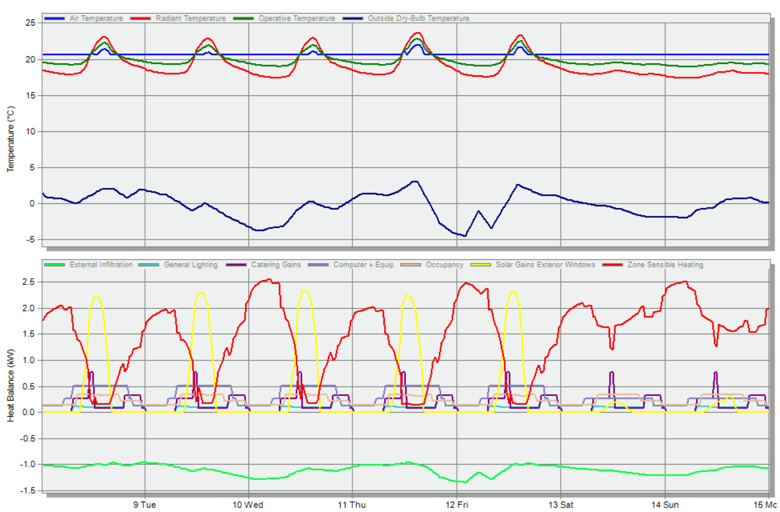



Figure 41: Winter typical week building performance (Final Model)

For the PV system a total of 8 260Wp modules is used connected in parallel with a 42° tilt and -5° azimuth. The total capacity is 2.1kWp and the capacity at operating conditions (50°C) 1.628kWp. At operating conditions the maximum power point voltage and the maximum power point current are 28V and 67A respectively. The total area needed is 13.4m$^2$ which allows to placed them on the roof. The soiling losses are 5% and no loss or gain due to quality loss is set. The thermal factor is set only constant at 15W/m2K (wind is not considered). The wiring ohmic loss is 2% at STC with a 9.4mOhm resistance. The module mismatch loss is 1% and the average degradation 0.4%year. A total of 18 batteries are used, 3 in series and 6 in parallel. The nominal capacity is 4086Ah and the voltage is 24V. The operation temperature is fixed at 20°C. The universal controller is a MPPT converter with 1.456W nominal power and 60.7A charging current.

The available energy is 1731kWh/year and the specific production 832kWh/kWp/year. The following table shows the main results. For the load the performance ratio is 27.47% and the solar fraction 100%. So there are no missing energy to supply the demand. As during summer the available energy is almost four times the used needs. This gives the opportunity to use the building for longer periods at this time but ensure the availability during winter. There are no other significant losses in the system but this need further study once the system is working, as there is no enough bibliography to ensure the performance of the array in the selected place.

| | GlobHor kWh/m² | GlobEff kWh/m² | E Avail kWh | EUnused kWh | E Miss kWh | E User kWh | E Load kWh | SolFrac |
|---|---|---|---|---|---|---|---|---|
| **January** | 134.8 | 118.9 | 211.5 | 103.4 | 0.000 | 53.25 | 53.25 | 1.000 |
| **February** | 101.6 | 99.6 | 178.3 | 113.6 | 0.000 | 53.25 | 53.25 | 1.000 |
| **March** | 76.9 | 87.5 | 159.3 | 98.4 | 0.000 | 49.59 | 49.59 | 1.000 |
| **April** | 41.7 | 58.6 | 107.2 | 47.1 | 0.000 | 49.59 | 49.59 | 1.000 |
| **May** | 24.2 | 43.7 | 81.5 | 22.2 | 0.000 | 49.59 | 49.59 | 1.000 |
| **June** | 15.6 | 33.5 | 63.1 | 10.1 | 0.000 | 43.55 | 43.55 | 1.000 |
| **July** | 18.6 | 35.5 | 67.6 | 14.2 | 0.000 | 43.55 | 43.55 | 1.000 |
| **August** | 34.7 | 54.9 | 103.7 | 50.6 | 0.000 | 43.55 | 43.55 | 1.000 |
| **September** | 60.6 | 74.5 | 138.0 | 79.1 | 0.000 | 49.59 | 49.59 | 1.000 |
| **October** | 101.7 | 106.2 | 195.7 | 136.0 | 0.000 | 49.59 | 49.59 | 1.000 |
| **November** | 121.5 | 109.4 | 199.1 | 139.4 | 0.000 | 49.59 | 49.59 | 1.000 |
| **December** | 143.8 | 123.8 | 225.7 | 159.6 | 0.000 | 53.25 | 53.25 | 1.000 |
| Year | 875.8 | 946.0 | 1730.5 | 973.7 | 0.000 | 587.93 | 587.93 | 1.000 |

Table 20: 8 modules array main results

## Not winter period used

In the original ICELAB project the building was not considered to be used during winter (June, July and August) as most researches are going to be outside. However, for this paper the objective was to give the adequate conditions to ensure the building's used through the whole year. Because, once this is accomplished, minor changes must be done if the lab is only going to be inhabited between September and May.

When winter period is not considered the demand goes down to 7.09kWh/d. This does not represent a significant variation with respect to the winter demand, so it is not going to be changed. But a smaller PV array can be used. The 5 modules option does not have enough power to supply May, June and July's demand, but it is big enough to ensure the user's needs for the rest of the year. Also a smaller array can be considered. Moreover, the battery can be reduced too. During these seasons as radiation is higher there are more chances to generate electricity, although weather conditions are not optimal. This allows to reduced the needed autonomy to 4 days, that is the minimum suggested autonomy described in the bibliography. When doing this, the battery's nominal capacity is reduced to 2832Ah; needing only 15 batteries for the system. This represents a reduction of 17% in the weight (from 2412kg to 2010kg) and a reduction of needed space from 126cm to 105 cm (the total high remains 216cm and the depth 46cm). The following table shows the same analysis done before (between 8 modules array and 5 modules array) considering a 5 modules array and 4 modules array with no demand during May, June, July and August. Also the days that the building can be used per month are changed in order to reduced losses due to unused energy.

As it was explained before losses are best reduces when the demand profile is not constant during the year, but has the same shape as the radiation graph. The total losses due to unused energy reduces to 12% with a 4 modules array.

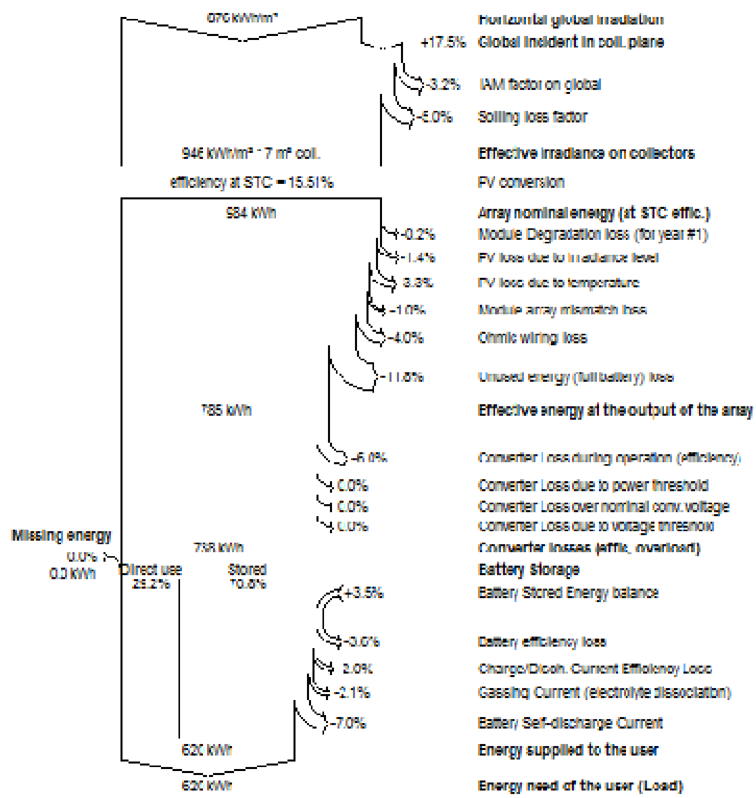



Figure 42: 4 module losses' graph without winter demand

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Days per month** | 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 |
| **Used period** | 25 | 20 | 10 | 7 | 0 | 0 | 0 | 0 | 7 | 11 | 12 | 25 |
| $I_{PV\ array}$ | 41.85 | | 5 modules array | | | | | | | | | |
| $V_{PV\ array}$ | 31.4 | | | | | | | | | | | |
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| kWh/d | 4 | 4 | 3 | 2 | 2 | 1 | 1 | 2 | 3 | 4 | 4 | 4 |
| kWh/used period | 108 | 80 | 32 | 15 | 0 | 0 | 0 | 0 | 20 | 42 | 49 | 112 |
| kWh/month | 134 | 112 | 98 | 66 | 49 | 38 | 40 | 62 | 84 | 119 | 123 | 139 |
| Daily demand | 4 | 4 | 7 | 7 | 0 | 0 | 0 | 0 | 7 | 7 | 7 | 4 |
| Unused daily energy | 0 | 0 | -4 | -5 | 2 | 1 | 1 | 2 | -4 | -3 | -3 | 0 |
| User period demand | 103 | 82 | 71 | 50 | 0 | 0 | 0 | 0 | 50 | 78 | 85 | 103 |
| Unused ener in used period | 5 | -2 | -39 | -34 | 0 | 0 | 0 | 0 | -30 | -36 | -36 | 10 |
| Unused period energy | 26 | 32 | 67 | 50 | 49 | 38 | 40 | 62 | 64 | 77 | 74 | 27 |
| Monthly demand | 103 | 82 | 71 | 50 | 0 | 0 | 0 | 0 | 50 | 78 | 85 | 103 |
| Unused monthly energy | 31 | 30 | 27 | 16 | 49 | 38 | 40 | 62 | 34 | 41 | 38 | 37 |
| Losses due to unused energy | 23% | 27% | 28% | 25% | 100% | 100% | 100% | 100% | 41% | 35% | 31% | 26% |
| Losses due to unused energy | 31 | 30 | 27 | 16 | 49 | 38 | 40 | 62 | 34 | 41 | 38 | 37 |
| $I_{PV\ array}$ | 33 | | 4 modules array | | | | | | | | | |
| $V_{PV\ array}$ | 31 | | | | | | | | | | | |
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| kWh/d | 3 | 3 | 3 | 2 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 4 |
| kWh/used period | 86 | 64 | 25 | 12 | 0 | 0 | 0 | 0 | 16 | 34 | 39 | 90 |
| kWh/month | 107 | 90 | 79 | 53 | 39 | 30 | 32 | 49 | 67 | 95 | 98 | 111 |
| Daily demand | 4 | 4 | 7 | 7 | 0 | 0 | 0 | 0 | 7 | 7 | 7 | 4 |
| Unused daily energy | -1 | -1 | -5 | -5 | 1 | 1 | 1 | 2 | -5 | -4 | -4 | -1 |
| User period demand | 103 | 82 | 71 | 50 | 0 | 0 | 0 | 0 | 50 | 78 | 85 | 103 |
| Unused ener in used period | -16 | -18 | -46 | -37 | 0 | 0 | 0 | 0 | -34 | -44 | -46 | -13 |
| Unused period energy | 21 | 26 | 53 | 40 | 39 | 30 | 32 | 49 | 51 | 62 | 59 | 22 |
| Monthly demand | 103 | 82 | 71 | 50 | 0 | 0 | 0 | 0 | 50 | 78 | 85 | 103 |
| Unused monthly energy | 4 | 7 | 8 | 3 | 39 | 30 | 32 | 49 | 17 | 17 | 13 | 9 |
| Losses due to unused energy | 4% | 8% | 10% | 6% | 100% | 100% | 100% | 100% | 26% | 18% | 13% | 8% |
| Losses due to unused energy | 4 | 7 | 8 | 3 | 39 | 30 | 32 | 49 | 17 | 17 | 13 | 9 |

Table 21: 5 and 4 modules PV array resume

The following picture shows the loss graph for a 5 modules panel array for the new demand. As it was explained before, this values do not match exactly the table values, but they are approximations.

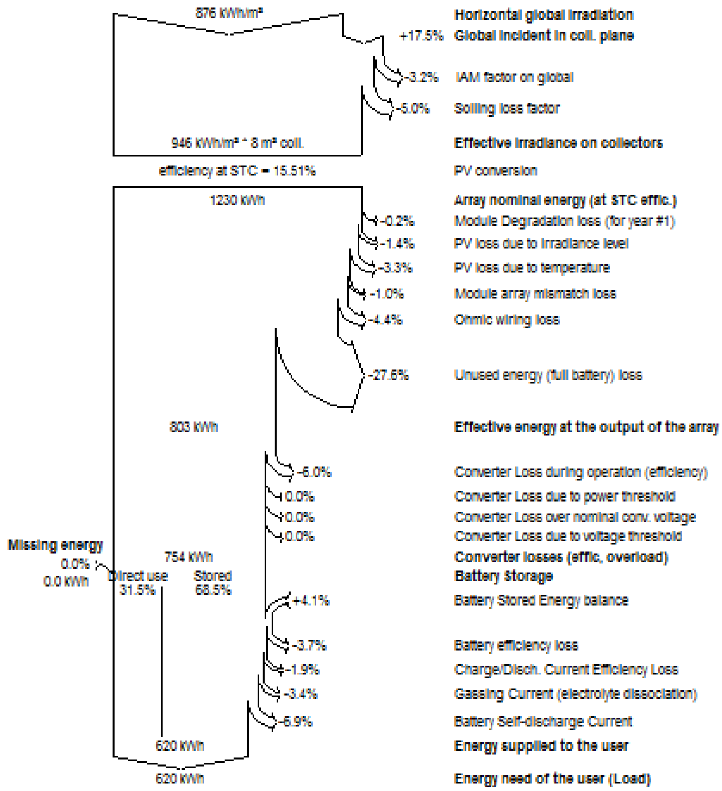



**Figure 43: 5 module losses' graph without winter demand**

# Summary and Conclusion

For the first part of this work thermal insulation alternatives and daylight distribution were studied in order to low the electrical consumption needed for heating the ICELAB II design building. Changes were done to the basic design looking for improvements in the building performance. DesignBuilder software was used as a tool to compare ameliorations regarding solar gains, internal heat gains, inside temperature, comfort coefficient, daylight distribution improvement due to new windows, infiltration, natural ventilation, energy need for heating and insulation materials performance for winter. On the other hand, summer period was also evaluated to ensure that the introduction of insulation and increasing openings do not generate high temperatures, as not cooling system was available. Middle seasons (spring and autumn) were not simulated as only extreme weather conditions were considered.

This part's results show that using insulation in constructions represents a major saving in terms of energy consumption; which leads to reduction in environment damage (like reducing the production of greenhouse effect's gases). By increasing only 22% the openings in the ground floor the daylight exploitation improves almost 80%, leaving the most part of the area over the minimum 2% threshold recommended. This means that not artificial light is needed during the day, reducing electrical demand in around 0.8kWh/day. On the other hand, introducing new windows increases both solar gains, which can generate overheating in summer, and heat losses in winter. By introducing windows' shading the solar gain fraction is reduced in 78%. While placing the minimal amount required by the country's regulation of thermal insulation in walls, roof and floor reduced the heat need 33%. There is a 52% reduction of heat loss in walls, 87% reduction is in the roof and 91% in the floor. The overall building's winter performance was further enhanced by reducing the infiltration rate. Decreasing the infiltration value from 5ac/h to 2ac/h results in a heating need reduction of 60% in the worst condition (using only 3.2kW).

Finally weekly simulation were run for summer and winter. Although the total heating power needed is 3.02kW, when solar and internal heat gains are considered the pick value stays around 2.5kW. This represents a suitable amount for the area. For summer, inside temperature goes up to a peak value of 27°C. There is not cooling system installed in the laboratory as natural ventilation is enough. Outside temperature always stays under inside temperature. Moreover, because of the weather conditions, air flow in the area reaches high values. By opening only 5% the windows in the ground floor total fresh air rate of 25ac/h can be achieved. This value is enough to reduced inside temperature to a comfort level. The previous improvements leave the building with a low energy demand and a good performance over the whole year.

For the second part, a standalone energy system based on photovoltaic (PV) cells was design to supply the building's electrical energy needs. The daily demand was calculated based on common household appliances, artificial light needs, heating demand and laboratory equipment. Different values were considered for each season resulting in peak value of 7.29kWh/day for winter. This number was used for sizing the PV array. On a first stage a pre assessment of the area was done to evaluate the area's irradiance using the Solar Explorer tool developed by Chile's University. This showed that sun radiation has a substantial variation through the year. There is 73% less irradiance between June (the worst month) and December (the best month). This presented a setback when designing the array, as it generates high losses due to unused energy in period with better irradiance or it was not big enough to supply winter demand. Moreover, a limited space was available to placed the array. As it was said before, the project's main idea is to avoid environment changes, because of that the PV panels were thought to be placed on the roof of the building. Using general PV cell's characteristics this tools estimates that a 3kWp PV array can be placed in the available space. Manual calculation were done to pre size all the elements needed in the system (PV panels, battery pack, controller and inverter). This values were then used as input in PVsyst software. Five different alternatives were simulated looking for a choice that supply the annual demand but at the same time reduced losses due to unused energy.

A eight modules (260Wp) array with 2.1kWp capacity was selected. It was placed with a 42° tilt and -5° azimuth for optimisation. The total area needed to placed the PV array is 13.4m$^2$, which means that the roof area is big enough. With a 876kWh/m$^2$ average radiation this system produces a total of 1731kWh/year. The specific production is 832kWh/kWp/year. The unused energy (loss) is 55% giving a performance ratio of 28% and a total array output of 807kWh when considering an almost constant demand profile along the year. From this 22% is direct used and the rest is used to charge the battery pack. The battery pack consists of 18 batteries of 8V each. The nominal capacity of the set is 4086Ah and the total voltage is 24V. The charging control is done with a 1456W MPPT system. Although this system has high losses due to unused energy this can be reduces when increasing the demand during summer and spring. Also, as this kind of systems depend on weather conditions a high variation can be achieved along the year. To ensure the supply it was considered that it is better to oversize the system without being excessive.

Moreover, a final analysis was done without considering winter period, because the original project (ICELABPatagonia, in which this projects is based on) does not contemplate it. For this a 5 or 4 modules array with a smaller battery pack can be used. For the new system 17 8V batteries form the storage system, with a nominal capacity of 2832Ah. This gives a reduction of 17% in the weight of the pack. A total capacity between 1.3kWp and 1.0kWp is enough to fulfil the demand.

In conclusion, when using adequate thermal insulation and glazing materials in the building, there is a great potential to place an autonomous system to provide electric energy to the laboratory, by means of direct solar radiation using a photovoltaic panels. It supplies the construction allowing the researchers to develop their investigation activities in a comfortable environment. As the building does not only creates a refuge against the tough weather conditions of the area (low temperatures, strong winds, rain and snow); but also, it gives the user the possibility to have electrical energy which is an important resource in everyday life. It allows the use of appliances, laboratory equipment, technology equipment, electric heating systems and electric hot water systems which stands as an advantage over the actual field research conditions in the place. With this conditions, the laboratory gives the users the possibility to stay for longer periods. The place's selected amenities are similar to those used in normal houses, allowing to develop everyday activities in a regular way. This means that there is no need to travel everyday several kilometres in order to reach the park, as it is possible to remain there during the night in better conditions than in a tent. Also, more sophisticated research equipment can be employed, this means that samples can be analysed in placed lowing the chances of contaminations or destruction. Moreover, there is no need to transport regular stuff (like heating system and small appliances) at it is available in the place.

This experience put up a new opportunity to explore in a comfortable way new areas without disturbing them. Protecting the environment is a major concern. Being able to continue developing but at the same time causing not damage to the surrounding area is a current challenge for researchers. This kind of constructions gives a further chance, giving protection not only to the environment but also to the people.

# Recommendations

Some recommendations are given if it is decided to used this work to build the laboratory in Karukinka Park.

- Because of the extension of the park several places can be selected as location. Many mountains can be found in the area. This need to be considered when selecting the construction place because it affects the irradiation on the building.
- A more detailed studied regarding the losses present in the PV array need to be done. Because the depend most on weather conditions to ensure the right PV system performance losses need to be measure in the location area. Zones with no or low near shading, regular cleaning of the panels to ensure that no dust or dirt accumulate need to be considered among others.
- To calculate the demand in order to design de PV system some appliances were used. This need to be evaluated regarding the user's needs. Also as there is enough space, a solar collector can be used to heat the water, reducing the demand.
- New analysis with different demand profile can be done on the 8 modules array system. The profile used in this work corresponds to the original request of 5 to 10 days use.
- Both software uses average monthly temperature. Peak temperature need to be studied to ensure the performance of the building.

# References

[1] OECD/IEA, “IEA - International Energy Agency,” IEA Publishing, 2017. [Online]. Available: https://www.iea.org/topics/electricity/. [Accessed 20 February 2017].

[2] American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), Handbook of Fundamentals, Atlanta, GA, USA, 2001.

[3] F. P. Incropera, D. P. DeWitt, T. L. Bergman and A. S. Lavine, Fundamentals of heat and mass transfer, vol. 6th, Ney York, NY: John Wiley and Sons, 2007.

[4] D. M. S. Al-Homoud, “Performance characteristics and practical applications of common building thermal insulation materials.,” Building and Environment, vol 40, no. 3, pp.353-366, Mar. 2005.

[5] U.S. Department of Energy, “Energy.Gov,” [Online]. Available: www.energy.gov. [Accessed November 2016].

[6] B. P. Jelle, A. Hynd, A. Gustavsen, A. Arasteh, H. Goudey and R. Hart, “Fenestration of today and tomorrow: a state of the art review and future research opportunities. Sol Energy Mater Sol Cells,” Solar Energy Materials & Solar Cells, vol. 96, pp 1-28, 2012.

[7] E. Cuce and S. B. Riffat, “A state-of-the-art review on innovative glazing technologies,” Renewable and Sustainable Energy Reviews, vol. 41, pp. 695-714, 2015.

[8] SmartRate, “Building Sustainability,” [Online]. Available: http://www.smartrate.com.au/. [Accessed November 2016].

[9] Efficient Windows Collaborative (EWC), “Windows for high-performance commercial buildings,” University of Minnesota and Lawrence Berkeley National Laboratory with support from the U.S. Department of Energy's Emerging Technologies Program, [Online]. Available: http://www.commercialwindows.org/. [Accessed December 2016].

[10] Instituto de la Construcción, “Manual de Aplicación de la Reglamentación Térmica (ORDENANZA GENERAL DE URBANISMO Y CONSTRUCCIONES ARTÍCULO 4.1.10),” Edicolor, Santiago de Chile, 2006.

[11] Worls Energy Council, “World Energy Resources,” World Energy Council Publishing, London, United Kingdom, 2013.

[12] Wikipedia Foundation Inc, “Stand alone power system,” 2017. [Online]. Available: https://en.wikipedia.org/wiki/Stand-alone_power_system. [Accessed February 2017].

[13] Conservation Technologies, “Energy Plus - Conservation Technologies - Photovoltaics solar,” www.SusanWillisWebDesign.com, [Online]. Available: http://www.conservtech.com/photovoltaicssolar101.html. [Accessed February 2017].

[14] C. Honsberg and S. Bowden, “Photovoltaic Education Network,” PV aducation.org, 2013. [Online]. Available: http://www.pveducation.org. [Accessed February 2017].

[15] C. Honsberg and S. Bowden, “Modules - Photovoltaic Education Network,” 2013. [Online]. Available: http://www.pveducation.org/pvcdrom/modules/introduction. [Accessed January 2017].

[16] R. Komp, “TED Ed Lessons Worth Sharing - How do solar panels work?,” TED Conferences, LLC , [Online]. Available: https://ed.ted.com/lessons/how-do-solar-panels-work-richard-komp. [Accessed 21 February 2017].

[17] Office of Energy Efficiency and Renewable Energy, “Solar Photovoltaics Cells Basics,” U.S. Department of Energy, [Online]. Available: https://energy.gov/eere/energybasics/articles/solar-photovoltaic-cell-basics. [Accessed 21 February 2017].

[18] R. W. Miles, “Photovoltaic solar cells: Choice of materials and production methods,” Vacuum, vol 80, no.10, pp. 1090-1097, Aug, 2006.

[19] NREL - National Renewable Energy Laboratory, “Photovoltaic Research,” U.S. Department of Energy, [Online]. Available: https://www.nrel.gov/pv/. [Accessed 21 February 2017].

[20] MIT Electric Vehicle Team, “A Guide to Understanding Battery Specifications,” MIT universuty, Massachusetts, December 2008.

[21] A. Jacobson, “Let's Begin - How batteries work?,” TED Ed - TED Conferences, LLC, [Online]. Available: https://ed.ted.com/lessons/why-batteries-die-adam-jacobson#watch. [Accessed 21 February 2017].

[22] A. Poullikkas, “Renewable and Sustainable Energy Reviews,” Renewable and Sustainable Energy Reviews, vol. 27, pp. 778-788, November, 2013.

[23] Northern Arizona Wind & Sun, “Everything you need to know about the basics of solar charge controllers,” Northern Arizona Wind & Sun, 2017. [Online]. Available: https://www.solar-electric.com/solar-charge-controller-basics.html/. [Accessed 21 February 2017].

[24] Northern Arizona Wind & Sun, “All about MPPT solar charge controllers,” Northern Arizona Wind & Sun , 2017. [Online]. Available: https://www.solar-electric.com/mppt-solar-charge-controllers.html. [Accessed 21 February 2017].

[25] DesignBuilder Software Ltd, “DesignBuilder,” [Online]. Available: www.designbuilder.co.uk. [Accessed September 2016].

[26] A. O. García, “Manual de ayuda DesignBuilder en español,” sol.arq, Santiago de Chile, 2014.

[27] Science, Technology and Production Secretariat, Defense Ministry, “Servicio Meteorológico Nacional,” [Online]. Available: http://www.smn.gov.ar/. [Accessed September 2016].

[28] J. Atkinson, Y. Chartier, F. Otaiza and C. L. Pessoa Silva, “Natural ventilation for infection control un health-care settings,” World Health Organization Publication/Guidelines, Canberra, Australia, 2009.

[29] Ministry of housing and urban planning, “Ministry of housing and urban planning,” Chile's goberment, [Online]. Available: http://www.minvu.cl/. [Accessed January 2017].

[30] World Energy Council, “Energy Efficiency Indicators,” Enerdata, 2009. [Online]. Available: www.wec-indicators.enerdata.eu. [Accessed January 2017].

[31] Energy Research and Development Centre, "Uso eficiente de energía," Instituto Nacional de Tecnologia Industrial, [Online]. Available: http://www.inti.gob.ar/energia/index.php?seccion=uResidencial. [Accessed January 2017].

[32] Llumor, “Llumor pasión por la eficiencia energética,” 2010. [Online]. Available: http://www.llumor.es/info-led/equivalencia-de-lumen-a-vatios. [Accessed February 2017].

[33] HP Development Company, L.P, “HP shop,” 2017. [Online]. Available: http://store.hp.com/SpainStore/Merch/Product.aspx?id=T7W11EA&opt=ABE&sel=NTB. [Accessed February 2017].

[34] C. Oeder, “Ice-Lab,” Bauphysik & TechnischerAusbau (fbta), Karlsruhe, 2015.

[35] Herschel Infrared Ltd, “Herschel far infrared heaters,” 2017. [Online]. Available: www.herschel-infrared.com. [Accessed February 2017].

[36] SMEG S.p.A. VAT, “Smeg technology with style,” 2017. [Online]. Available: http://www.smeg.com/product/fab10hlb/. [Accessed February 2017].

[37] Geofisica-Facultad the ciencias fisicas y matematicas - Universidad de Chile, “Explorador para autoconsumo,” Ministerio de Energia - Gobierno de Chile, [Online]. Available: http://walker.dgf.uchile.cl/Explorador/Solar3/. [Accessed January 2007].

[38] SunFields Europe, “Manual de cálculo de sistemas fotovoltaicos aislados/autónomos,” 2015. [Online]. Available: https://www.sfe-solar.com/suministros-fotovoltaica-aislada-autonoma/manual-de-calculo-sistemas-fotovoltacios-aislados-autonomos-parte-ii/. [Accessed January 2017].

[39] Sustainable Energy Industry Association of the Pacific Islands, “Off grid PV power systems - System design guidelines,” Pacific Islands, 2012.

[40] Sunreport srl, “SUN REPORT,” Algoweb, 2015. [Online]. Available: www.sunreport.it. [Accessed February 2017].

[41] PVsyst SA, “PVsyst Photovoltaics Software,” 2012. [Online]. [Accessed December 2016].

[42] Wikimedia Foundation, Inc, “Wikipedia free encyclopedia,” [Online]. Available: https://en.wikipedia.org/wiki/Steady_state. [Accessed February 2017].

[43] PVSyst SA, “Help:Standard one diode model,” [Online]. Available: http://files.pvsyst.com/help/pvmodule_model.htm. [Accessed February 2017].

[44] Rolls Battery, “Rolls battery engineering - about us,” [Online]. Available: http://www.rollsbattery.com/about-us/. [Accessed February 2017].

[45] Wikipedia Foundation Inc, “Solar Tracker - Wikipedia,” 2017. [Online]. Available: https://en.wikipedia.org/wiki/Solar_tracker. [Accessed 20 February 2017].

[46] Wikipedia Foundation Inc, “Photon - Wikipedia,” 2017. [Online]. Available: https://en.wikipedia.org/wiki/Photon. [Accessed 20 February 2017].

[47] THE COMMISSION OF THE EUROPEAN COMMUNITIES, “COMMISSION DECISION on the State aid C 21/08 (ex N 864/06),” COMMISSION OF THE EUROPEAN COMMUNITIES Publications, Brussels, 17 June 2009.

[48] Solar Power Craze, “Definitions of solar power termns,” Blogger, [Online]. Available: http://nature-log.blogspot.de/2010/01/definitions-of-solar-power-terms.html. [Accessed 23 February 2017].

## Appendix A: Karukinka Natural Park

Karukinka is a private natural Park situated in Isla Grande de Tierra del Fuego, in Chile. The island is located in the southern part of South America continent and separated from it by the Strait of Magellan. With a total area of approximately 48.000km2, the 60% of the island belongs to Chile, while the rest to Argentina. The biggest cities in the region are Ushuaia and Rio Grande, both part of Argentina, where the higher population density can be found.

The park consists of 300,000 hectares of mountains and forest, which makes it hard to access the place. It is located in the southern part of the bigger island, in the Chile region, limiting with Argentina, nearby Ushuaia. The climate is subpolar oceanic, similar to Island. There is not a big temperature amplitude between the short summer and the winter, locating it in average between 9C and 1C. It is characterized by the strong winds, around 25km/h, and constant precipitations during the whole year, which makes the region inhospitable. During the winter season the light hours are rare, locating sunrise around 9.30 and sunset around 15.00.

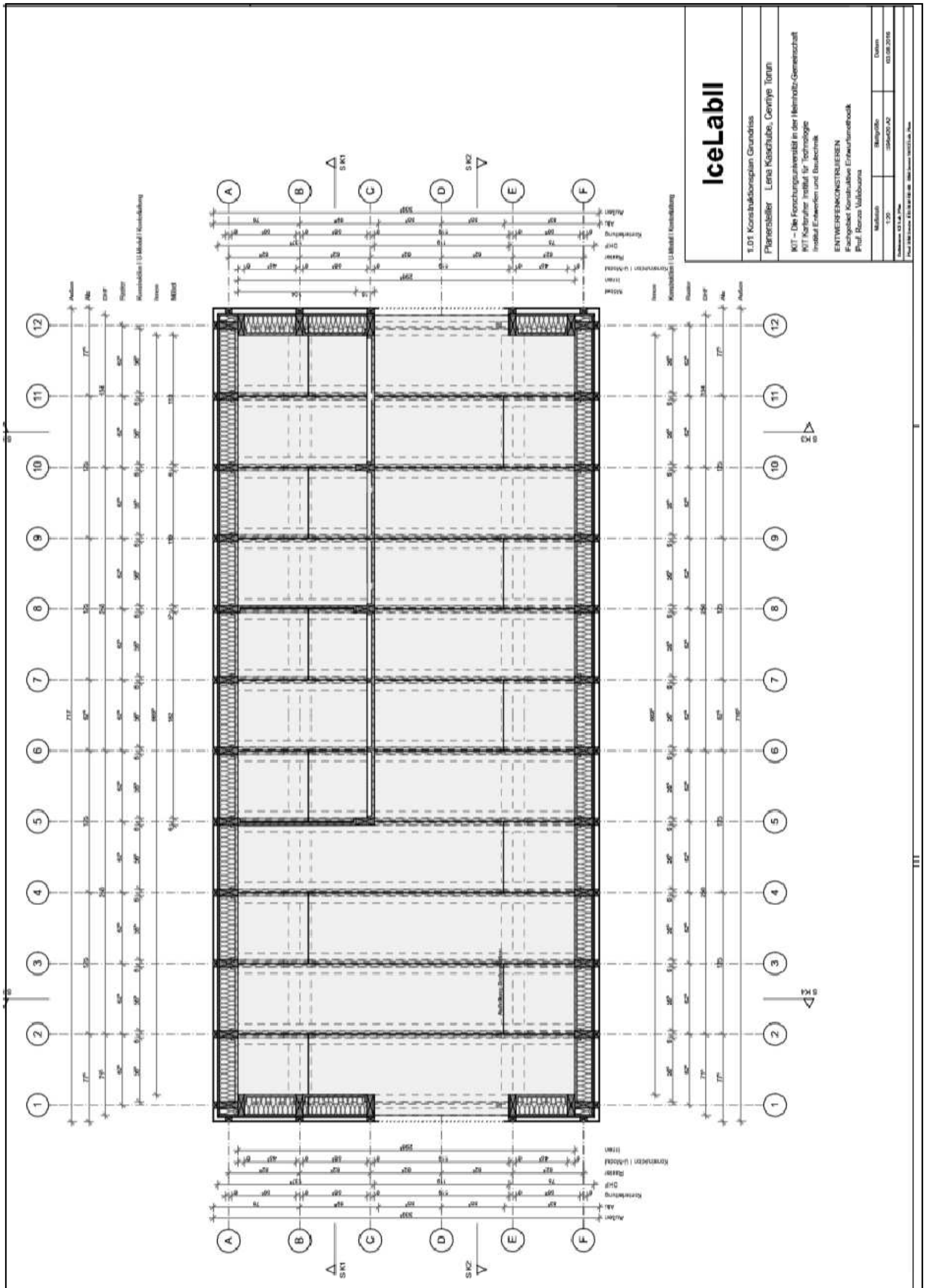

**Appendix figure 1: Karukinka location**

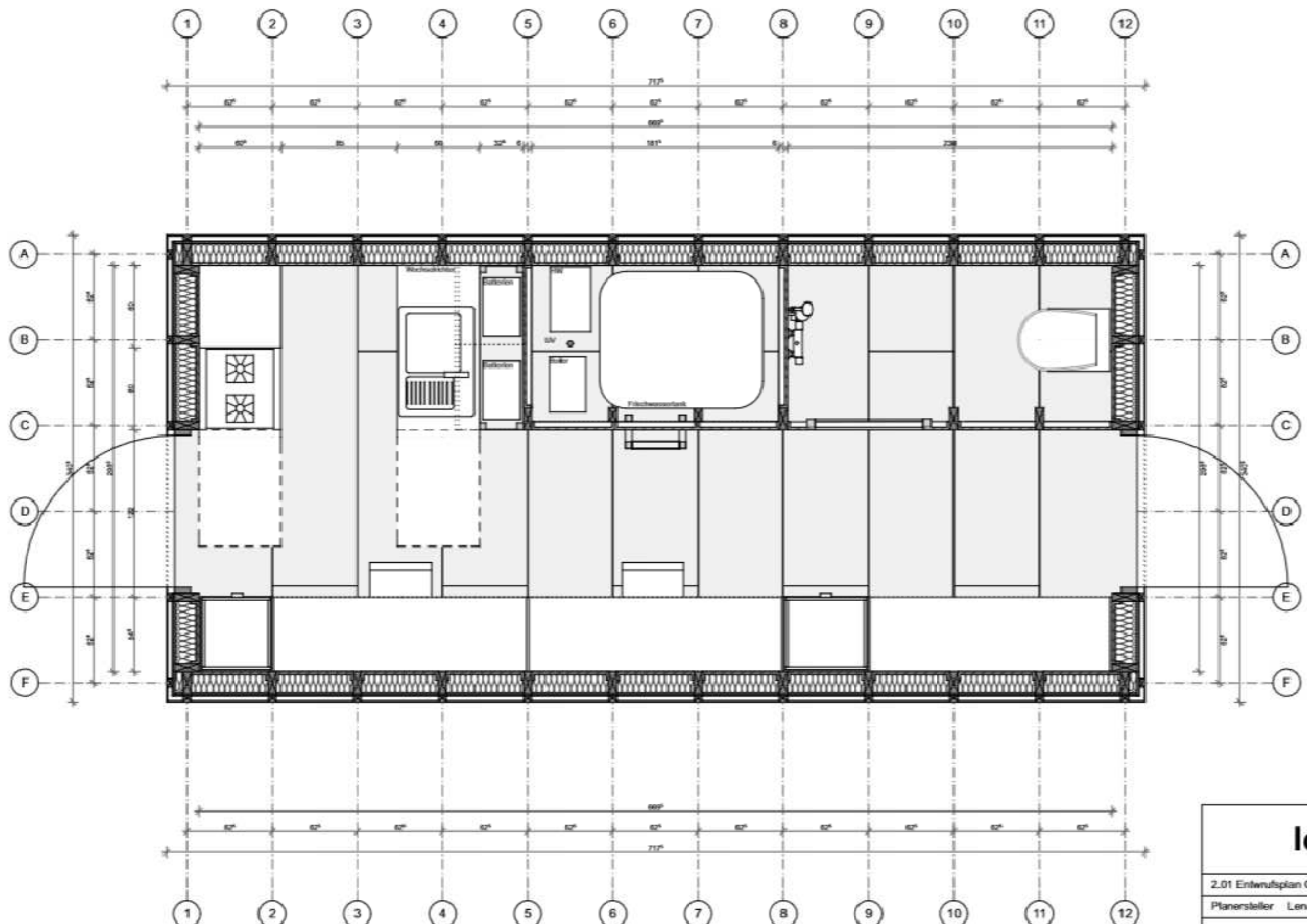
It is a heritage of unique biodiversity, which has not been change by the human hand, and only the nature has taken part of the region.

Karukinka Park is owned by Wildlife Conservation Society (WCS), which is responsible for the preservation of the biodiversity of the park. WCS is an international organization dedicated to the conservation of the wild life and their environments all around the world. In 2004 the Karukinka project was born, orientated to the effective promotion and maintenance, both natural and also economical, of the Karukinka Park and the Patagonia environment. With an interdisciplinary group form the most by people from the region, the project look forward to protecting the richest biodiversity of the terrestrial and marine zones through science, education and good use of the public area.

Furthermore, the main purpose of the organization is to share the park in a way that allows all people enjoy this extraordinary natural environment. It is intended to receive not only scientific research visits, but also educational and touristic. Therefore, continuous improvements in the infrastructure of the Park is needed, in order to enhance the stay of the visitors. However, it is important that any constructions do not change the actual conditions of the place, giving a new approach for a sustainable development in Chile.

## Appendix B: ICELAB II original plans






# IceLabII

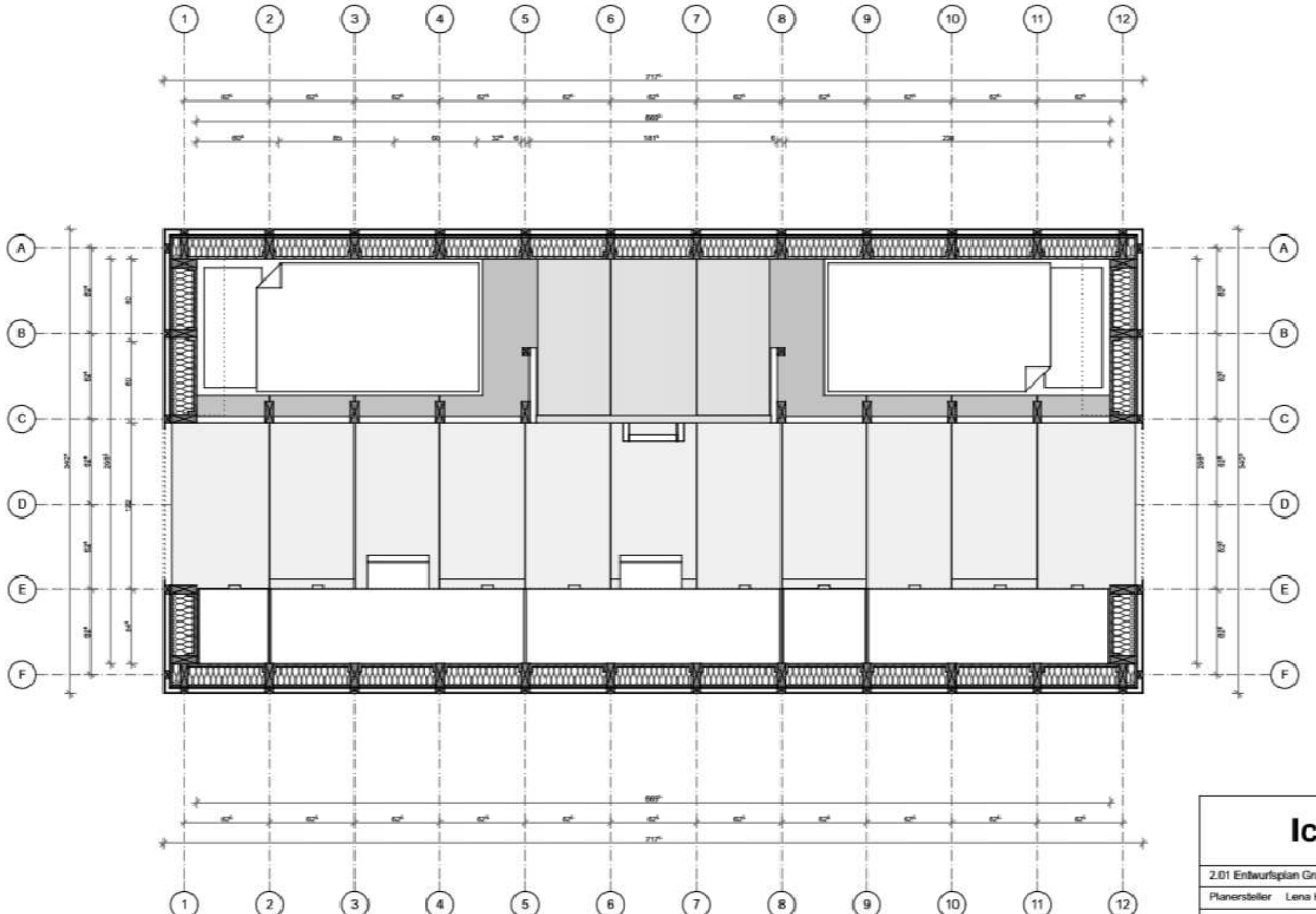
2.01 Entwurfsplan Grundriss Ebene 1

Planersteller Lena Kaschube, Cevriye Torun

KIT – Die Forschungsuniversität in der Helmholtz-Gemeinschaft
KIT Karlsruher Institut für Technologie
Institut Entwerfen und Bautechnik

ENTWERFENKONSTRUIEREN
Fachgebiet Konstruktive Entwurfsmethodik
Prof. Renzo Vallebuona

| Maßstab | Blattgröße | Datum |
| --- | --- | --- |
| 1:20 | 594x420 A2 | 27.07.2016 |




# IceLabII

2.01 Entwurfsplan Grundriss Ebene 2

Planersteller Lena Kaschube, Cevriye Torun

KIT – Die Forschungsuniversität in der Helmholtz-Gemeinschaft
KIT Karlsruher Institut für Technologie
Institut Entwerfen und Bautechnik

ENTWERFENKONSTRUIEREN
Fachgebiet Konstruktive Entwurfsmethodik
Prof. Renzo Vallebuona

| Maßstab | Blattgröße | Datum |
|---|---|---|
| 1:35 | 594x420 A2 | 27.07.2016 |


technical plan

## Appendix C: DesignBuilder data used and further calculation

### DesignBuilder base and final model's schedules

```
Profiles
Schedule:Compact,
Dwell_DomLounge_Occ,
Fraction,
Through: 31 Dec,
For: Weekdays SummerDesignDay Holidays Weekends,
Until: 08:00, 0.4,
Until: 18:00, 1,
Until: 23:00, 0.65,
Until: 24:00, 0.4,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;
```

**Appendix figure 2: Occupancy and windows shading**

```
Profiles
Schedule:Compact,
Office_WkshpSS_Equip,
Fraction,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 05:00, 0.2566,
Until: 07:00, 0.5,
Until: 20:00, 1,
Until: 21:00, 0.5,
Until: 24:00, 0.2566,
For: Weekends Holidays,
Until: 05:00, 0.2566,
Until: 21:00, 0.5,
Until: 24:00, 0.2566,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;
```

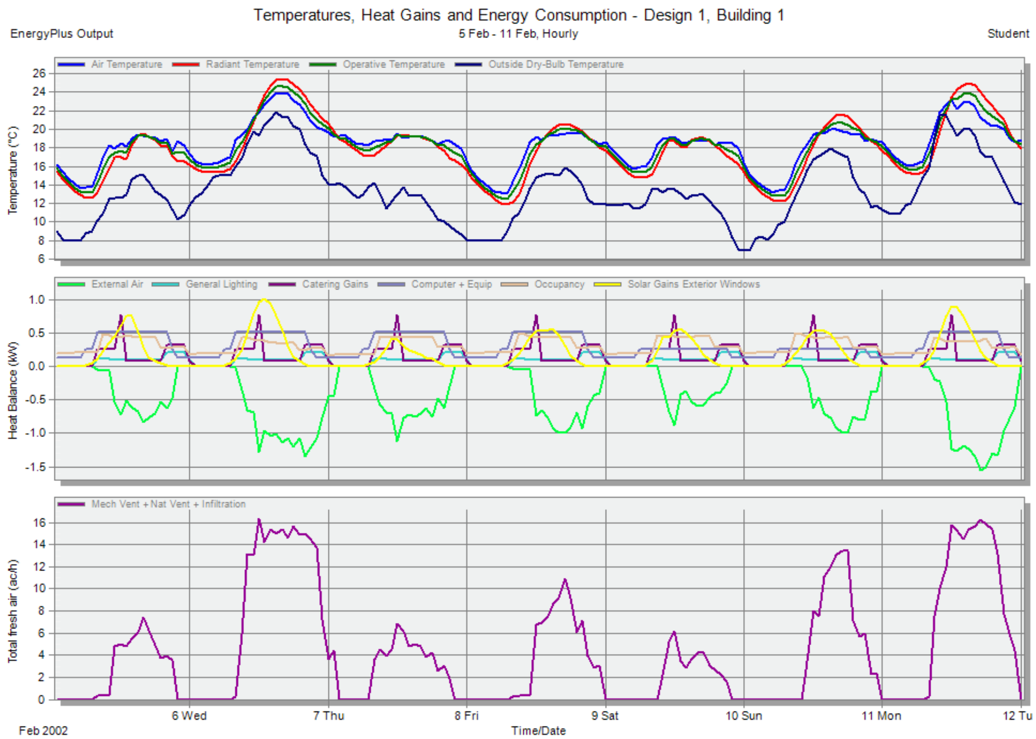
**Appendix figure 3: Office and computer Equipment**

```
Profiles
Schedule:Compact,
Dwell_DomKitchen_Equip,
Fraction,
Through: 31 Dec,
For: Weekdays SummerDesignDay Weekends,
Until: 07:00, 0.00,
Until: 11:00, 0.20,
Until: 12:00, 0.6,
Until: 19:00, 0.06605,
Until: 23:00, 0.25284,
Until: 24:00, 0.06605,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;
```

**Appendix figure 4: Catering**

### DesignBuilder natural ventilation calculation (Base Model)

For this infiltration is not considered in order not to influence the final number. The opening are schedule to be opened during the whole day and with a 100% area opens (as it was mentioned before outside temperature is lower than inside). The door has a 50% opens area, and only 5% of the time it is opened. The following figure shows the result simulated for a typical summer design week (hotter situation). The total fresh air in the building goes up to 16ac/h while inside temperature stays between 12° and 25° (comfortable temperatures). This results indicates that the constant value of 18ac/h is reasonable, and also that it could be reduced to 16ac/h (with infiltration this value can be even lower).




**Appendix figure 5: Simulation results for a design summer week with natural ventilation calculated**

## Appendix D: Hourly demand calculated for each season

| | Summer | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Refriger | Work area illumin | Other areas illumin | Coffee Mach | Micro oven | Water heater | Office/ Compu equip | Lab Equip | Heating | **Total (kWh)** |
| Power (W) /hs | 14 | 70 | 25 | 900 | 800 | 1330 | 130 | 142.75 | 700 | |
| 1 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 2 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 3 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 4 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 5 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 6 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 7 | 14.00 | | | 75.0 | | 55.42 | | | | **0.14** |
| 8 | 14.00 | | 1.06 | | | 55.42 | 130.00 | | | **0.20** |
| 9 | 14.00 | | 1.06 | | | 55.42 | 130.00 | | | **0.20** |
| 10 | 14.00 | | 1.06 | | | 55.42 | | 142.75 | | **0.21** |
| 11 | 14.00 | | 1.06 | | | 55.42 | | 142.75 | | **0.21** |
| 12 | 14.00 | | 1.06 | | 133.33 | 55.42 | | 142.75 | | **0.35** |
| 13 | 14.00 | | 1.06 | | | 55.42 | | | | **0.07** |
| 14 | 14.00 | | 1.06 | | | 55.42 | | | | **0.07** |
| 15 | 14.00 | | 1.06 | | | 55.42 | 130.00 | 142.75 | | **0.34** |
| 16 | 14.00 | | 1.06 | 75.0 | | 55.42 | 130.00 | 142.75 | | **0.42** |
| 17 | 14.00 | | 1.06 | | | 55.42 | | 142.75 | | **0.21** |
| 18 | 14.00 | | 1.06 | | | 55.42 | | 142.75 | | **0.21** |
| 19 | 14.00 | | 12.50 | | 133.33 | 55.42 | 65.00 | 142.75 | | **0.42** |
| 20 | 14.00 | 35.00 | 12.50 | | | 55.42 | 65.00 | | | **0.18** |
| 21 | 14.00 | 35.00 | 12.50 | | | 55.42 | | | | **0.12** |
| 22 | 14.00 | 35.00 | 12.50 | | | 55.42 | | | | **0.12** |
| 23 | 14.00 | 35.00 | 12.50 | | | 55.42 | | | | **0.12** |
| 24 | 14.00 | | 12.50 | | | 55.42 | | | | **0.08** |
| **W/day** | **0.34** | **0.14** | **0.09** | **0.15** | **0.27** | **1.33** | 0.65 | 1.14 | | **4.10** |

**Appendix table 1: Summer hourly demand**

| | Autumn | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Refriger | Work area illumin | Other areas illumin | Coffee Mach | Micro oven | Water heater | Office/ Compu equip | Lab Equip | Heating | **Total (kWh)** |
| Power (W) /hs | 14 | 70 | 25 | 900 | 800 | 1330 | 130 | 142.75 | 700 | |
| 1 | 14.00 | | | | | 55.42 | | | 700.00 | **0.77** |
| 2 | 14.00 | | | | | 55.42 | | | 700.00 | **0.77** |
| 3 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 4 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 5 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 6 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 7 | 14.00 | | 12.50 | 75.00 | | 55.42 | | | | **0.16** |
| 8 | 14.00 | 35.00 | 1.06 | | | 55.42 | 130.00 | | | **0.24** |
| 9 | 14.00 | | 1.06 | | | 55.42 | 130.00 | | | **0.20** |
| 10 | 14.00 | | 1.06 | | | 55.42 | | 142.75 | | **0.21** |
| 11 | 14.00 | | 1.06 | | | 55.42 | | 142.75 | | **0.21** |
| 12 | 14.00 | | 1.06 | | 133.33 | 55.42 | | 142.75 | | **0.35** |
| 13 | 14.00 | | 1.06 | | | 55.42 | | | | **0.07** |
| 14 | 14.00 | | 1.06 | | | 55.42 | | | | **0.07** |
| 15 | 14.00 | | 1.06 | | | 55.42 | 130.00 | 142.75 | | **0.34** |
| 16 | 14.00 | | 1.06 | 75.00 | | 55.42 | 130.00 | 142.75 | | **0.42** |
| 17 | 14.00 | | 1.06 | | | 55.42 | | 142.75 | | **0.21** |
| 18 | 14.00 | 70.00 | 1.06 | | | 55.42 | | 142.75 | | **0.28** |
| 19 | 14.00 | 70.00 | 12.50 | | 133.33 | 55.42 | 65.00 | 142.75 | | **0.49** |
| 20 | 14.00 | 35.00 | 12.50 | | | 55.42 | 65.00 | | | **0.18** |
| 21 | 14.00 | 35.00 | 12.50 | | | 55.42 | | | | **0.12** |
| 22 | 14.00 | 35.00 | 12.50 | | | 55.42 | | | 700.00 | **0.82** |
| 23 | 14.00 | 35.00 | 12.50 | | | 55.42 | | | 700.00 | **0.82** |
| 24 | 14.00 | | 12.50 | | | 55.42 | | | | **0.08** |
| **W/day** | **336.00** | **315.00** | **99.19** | **150.00** | **266.67** | **1330.0** | **650.00** | **1142.0** | **2800.0** | **7.09** |

**Appendix table 2: Autumn hourly demand**

| | Winter | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Refriger | Work area illumin | Other areas illumin | Coffee Mach | Micro oven | Water heater | Office/ Compu equip | Lab Equip | Heating | **Total (kWh)** |
| Power (W) /hs | 14 | 70 | 25 | 900 | 800 | 1330 | 130 | 142.75 | 700 | |
| 1 | 14.00 | | | | | 55.42 | | | 700.00 | **0.77** |
| 2 | 14.00 | | | | | 55.42 | | | 700.00 | **0.77** |
| 3 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 4 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 5 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 6 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 7 | 14.00 | | 12.50 | 75.00 | | 55.42 | | | | **0.16** |
| 8 | 14.00 | 70.00 | 1.06 | | | 55.42 | 130.00 | | | **0.27** |
| 9 | 14.00 | | 1.06 | | | 55.42 | 130.00 | | | **0.20** |
| 10 | 14.00 | | 1.06 | | | 55.42 | | 142.75 | | **0.21** |
| 11 | 14.00 | | 1.06 | | | 55.42 | | 142.75 | | **0.21** |
| 12 | 14.00 | | 1.06 | | 133.33 | 55.42 | | 142.75 | | **0.35** |
| 13 | 14.00 | | 1.06 | | | 55.42 | | | | **0.07** |
| 14 | 14.00 | | 1.06 | | | 55.42 | | | | **0.07** |
| 15 | 14.00 | | 1.06 | | | 55.42 | 130.00 | 142.75 | | **0.34** |
| 16 | 14.00 | 70.00 | 1.06 | 75.00 | | 55.42 | 130.00 | 142.75 | | **0.49** |
| 17 | 14.00 | 70.00 | 1.06 | | | 55.42 | | 142.75 | | **0.28** |
| 18 | 14.00 | 70.00 | 1.06 | | | 55.42 | | 142.75 | | **0.28** |
| 19 | 14.00 | 70.00 | 12.50 | | 133.33 | 55.42 | 65.00 | 142.75 | | **0.49** |
| 20 | 14.00 | 35.00 | 12.50 | | | 55.42 | 65.00 | | | **0.18** |
| 21 | 14.00 | 35.00 | 12.50 | | | 55.42 | | | | **0.12** |
| 22 | 14.00 | 35.00 | 12.50 | | | 55.42 | | | | **0.12** |
| 23 | 14.00 | 35.00 | 12.50 | | | 55.42 | | | 700.00 | **0.82** |
| 24 | 14.00 | | 12.50 | | | 55.42 | | | 700.00 | **0.78** |
| **W/day** | **336.00** | **490.00** | **99.19** | **150.00** | **266.67** | **1330.0** | **650.00** | **1142.0** | **2800.0** | **7.26** |

**Appendix table 3: Winter hourly demand**

| | Spring | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Refriger | Work area illumin | Other areas illumin | Coffee Mach | Micro oven | Water heater | Office/ Compu equip | Lab Equip | Heating | **Total (kWh)** |
| Power (W) /hs | 14 | 70 | 25 | 900 | 800 | 1330 | 130 | 142.75 | 700 | |
| 1 | 14.00 | | | | | 55.42 | | | 700.00 | **0.77** |
| 2 | 14.00 | | | | | 55.42 | | | 700.00 | **0.77** |
| 3 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 4 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 5 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 6 | 14.00 | | | | | 55.42 | | | | **0.07** |
| 7 | 14.00 | | 12.50 | 75.00 | | 55.42 | | | | **0.16** |
| 8 | 14.00 | 35.00 | 1.06 | | | 55.42 | 130.00 | | | **0.24** |
| 9 | 14.00 | | 1.06 | | | 55.42 | 130.00 | | | **0.20** |
| 10 | 14.00 | | 1.06 | | | 55.42 | | 142.75 | | **0.21** |
| 11 | 14.00 | | 1.06 | | | 55.42 | | 142.75 | | **0.21** |
| 12 | 14.00 | | 1.06 | | 133.33 | 55.42 | | 142.75 | | **0.35** |
| 13 | 14.00 | | 1.06 | | | 55.42 | | | | **0.07** |
| 14 | 14.00 | | 1.06 | | | 55.42 | | | | **0.07** |
| 15 | 14.00 | | 1.06 | | | 55.42 | 130.00 | 142.75 | | **0.34** |
| 16 | 14.00 | | 1.06 | 75.00 | | 55.42 | 130.00 | 142.75 | | **0.42** |
| 17 | 14.00 | | 1.06 | | | 55.42 | | 142.75 | | **0.21** |
| 18 | 14.00 | 70.00 | 1.06 | | | 55.42 | | 142.75 | | **0.28** |
| 19 | 14.00 | 70.00 | 12.50 | | 133.33 | 55.42 | 65.00 | 142.75 | | **0.49** |
| 20 | 14.00 | 35.00 | 12.50 | | | 55.42 | 65.00 | | | **0.18** |
| 21 | 14.00 | 35.00 | 12.50 | | | 55.42 | | | | **0.12** |
| 22 | 14.00 | 35.00 | 12.50 | | | 55.42 | | | | **0.12** |
| 23 | 14.00 | 35.00 | 12.50 | | | 55.42 | | | 700.00 | **0.82** |
| 24 | 14.00 | | 12.50 | | | 55.42 | | | 700.00 | **0.78** |
| **W/day** | **336.00** | **315.00** | **99.19** | **150.00** | **266.67** | **1330.0** | **650.00** | **1142.0** | **2800.0** | **7.09** |

**Appendix table 4: Spring hourly demand**

## Appendix E: Solar module specification

# Sunmodule® Plus SW 260 poly

SOLARWORLD
REAL VALUE

### PERFORMANCE UNDER STANDARD TEST CONDITIONS (STC)*

| | | 260 Wp |
|---|---|---|
| *Maximum power* | $P_{max}$ | 260 Wp |
| *Open circuit voltage* | $U_{oc}$ | 38.4 V |
| *Maximum power point voltage* | $U_{mpp}$ | 31.4 V |
| *Short circuit current* | $I_{sc}$ | 8.94 A |
| *Maximum power point current* | $I_{mpp}$ | 8.37 A |
| *Module efficiency* | $\eta_m$ | 15.51 % |

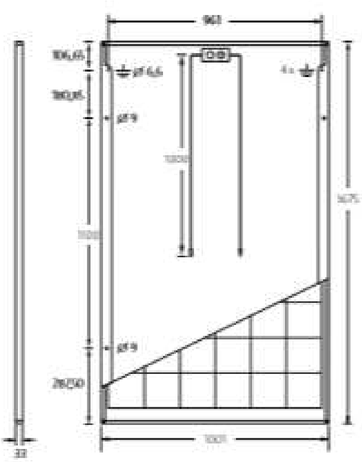
Measuring tolerance ($P_{max}$) traceable to TUV Rheinland: +/- 2% (TUV Power controlled)

*STC: 1000W/m², 25°C, AM 1.5

### PERFORMANCE AT 800 W/m², NOCT, AM 1.5

| | | 260 Wp |
|---|---|---|
| *Maximum power* | $P_{max}$ | 192.4 Wp |
| *Open circuit voltage* | $U_{oc}$ | 34.8 V |
| *Maximum power point voltage* | $U_{mpp}$ | 28.5 V |
| *Short circuit current* | $I_{sc}$ | 7.35 A |
| *Maximum power point current* | $I_{mpp}$ | 6.76 A |

Minor reduction in efficiency under partial load conditions at 25°C: at 200 W/m², 100% (+/-2%) of the STC efficiency (1000 W/m²) is achieved.




### COMPONENT MATERIALS

| | |
|---|---|
| *Cells per module* | 60 |
| *Cell type* | Poly crystalline |
| *Cell dimensions* | 156 mm x 156 mm |
| *Front* | Tempered safety glass (EN 12150) |
| *Back* | Film, white |
| *Frame* | Clear anodized aluminum |
| *J-Box* | IP65 |
| *Connector* | H4 |

### DIMENSIONS / WEIGHT

| | |
|---|---|
| *Length* | 1675 mm |
| *Width* | 1001 mm |
| *Height* | 33 mm |
| *Weight* | 18.0 kg |

### THERMAL CHARACTERISTICS

| | |
|---|---|
| *NOCT* | 46 °C |
| *TK $I_{sc}$* | 0.051 %/K |
| *TK $U_{oc}$* | -0.31 %/K |
| *TK $P_{mpp}$* | -0.41 %/K |

### PARAMETERS FOR OPTIMAL SYSTEM INTEGRATION

| | |
|---|---|
| *Power sorting* | -0 Wp / +5 Wp |
| *Maximum system voltage SC II* | 1000 V |
| *Maximum reverse current* | 25 A |
| *Load / dynamic load* | 5.4 / 2.4 kN/m² |
| *Number of bypass diodes* | 3 |
| *Operating range* | -40°C bis +85°C |

### ORDERING INFORMATION

| *Order number* | *Description* |
|---|---|
| *82000008* | Sunmodule Plus SW 260 poly |

SolarWorld AG reserves the right to make specification changes without notice.
This data sheet complies with the requirements of EN 50380.

Your SolarWorld Official Distributor:

SunFields

www.sfe-solar.com - info@sfe-solar.com
Phone: +34 981595856

2016-03-08 EN

# Tender Text

| Item no. | Specifications | |
|---|---|---|
| | ***SolarWorld Sunmodule Plus SW 260 poly*** | |
| | Crystalline glass-backsheet solar module, framed | |
| | Available power classes: | 260 W |
| | Manufactured in: | Germany |
| | **Structure:** | |
| | Dimensions: | 1675 mm x 1001 mm x 33 mm |
| | Weight: | 18.0 kg |
| | Cell type: | Polycrystalline, solid blue appearance |
| | Cells per module: | 60 |
| | Cell layout: | 6 strings of 10 cells each |
| | Cell size: | 156 mm x 156 mm |
| | Covering material: | highly transparent, tempered, strengthen microstructured solar glass with 3.2 mm thickness |
| | Encapsulation: | Solar cell matrix embedded in EVA film |
| | Back material: | durable composite backsheet film, white |
| | Frame: | Silver-colored aluminum frame with hollow-chamber profile, corners with drainage opening and mounting flange with grounding holes (enables rear screws to prevent slipping) |
| | Junction box: | SolarWorld junction box with integrated 3 bypass diodes, IP65, welded contacts, fully encapsulated |
| | Cable: | Solar cable with 1000 mm length, 4 mm² conductor cross-section |
| | Plugs: | H 4 touch-proof plug connectors with polarity reversal protection |
| | **Permitted ambient conditions/system parameters:** | |
| | Power sorting: | Positive, -0 Wp to +5 Wp over nominal power Pmax |
| | Maximum system voltage: | PC II 1000 V / 600 V according to UL 1703 |
| | Maximum reverse current: | 25 A |
| | Roof load (snow load): | 5.4 kN/m² (5,400 Pa) |
| | Dynamic load (wind load): | 2.4 kN/m² (2,400 Pa) |
| | Permitted operating temperature: | -40°C to +85°C |
| | **Certifications and approvals:** | |
| | **Product:** | |
| | DIN EN / IEC 61215 Ed 2.: | Crystalline silicon terrestrial photovoltaic modules - design qualification and type approval |
| | DIN EN 61730 incl. PC II: | Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction |
| | UL 1703: | Flat-plate photovoltaic modules and panels |
| | MCS 010-1.5: | Generic Factory Production Control (FCP) Requirements |
| | MCS 005-2.3: | Product Certification Requirements for Solar Photovoltaic Modules |
| | VDE certified safety: | Sunmodule Plus in combination with Sunfix plus system and frame technology |
| | IEC 62804: draft 2013-12: | Highly resistant to potential-induced degradation = PID |
| | IEC 61701 ed. 2.0: | Salt mist corrosion testing of photovoltaic modules (very well suited for use near the coast) |
| | IEC 62716 ed. 1.0: | Ammonia resistance (very well suited for use in agricultural operations) |
| | IEC 60068-2-68 Lc2 plus: | Blowing Sand Test severity level Lc 2 (very well suited for use in dusty or sandy areas e.g. near deserts) |
| | VKF Nr. 23544: | Hail resistance class 4 (HW4) |
| | EN 13 501-1: | Fire classification: normal flammability according to reaction-to-fire performance class E |
| | UNI 9177: | Fire reaction class 1 |
| | DIN V ENV 1187-1: | General appraisal certificate from the building authorities in combination with Sundeck (thus considered a hard roof covering) |
| | DIN EN 13 501-5: | Classification as BROOF (t1) |
| | DIN EN 13 501-5: | Classification as BROOF (t1) |

# *Tender Text*

| | |
|---|---|
| PV+Test: | Top mark "excellent" in independent product test carried out by Solarpraxis and TUV Rheinland for quality, durability, and performance |
| Ökotest: | Top mark "excellent" by consumer magazine |

**Company:**

| | |
|---|---|
| ISO 9001: | Quality management system |
| ISO 14001: | Environmental management system |
| BS OHSAS 18001: | Occupational health and safety management systems |
| ISO 50001: | Energy management system |
| Power controlled: | TUV Rheinland inspection mark for guaranteed compliance with stated nominal power of solar modules; verified externally at regular intervals |
| Green Brand: | Seal of quality for demonstrated environmental sustainability |
| Deutschlands Kundenchampions: | 2015 German Customer Champions label for excellent customer-oriented management |

**Warranties:**

10-year product warranty

Linear 25-year performance warranty (the actual power is at least 97% of the nominal power in the first year; no more decline than 0.7% annually beginning in the second year, with power of at least 80.2% guaranteed after 25 years)

**Technical data:**

**Data under STC:**

| | |
|---|---|
| Nominal power Pmax: | 260 Wp |
| Module efficiency: | 15.51% |
| Cell efficiency: | 17.71 % |
| Open circuit voltage Uoc: | 38.4 V |
| Rated voltage Umpp: | 31.4 V |
| Short circuit current Isc: | 8.94 A |
| Nominal current Impp: | 8.37 A |
| Partial load behavior: | 100% (+/- 2%) of the STC efficiency (1000 W/m²) is achieved at 200 W/m². |

**Temperature coefficients:**

| | |
|---|---|
| NOCT: | 46°C |
| TC Isc: | 0.051%/K |
| TC Uoc: | -0.31%/K |
| TC Pmpp: | -0.41%/K |

## Appendix F: Battery specifications

Rolls

FLOODED DEEP CYCLE BATTERIES

# 8 CS 25P

**8 VOLTS**

| | |
|---|---|
| CONTAINER: (INNER) | Polypropylene |
| COVER: (INNER) | Polypropylene - heat sealed to inner container |
| CONTAINER: (OUTER) | High Density Polyethylene |
| COVER: (OUTER) | High Density Polyethylene snap fit to outer container |
| TERMINALS: | Flag with stainless steel nuts & bolts |
| HANDLES: | Molded |

| | | | | |
|---|---|---|---|---|
| WEIGHT DRY: | 155 | kg | 342 | Lbs. |
| WEIGHT WET: | 192 | kg | 424 | Lbs. |
| LENGTH: | 718 | mm | 28 1/4 | Inches |
| WIDTH: | 286 | mm | 11 1/4 | Inches |
| HEIGHT: | 464 | mm | 18 1/4 | Inches |

| | | | | |
|---|---|---|---|---|
| PLATE HEIGHT: | 273 | mm | 10.750 | Inches |
| PLATE WIDTH: | 143 | mm | 5.625 | Inches |
| THICKNESS (POSITIVE): | 6.60 | mm | 0.260 | Inches |
| THICKNESS (NEGATIVE): | 4.57 | mm | 0.180 | Inches |

POSITIVE PLATE DOUBLE WRAPPED WITH SLYVER

ENVELOPED WITH HEAVY DUTY SEPARATOR

Certified System

ISO 9001 Quality

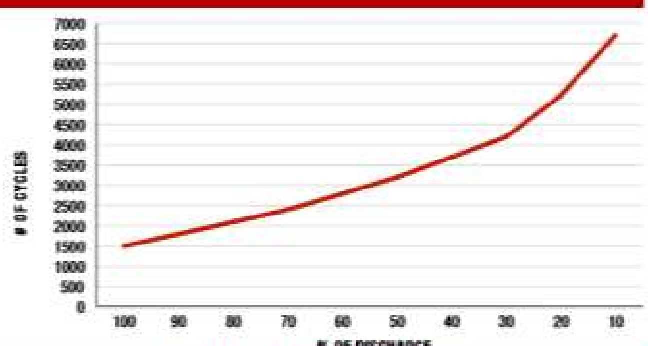
| | | | | |
|---|---|---|---|---|
| CELLS: | 25 | Plates/Cell | 4 | Cell |
| SEPARATOR THICKNESS: | 3 | mm | 0.105 | Inches |
| GLASS MAT INSULATION: | 1 | mm | 0.020 | Inches |
| ELECTROLYTE RESERVE ABOVE PLATES: | 95 | mm | 3.75 | Inches |

| | | |
|---|---|---|
| COLD CRANK AMPS (CCA): | 0°F / -17.8°C | 2184 |
| MARINE CRANK AMPS (MCA): | 32°F / 0°C | 2610 |
| RESERVE CAPACITY (RC @ 25A): | | 1624 Minutes |

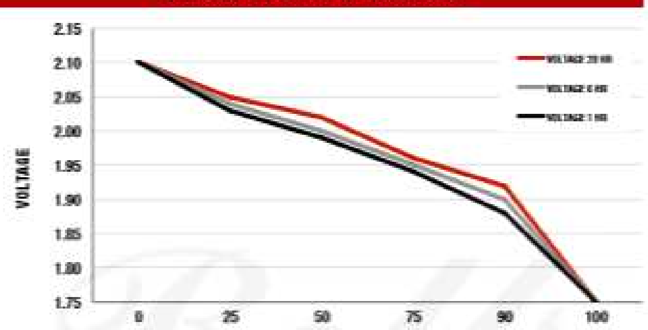
**CAPACITY** **820 AH**

| HOUR RATE: | SPECIFIC GRAVITY | CAPACITY / AMP HOUR | CURRENT / AMPS |
|---|---|---|---|
| @ 100 HOUR RATE | 1.280 | 1156 | 11.56 |
| @ 72 HOUR RATE | 1.280 | 1091 | 15.15 |
| @ 50 HOUR RATE | 1.280 | 1009 | 20.17 |
| @ 24 HOUR RATE | 1.280 | 853 | 35.53 |
| @ 20 HOUR RATE | 1.280 | 820 | 41.00 |
| @ 15 HOUR RATE | 1.280 | 763 | 50.84 |
| @ 12 HOUR RATE | 1.280 | 713 | 59.45 |
| @ 10 HOUR RATE | 1.280 | 681 | 68.06 |
| @ 8 HOUR RATE | 1.280 | 640 | 79.95 |
| @ 6 HOUR RATE | 1.280 | 582 | 97.03 |
| @ 5 HOUR RATE | 1.280 | 549 | 109.88 |
| @ 4 HOUR RATE | 1.280 | 508 | 127.10 |
| @ 3 HOUR RATE | 1.280 | 459 | 153.07 |
| @ 2 HOUR RATE | 1.280 | 394 | 196.80 |
| @ 1 HOUR RATE | 1.280 | 279 | 278.80 |

CYCLE LIFE VS. DEPTH OF DISCHARGE




VOLTAGE VS. DEPTH OF DISCHARGE




Ampere Hour capacity ratings based on specific gravities of 1.280. Reduce capacities 5% for 1.265 specific gravity and 10% for specific gravities of 1.250

## Appendix G: 6 Module array study

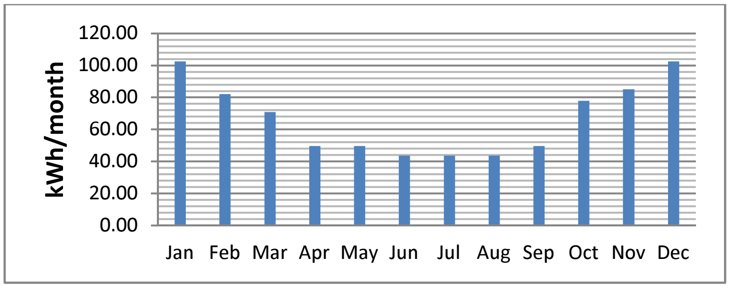
A total capacity of 1.6kWp is installed. The following tables shows the results manually calculated. When simulating this alternative in PVsyst software a total of 1283kWh/year is produced. The solar fraction stays in 100% and the unused energy reduces to 530kWh/year (40% energy is lost). The performance is 36.62%. There is no missing energy and every month the available energy is bigger than the user's need. This ensure the battery charge and because of that the 6 days autonomy. However, losses during summer and spring are still high.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Days per month** | 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 |
| **Used period** | 13 | 13 | 7 | 7 | 7 | 6 | 6 | 6 | 7 | 7 | 7 | 13 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $I_{PV\ array}$ | 50.22 | | 6 modules array | | | | | | | | | |
| $V_{PV\ array}$ | 31.4 | | | | | | | | | | | |
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| kWh/d | 5 | 5 | 4 | 3 | 2 | 2 | 2 | 2 | 3 | 5 | 5 | 5 |
| kWh/used period | 67 | 62 | 27 | 18 | 13 | 9 | 9 | 14 | 23 | 32 | 34 | 70 |
| kWh/month | 160 | 134 | 118 | 79 | 59 | 45 | 48 | 74 | 100 | 143 | 147 | 167 |
| | | | | | | | | | | | | |
| Daily demand | 4 | 4 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 4 |
| Unused daily energy | 1 | 1 | -3 | -4 | -5 | -6 | -6 | -5 | -4 | -2 | -2 | 1 |
| | | | | | | | | | | | | |
| User period demand | 53 | 53 | 50 | 50 | 50 | 44 | 44 | 44 | 50 | 50 | 50 | 53 |
| Unused ener in used period | 14 | 9 | -23 | -31 | -36 | -35 | -34 | -29 | -26 | -17 | -15 | 17 |
| Unused period energy | 93 | 72 | 91 | 61 | 46 | 36 | 39 | 60 | 77 | 111 | 113 | 97 |
| | | | | | | | | | | | | |
| Monthly demand | 53 | 53 | 50 | 50 | 50 | 44 | 44 | 44 | 50 | 50 | 50 | 53 |
| Unused monthly energy | 107 | 81 | 68 | 29 | 9 | 2 | 4 | 30 | 51 | 94 | 98 | 114 |
| | | | | | | | | | | | | |
| Losses due to unused energy | 107 | 81 | 68 | 29 | 9 | 2 | 4 | 30 | 51 | 94 | 98 | 114 |
| | 67% | 60% | 58% | 37% | 16% | 4% | 9% | 41% | 51% | 65% | 66% | 68% |

Appendix table 5: 6 Module array calculated values

In order to reduce the unused energy loss in the year it is necessary to change the demand profile and make it similar to the radiation graph. This means that consumption can be higher at the beginning and the end of the year and lower in the middle of the year. The following figure shows the new demand profile. By using this values losses due to unused energy reduced to 25% when using 6 modules panel. Table 21 shoes the new results




**Appendix figure 6: New demand profile**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Days per month** | 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 |
| **Used period** | 13 | 13 | 7 | 7 | 7 | 6 | 6 | 6 | 7 | 7 | 7 | 13 |
| **New used period** | 25 | 20 | 10 | 7 | 6 | 6 | 6 | 6 | 7 | 11 | 12 | 25 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $I_{PV\ array}$ | 50.22 | | 6 modules array - new used period | | | | | | | | | |
| $V_{PV\ array}$ | 31.40 | | | | | | | | | | | |
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| kWh/d | 5 | 5 | 4 | 3 | 2 | 2 | 2 | 2 | 3 | 5 | 5 | 5 |
| kWh/used period | 129 | 96 | 38 | 18 | 11 | 9 | 9 | 14 | 23 | 51 | 59 | 135 |
| kWh/month | 160 | 134 | 118 | 79 | 59 | 45 | 48 | 74 | 100 | 143 | 147 | 167 |
| Daily demand | 4 | 4 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 4 |
| Unused daily energy | 1 | 1 | -3 | -4 | -5 | -6 | -6 | -5 | -4 | -2 | -2 | 1 |
| User period demand | 103 | 82 | 71 | 50 | 43 | 44 | 44 | 44 | 50 | 78 | 85 | 103 |
| Unused ener in used period | 27 | 14 | -33 | -31 | -31 | -35 | -34 | -29 | -26 | -27 | -26 | 32 |
| Unused period energy | 31 | 38 | 80 | 61 | 48 | 36 | 39 | 60 | 77 | 92 | 88 | 32 |
| Monthly demand | 129 | 96 | 38 | 18 | 11 | 9 | 9 | 14 | 23 | 51 | 59 | 135 |
| Unused monthly energy | 31 | 38 | 80 | 61 | 48 | 36 | 39 | 60 | 77 | 92 | 88 | 32 |
| Losses due to unused energy | 58 | 52 | 47 | 29 | 16 | 2 | 4 | 30 | 51 | 65 | 62 | 64 |
| | 36% | 39% | 40% | 37% | 28% | 4% | 9% | 41% | 51% | 46% | 42% | 39% |

**Appendix table 6: 6 modules array calculated values with new demand profile**

## Appendix H: Lithium iron phosphate battery calculations

When using this battery a full discharge will be considered. Because of their low memory effect they can still reach 92% performance with a full cycle [23]. Also they are smaller and lighter than a lead acid battery.

Same equations as before are used. The SOC will be 0% (giving a DOC of 100%). The lithium iron phosphate 12.8V battery from Victron Energy with a battery management system (BMS) is chosen to form the pack.

$$C_{ns}(Wh) = \frac{L_{md} * N}{DOD_{max,s}}$$

$$C_{ns}(Ah) = \frac{C_{ns}(Wh)}{V_{bat}}$$

The following table shows the Ah needed for different days of autonomy. As it was explained before, 12V system can be used as the pick demand does not goes over 1kWh. However, it was also explained that some appliances use three to four times their nominal power when starting generating a peak. When the final set of appliances is selected the correct battery voltage should be used. If a 25.6V pack want to be installed the Ah needed is half the one for 12.8V. Both the inverter and battery efficiency are 95%. The total load used is 8.08kWh/day (not safety factor is considered).

| 12.8V Battery | | | | |
|---|---|---|---|---|
| Days of autonomy | Ah | Number of batteries | Total battery pack energy | Total battery pack current |
| | | | kWh | Ah |
| 2 | 1262 | 5 | 19.2 | 1500 |
| 3 | 1893 | 7 | 26.88 | 2100 |
| 4 | 2524 | 9 | 34.56 | 2700 |
| 5 | 3155 | 11 | 42.24 | 3300 |
| 6 | 3786 | 13 | 49.92 | 3900 |

Appendix table 7: 12.8V Lithium battery calculation

When using a safety factor for the load (20%), it goes up to 9.69kWh/day. All the values shows before need to be incremented in 20% also.