Project Title:

**Innovative compact HYbrid electrical/thermal storage systems for low energy BUILDings**

Project Acronym:

**HYBUILD**

# Deliverable Report

Deliverable Number:

**D6.2**

Deliverable title:

# Report of the energy performance analysis before intervention

| | |
|---|---|
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# Table of contents

# 1 Executive summary

## 1.1 Description of the deliverable content and purpose

This document provides the synthesis of the pre-intervention monitoring conducted during the baseline period of the HYBUILD project meaning before the installation of the HYBUILD systems in the three demo sites. Deliverable 6.2 is related to *T6.2: Installation of the measurement system for the pre-intervention monitoring*. It reports the main results established during the baseline period: energy consumptions for heating, cooling, domestic hot water, and indoor environmental conditions are presented for each of the three pilots.

The general monitoring guidelines and descriptions of demo sites have been previously delivered in a separated document for each demo site of HYBUILD. The Measurement & Verification (M&V) plans have been defined and described for each pilot with a common agreement on the monitoring strategy, it takes into account the current best practice techniques available from the International Performance Measurement and Verification Protocol (IPMVP). A monitoring protocol was also defined for the three demo sites, allowing comparative analysis before and after the installation of HYBUILD systems, the objective is to design and develop a distributed monitoring system to establish a communication with sensors and management hardware in operation. The monitoring plan for each demo site was discussed and validated by demo sites' owners and all the partners involved in the definition and production of KPIs for the project.

At least, a one-year monitoring period has been carried out in Aglantzia, Almatret, Bordeaux, and Langenwang demo site. According to the IPMVP protocol [1], a sufficient monitoring period is required to establish the energy consumption baseline to compare the consumptions post intervention and then for assessing energy savings. The HYBUILD systems implementation in the demo sites was planned for March 2020, and additional data from the following periods has been included to complement this deliverable and the baseline assessment.

More especially, due to the replacement of the French continental demo site (Bordeaux) by the Austrian demo site (Langenwang) during the project development, section 5.4 has been added in the update done to this deliverable in 2021.

Sections 2 and 3 present the monitoring objectives and equipment for the measurements done prior to the installation of the HYBUILD system (baseline).

In section 4, the general methodology used for analysing the data collected in the demonstration sites during the baseline situation is presented. The selected KPIs selected by the project are also listed in this chapter.

Section 5 reports the main results obtained so far for each pilot in terms of energy performance measurements and indoor environmental conditions. The results are detailed for each demo site: Almatret (Spain), Aglantzia (Cyprus), and Bordeaux (France) replaced then by Langenwang (Austria). They include energy consumption analysis and detailed hygrothermal comfort conditions analysis.

## 1.2 Relation with other activities in the project

The activities presented in this deliverable are a consequence of the definition of the measurement and evaluation plan in task 6.1.

The results here offer a baseline that will be used for the evaluation of performance of the demonstrators in the next task 6.4 (monitoring and evaluation after installation).

Of course, all the measurements and monitoring activities are deeply dependent on the technical details of the implementation of the demonstrators, in task 6.3.

## 1.3 Acronyms and Abbreviations

| | |
|---|---|
| **DHW** | Domestic Hot Water |
| **GA** | Grant Agreement |
| **HDD** | Heating Degree Days |
| **IPMVP** | International Performance Measurement and Verification Protocol |
| **KPIs** | Key Performance Indicators |
| **MAE** | Mean Average Error |
| **M&V** | Measurements and Verification |
| **RH** | Relative Humidity |
| **ROI** | Return on Investment |
| **T** | Temperature |
| **DL** | Data Logger |
| ACS | Adaptive Comfort Standard |

# 2 Monitoring objectives

It is of crucial importance to clearly understand the context and objectives of the HYBUILD project to take them into account for the monitoring plan. Numerous key parameters have to be integrated in the monitoring program in order to cover all the objectives:

- Demonstration project with real-technology implementation (demonstration of a large portfolio of building-integrated storage technologies and systems).
- European dimension as the project aims at driving HYBUILD technology to a large market deployment.
- Three demonstration sites in three different countries with different climates and different building typologies.
- A monitoring program aiming at assessing the performances of the HYBUILD technologies implemented in each demo site and assessing the impact of these technologies on the energy performance and indoor conditions of each demo site.
- A monitoring program based on the IPMVP protocol [1].
- A comparison with the simulated data in order to assess the performance gap associated to the energy storage technologies, identify if possible, the sources of the gap and conduct corrective actions to reduce this gap.
- The whole monitoring approach should lead to a set of lessons learnt and guidelines that will serve the investors in ensuring security related to the installation.

The main objective of the monitoring is to demonstrate the full system performance in near-life operation buildings in three demo sites; Almatret (Spain), Aglantzia Municipality (Cyprus), and Bordeaux (France) replaced then by Langenwang (Austria).

The M&V plans aim at evaluating the impact of the HYBUILD technologies on the performance of the building or a portion of the buildings in terms of energy consumptions and indoor environmental conditions.

This document is associated to the WP6 “Demonstration & Evaluation” and specifically related with tasks 6.1, 6.2 & 6.3.

# 3 Monitoring equipment installation

In the case of HYBUILD, the monitoring equipment will be installed in **two different phases**:

- A first phase before the implementation of the HYBUILD technologies, in order to establish the baseline of the sites and monitor the reporting period for comparison.
- A second phase after the implementation of the HYBUILD systems on site, in order to measure the systems performances. For the monitoring of this phase, additional measurement devices (in comparison to the first phase) will be installed in relation with HYBUILD performance assessment.

# 4 Methodology for data analysis

This chapter presents the methodology that is applied to analyse the measured data collected in the demo sites in agreement with the overall objectives of the monitoring activities within the HYBUILD project, which are the following:

- Impact of HYBUILD technologies on the building performances:
  - In terms of energy performances.
  - In terms of indoor environmental conditions.
- Assessing the HYBUILD performance once integrated in the demo buildings meaning in real conditions.

This methodology is based on several KPIs allowing an exhaustive understanding of the functioning, the energy performance and usages of the building.

## 4.1 Key performances indicators (KPIs)

Following the methodology described in Deliverable 1.3 (Requirements: Key performance Indicators, system components and performance targets), and considering the HYBUILD main objectives for Mediterranean and Continental HYBUILD systems, the KPIs selected by the project partners are:

- KPI.1 – Thermal Energy Storage Density;
- KPI.2 – Seasonal Energy Performance;
- KPI.3 – Share of renewable and self-consumption;
- KPI.4 – Energy savings and $CO_2$ emission saving;
- KPI.5 – Compactness;
- KPI.6 – Flexibility;
- KPI.7 – Return on Investment

Annex 2 presents the link between the selected KPIs and the monitoring devices to be installed in the demos. For the complete description of the KPIs, the authors refer to D1.3 to evaluate the link between the KPIs and the monitoring system.

Table 1. - Relevant KPIs with the corresponding HYBUILD objectives

| | HYBUILD objectives | KPI |
|---|---|---|
| **1** | Increase of thermal energy storage density | KPI.1 |
| **2** | Expected energy and $CO_2$ emissions reduction ranging from 20% to 40% depending on the configuration and contexts | KPI.2, 3 and 4 |
| **3** | Increase of seasonal performance of the heating and cooling system | KPI.2 |
| **4** | Easy to integrate and compact solution into existing building | KPI.5 |
| **5** | ROI of 8 years for building non-connected to DHC and 15 years for buildings connected to DHC | KPI.7 |
| **6** | Superior energy performance contributing to the energy system flexibility | KPI.6 |

## 4.2 Parallel analysis

The measurements are analysed in several different ways in order to obtain a precise knowledge of the energy behaviour of the demonstration site prior to the installation.

Consumption profiles are estimated on daily basis, but also weekly, monthly and yearly basis, in order to identify peaks of consumption.

Multiple levels of analysis are applied: one-month to one-month comparison, season to season comparison, week analysis (coldest[1] and warmest[2] weeks or days for instance).

Heating Degree Day (HDD) values are also used, as independent variables of the model (according to the IPMVP approach). HDD provides information on how much (in degrees) and for how long (in days) the outside air temperature is lower than a specific "base temperature"[3] (or "balance point"). Monthly HDD are calculated for the heating period using 18.5°C as the reference temperature.

HDDs are used to adjust heating consumptions and make comparison with heating consumptions measured during other periods of time. Attached to this model, confidence indicators (for instance determination of the $R^2$ coefficient) are also calculated to show the relevance and quality of the model for comparison purposes.

[1] Week during which the outdoor temperature is the lowest over the period considered.

[2] Week during which the outdoor temperature is the highest over the period considered.

[3] The reference temperature is known as base temperature and is defined as the outdoor temperature at which the heating (or cooling) systems in a building do not need to run to maintain comfort conditions.

# 5 Baseline assessment of the demo sites

This section provides the main results obtained for the three demo sites in terms of energy performances and indoor comfort conditions.

## 5.1 Almatret, Doctor house (Almatret, Spain)

### 5.1.1 Building analysis

#### *5.1.1.1 Site context and data*

The house where one of the two demo sites to test the HYBUILD Mediterranean concept is located in street Sant Joan in Almatret, which is a small village of around 300 inhabitants located in Catalonia, Spain. The house was built in 1970, and it is a single-family house of two floors. On the ground floor there is the medical office of the village, while the first floor is where the doctor lives with his family. Only the first floor of the house will be used for testing the HYBUILD system. Some retrofitting works were done in 2003 where an extension of the garage on the ground floor was performed.

Table 2. summarises the main features of the demo site.

Table 2. main features of the demo in Almatret.

| Main features | Description |
|---|---|
| Address | Sant Joan street no. 621, 25187, Almatret, Spain |
| Building typology | Residential |
| Surface | 112.5 $m^2$ |
| Number of floors | 2 (only one is analysed) |
| PV installation location | On the roof of the building next to the house |
| Planned HYBUILD system | Mediterranean |
| Owner of the building | Municipality of Almatret |
| Occupancy | 4 people |
| Building plans (floor plans, electrical network, ventilation network…) | Plans and photos are provided in Annex 8.1 |

#### *5.1.1.2 Main equipment existing in the building before the project*

As previously mentioned, the whole building consists of two floors. The ground floor is the doctor's office and garage, while the first floor is where the doctor lives with his family. There is no information on the level of thermal insulation between the two floors. Therefore, the monitoring of the comfort level on the ground floor as well as the energy and water consumption was also considered in the pre-intervention monitoring.

Currently, a gas boiler is used for heating and hot water production at the Almatret demo site. The gas consumption is measured with two gas meters, one for the doctor office and one for the doctor house. However, the separate gas consumption for heating and for DHW production of the doctor house cannot be measured using the existing gas meters. The electricity consumption of the ground and first floors are also measured separately with two energy meters. Moreover, the overall water consumption is also available using two water meters, one for the ground floor and one for the first floor. Figure 1 shows some pictures of the gas boiler and electric and gas meters available at Almatret demo site.


(a) (b)

(c)

**Figure 1. Pictures of the (a) gas boiler used for heating and DHW supply, (b) gas meter, and (c) electric meters**

A synthesis of the equipment available in the house (Heating/Ventilation/DHW/solar panels/number of electrical board) and energy used for each system is shown in Table 3. The table also highlights the existing possibilities for monitoring implementation.

**Table 3. Summary of the current equipment**

| | Equipment | Energy used | Comments and possibilities of monitoring |
|---|---|---|---|
| **Heating** | Gas boiler for heating & DHW | Propane gas | Gas meter on site; measurement for both heating & DHW |
| **Cooling** | No cooling system | - | - |
| **DHW** | Gas boiler for heating & DHW | Propane gas | Gas meter on site; measurement for both heating & DHW |
| **Ventilation** | No ventilation system | - | - |
| **Indoor comfort** | Programable thermostat | - | - |
| **Electricity consumptions** | Connection to the grid | Electricity from the grid | Separate electricity meter on site |
| **Outdoor conditions** | No equipment | - | - |

#### *5.1.1.3 Main monitoring equipment installed for pre intervention*

To separate the overall energy consumption of the doctor house, two possibilities were initially considered:

1. To estimate the energy needs for DHW production using a water meter and assuming a value for the efficiency of the boiler. Thus, the energy consumption for heating can be calculated using data from the gas meter on site.
2. To measure the energy consumption using two thermal energy meter devices, one for heating and one for DHW consumption. These devices can be used later for the post-intervention monitoring phase of the project, after the installation of the HYBUILD system.

The second option was chosen because of a better accuracy of the measurements in addition to the fact that it was also the cheapest option. The main monitoring equipment used for the pre-intervention monitoring is shown in Table 4.

**Table 4. Equipment used for the pre-intervention monitoring in Almatret Demonstration site.**

| | Units | Instrument | Data acquisition | COST |
|---|---|---|---|---|
| **Heating consumption** | kWh-MJ | Energy meter | Home-made data logger | 123.13 € |
| **DHW consumption** | kWh-MJ | Energy meter | Home-made data logger | 123.13 € |

| | | | | |
|---|---|---|---|---|
| **Indoor Comfort** | T (ºC), RH (%) | BENETECH GM1365 | Data Logger Meter LCD Digital Auto USB Flash Disk Pen | 2×31 € |
| **Electricity consumption** | kWh | Standard electricity meter | Manual reading/electricity consumption bill | 0 € |
| **Gas consumption** | $m^3$ | Standard gas meter | Manual reading/gas consumption bill | 0 € |
| **Outdoor conditions** | T (ºC), RH (%) | BENETECH GM1365 | Data Logger Meter LCD Digital Auto USB Flash Disk Pen | 1×31 € |
| **Indoor temperature (ground floor)** | T (ºC), RH (%) | BENETECH GM1365 | Data Logger Meter LCD Digital Auto USB Flash Disk Pen | 1×31 € |
| **Gas consumption (ground floor)** | $m^3$ | Standard gas meter | Manual reading/gas consumption bill | 0 € |

A total of four sensors were installed to measure the temperature and relative humidity, two of them inside the doctor house (Figure 2), one inside the doctor office, and one outdoors. The temperature and relative humidity sensors were installed at a height of 1.5 m (Figure 3) with respect to the ground and far enough from heat emitters and windows.

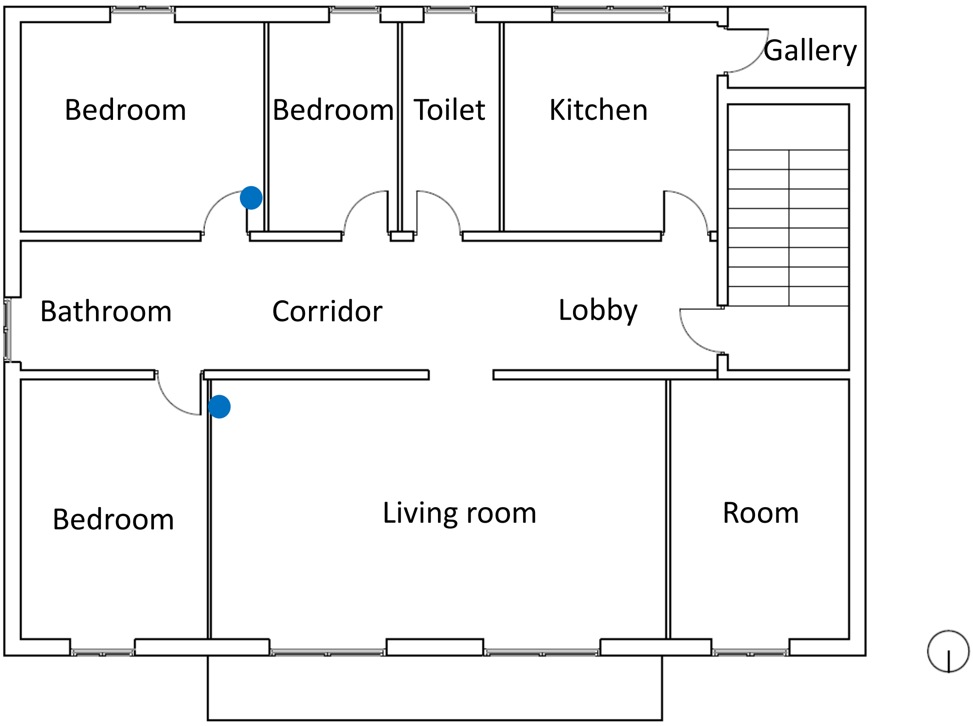



Figure 2. Schematic of the location of the temperature and relative humidity sensors inside the doctor's house

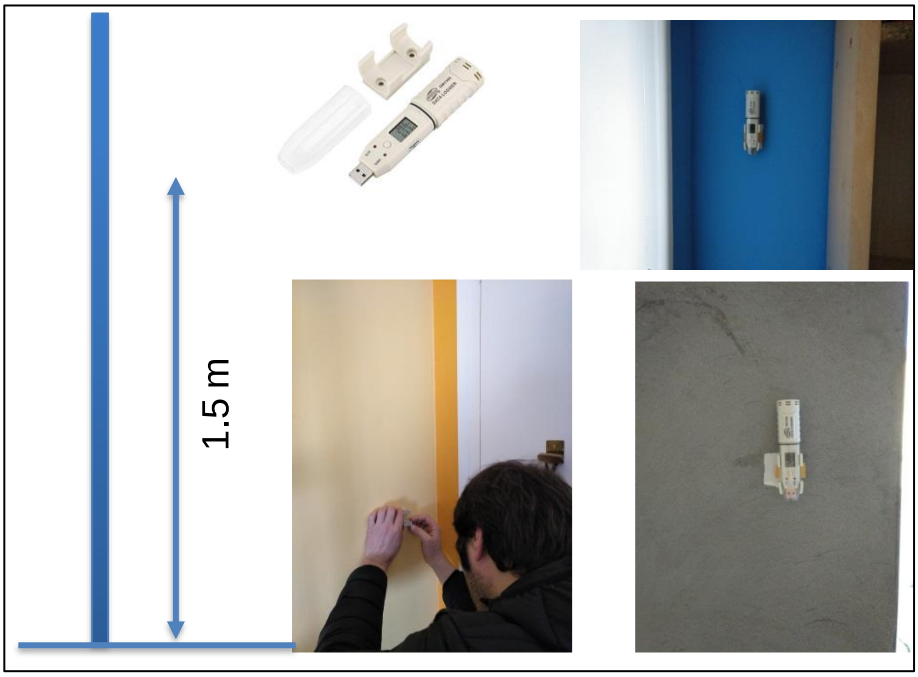



Figure 3. Details of the installation in situ of the temperature and relative humidity sensors

As for the energy meter devices used to monitor energy consumption for heating and DHW production, two ZELSIUS C5-ISF energy meters were used. Each of them has a flow sensor and a temperature sensor. The meters perform the calculation of the energy consumed and allow its acquisition through the M-Bus communication port (communication standard for thermal energy measurement equipment). An automatic system that allows to correctly get the information of the M-Bus port and store it in a database for later analysis was designed and implemented, as shown in Figure 4.

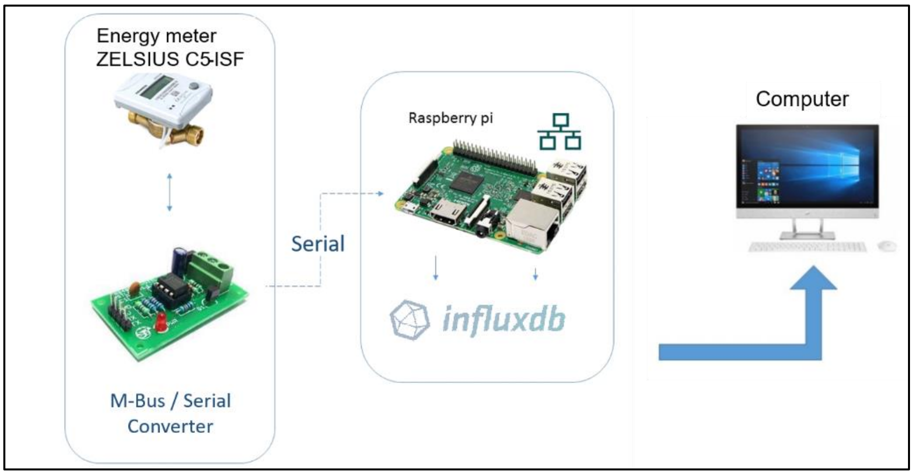



Figure 4. Flowchart of the data acquisition system

The following two energy meters models were used:

- ZELSIUS ISF DN 15 L110 M-Bus for DHW consumption.
- ZELSIUS ISF DN 20 L130 M-Bus for heating consumption.

Each meter must be connected to a Raspberry Pi using an M-bus/Serial adapter, or an electrical interface circuit. This is designed to provide the power supply of the energy meter and to adapt the voltage levels of the M-Bus output of the meter (30 V) to the voltage levels of the RX and TX terminals of the Raspberry Pi. The data was stored in the memory of the Raspberry Pi using Influxdb as database, and sent to a cloud account or an email on a daily basis.

Some pictures of the two energy meters installed in situ are shown in Figure 5.


Figure 5. Pictures of the energy meters

#### *5.1.1.4 Monitoring period*

The monitoring period reported in this deliverable covers the months from February 2019 to August 2020. Specifically, the devices installed to measure temperature and relative humidity both outdoors and indoors, started to record data on 7 February 2019, while the energy meters for monitoring the gas energy consumption for heating and DHW production were installed on 22 February 2019. In parallel, the electricity, gas, and water consumption of both the doctor office and doctor house were also monitored by manually recording the readings of the corresponding metering devices starting from 16 January 2019.

### 5.1.2 Data collected

As already mentioned previously, several devices were used to collect data regarding the energy consumption as well as the thermal comfort of the building during the pre-intervention period. The focus during this pre-intervention period is to monitor indoor temperature and relative humidity, and energy consumption for heating and DHW production. Outside temperature and relative humidity was also registered as the main parameters relating to outdoor conditions.

Table 5. summarizes all data collected during the pre-intervention monitoring period and shows some details regarding each data.

**Table 5. Data collected during the pre-intervention monitoring period**

| Data point | Physical correspondence | Units | Sample rate (min) | Data available |
|---|---|---|---|---|
| **Outdoor temperature** | Outdoor temperature | °C | 15 | 07/02/2019 |
| **Outdoor relative humidity** | Outdoor relative humidity | % | 15 | 07/02/2019 |
| **Indoor temperature** | Indoor temperature | ºC | 15 | 07/02/2019 |
| **Indoor relative humidity** | Indoor relative humidity | % | 15 | 07/02/2019 |
| **Domestic hot water energy consumption** | Energy consumption for DHW production | MWh | Monthly | 22/02/2019 |
| **Heating system energy consumption** | Energy consumption for heating | MWh | Monthly | 22/02/2019 |

## 5.1.3 Energy consumption analysis

### 5.1.3.1 *Analysis of heating demand*

Figure 6 shows the monthly energy consumption for heating and the monthly average outdoor temperature for the period comprised between 8 February 2019 and 31 August 2020. The maximum energy consumption occurs in March 2019, even though the average outdoor temperature was similar to the average temperature in April. Moreover, the peak of energy consumption during the winter of 2020 occurred in January 2020, when the average outdoor temperature was the lowest. Despite of this, the energy consumption during December 2019 and January 2020 was lower than in March 2019. This can be explained by a reduction of the house occupancy during April 2019 because of Eastern holidays and also in December 2019 and January 2020 because of Christmas holidays. Regarding energy consumption in February 2019, it is not the highest one because it does not cover the full month, but only from 8 February 2019, despite the average outdoor temperature was the lowest of the period considered in winter 2019.

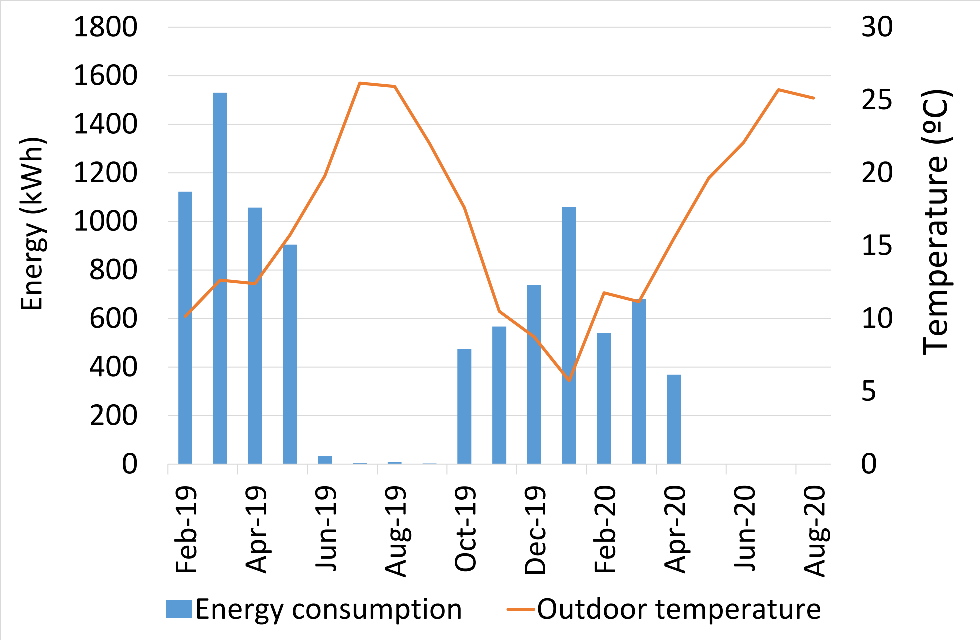



Figure 6. Evolution of the monthly energy consumption for heating (solid bars) and outdoor temperature (line) over the monitored period

#### *5.1.3.2 Energy consumption vs HDD*

Figure 7 shows the energy consumption for heating against the HDD for the time period considered. The energy consumption linearly increases with the HDD, with a coefficient of determination $R^2$=0.49.

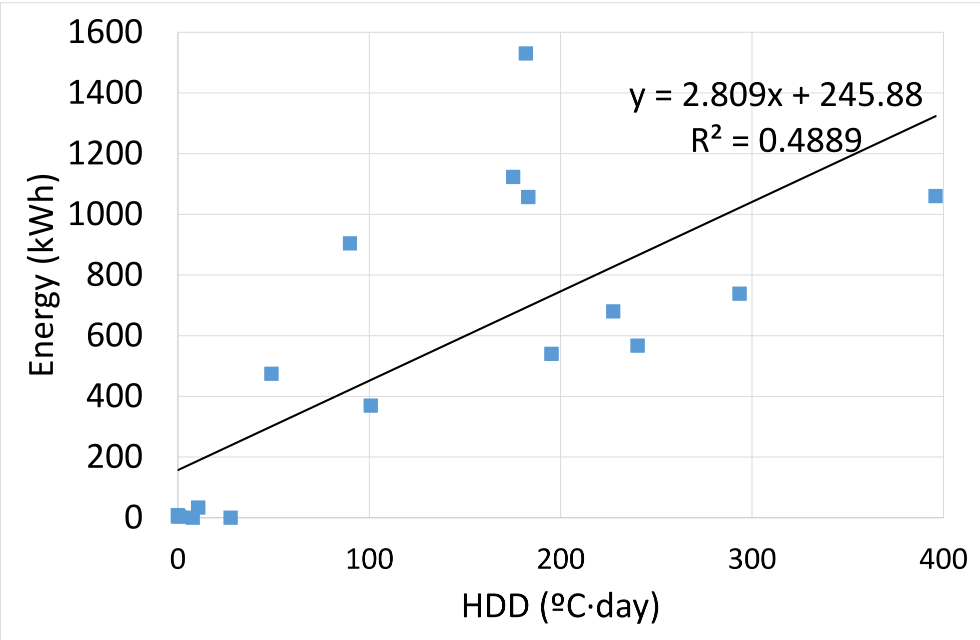



Figure 7. Energy consumption for heating versus heating degree day (HDD)

#### *5.1.3.3 DHW Consumption*

The monitoring of the energy consumption for DHW started on 22 February 2019 and only monthly values are available for the period reported in this deliverable. The monthly energy consumption for DHW along with the daily average over the monitored period is shown in Figure 8. Relatively high variations in the consumption is observed between the different months, which is confirmed by the daily average that varies from around 2 kWh/day in February 2019 and May 2019 up to around 10 kWh/day in June 2019. Starting from March 2020, a problem occurred with the energy meter that monitors the DHW consumption, which could not be detected on time nor fixed during the following few months due to mobility restrictions caused by the COVID-19 pandemic, which made it impossible to go to the demo site.

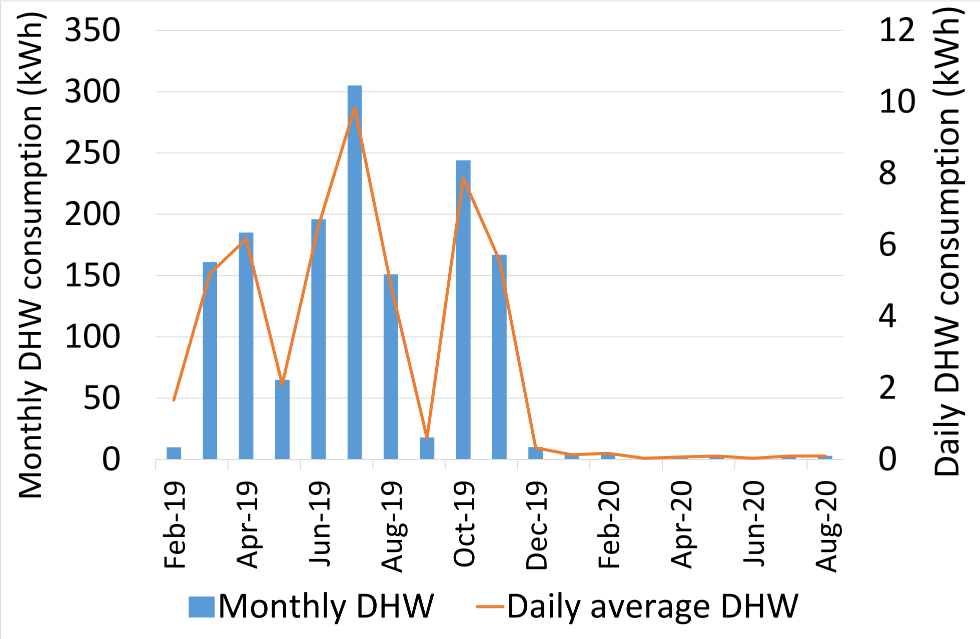



Figure 8. Monthly and daily average energy consumption for DHW

### 5.1.4 Indoor comfort conditions

Indoor temperature and relative humidity were measured in two different rooms of the doctor house and also in the doctor office to monitor if comfort conditions were met. The outdoor temperature and relative humidity were also monitored to have a reference of the ambient conditions.

#### *5.1.4.1 Temperatures evolution in the building*

The evolution of the temperature both inside and outside of the building are shown in Figure 9, for the period comprised between 8 February 2019 and 31 August 2020. The temperature is generally within the comfort range during most of the time, except for brief periods in February 2019 and 2020 when the heating system was not operating because of some issues with the gas boiler of the doctor house, and also in summer because no cooling system was installed in the house. Comfort temperature is neither met at the doctor office in weekend days during cold months and in summer, because the heating system is switched off during the weekend and in summer holidays.

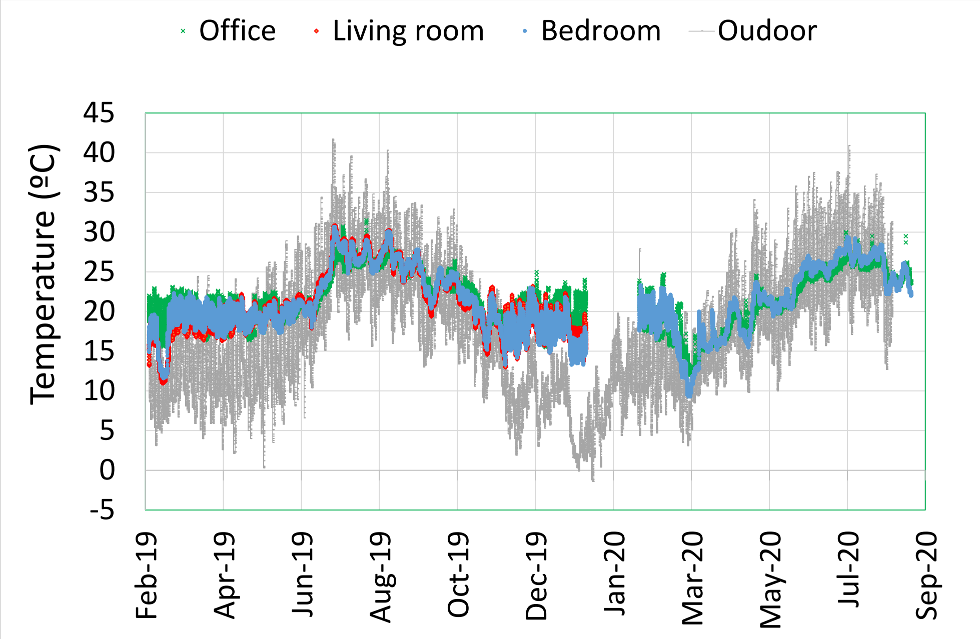



Figure 9. Indoor temperatures evolution in the different rooms of the house and outdoor temperature

The temperature evolution both indoors and outdoors during the warmest week of the monitored period, from 24 June 2020 to 1 July 2020, is shown in Figure 10. The indoor temperatures follow the increasing trend of the outdoor temperature and despite the large variations of the outdoor temperature between day and night, the indoor temperature variations are relatively small, especially at the doctor office. Indoor temperature stays within the comfort range during the first half of the warmest week, after which it reaches uncomfortable values around 30 ºC. It can also be observed that the temperature in the doctor office remains up to 4 ºC below the temperature inside the house, probably because of the fact that the office is located at the ground floor and it is less exposed to solar radiation.

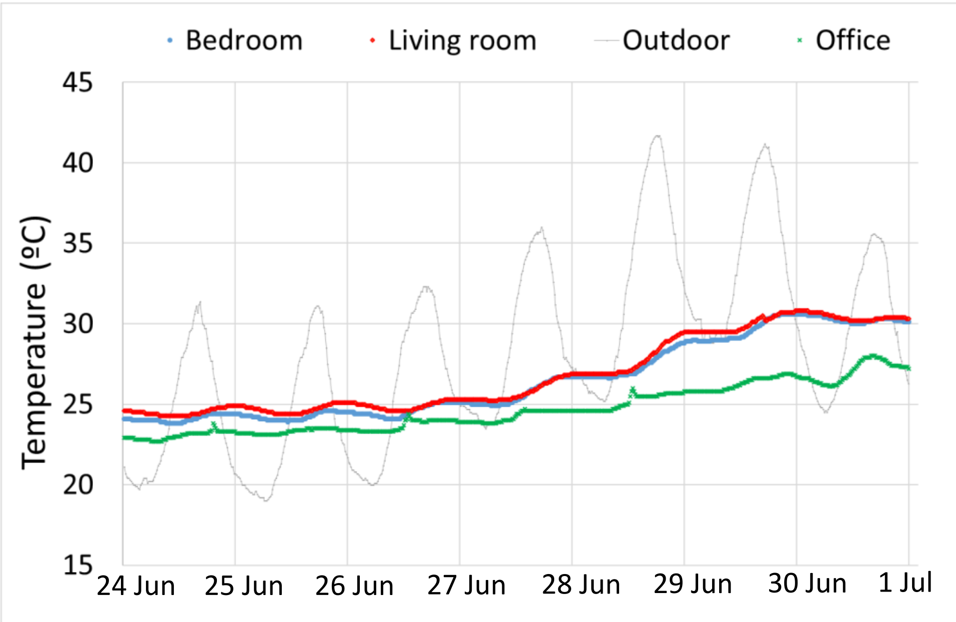



Figure 10. Indoor temperatures evolution during the warmest week

A similar analysis was performed for the coldest week of the period. The temperature evolution both indoors and outdoors corresponding to the coldest week, from 1 January 2020 to 8 January

2020, is shown in Figure 11. It comprises five working days and two weekend days, from 4 to 5 January. The temperature at the doctor office met comfort conditions during the working hours of the working days, but the temperature decreased during the night and weekend below the comfort range. The temperature inside the doctor house is generally below the comfort range even when the heating system was working, probably due to a lower set-point temperature.

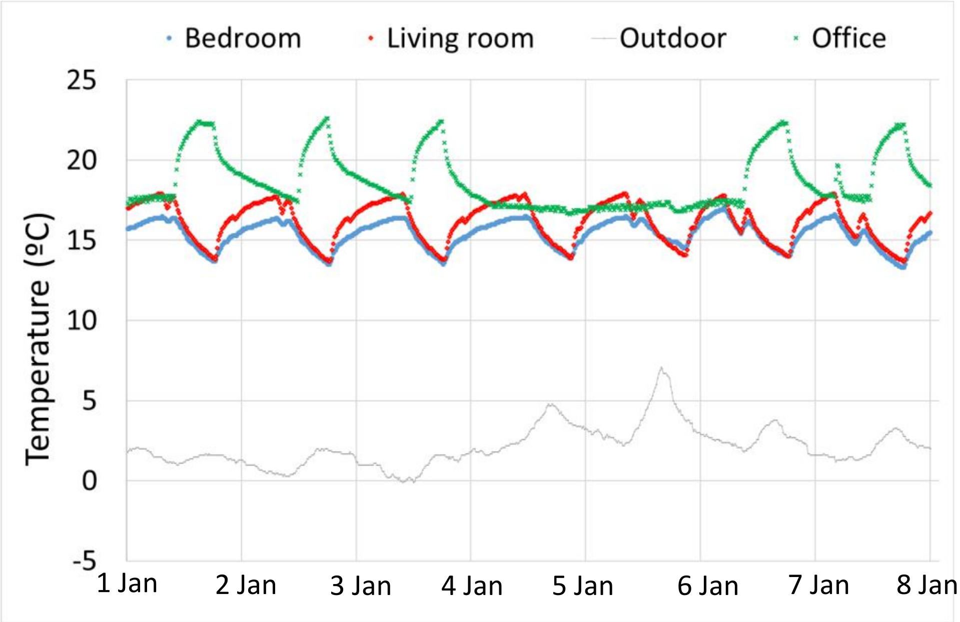


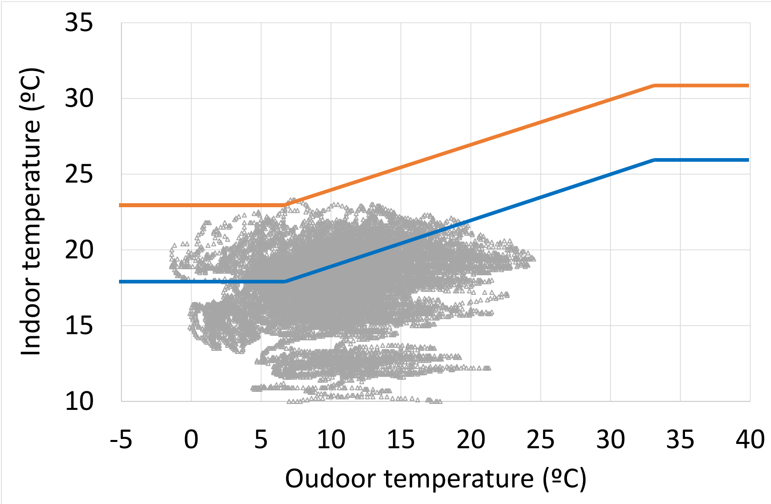

**Figure 11. Indoor temperatures evolution during the coldest week**

### *5.1.4.2 Comfort rating in the building*

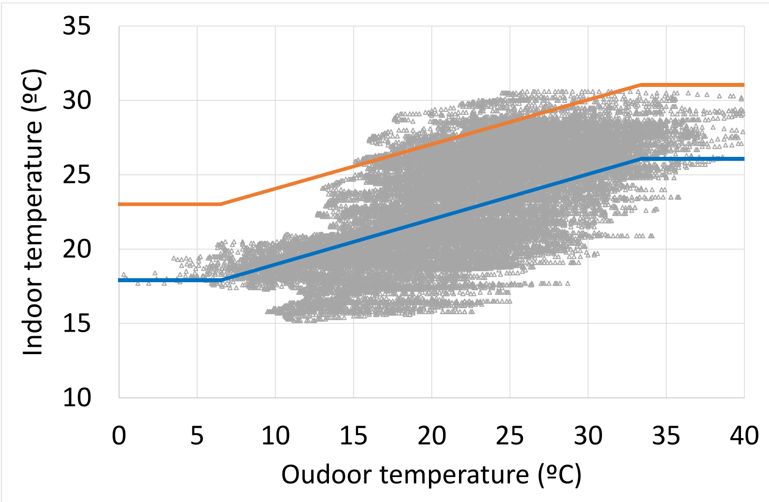
This section describes and analyses the comfort inside the doctor house in two different periods. The first period comprises the colder half period of the year, from 7 February 2019 to 15 April 2019 and from 16 October 2019 to 15 April 2020, while the second period corresponds to the warmer half period of the year comprised between 16 April 2019 and 15 October 2019, and between 16 April 2020 and 31 August 2020.

The Brager index was used for that purpose, which defines the building occupant thermal comfort zone as a function of indoor and outdoor air temperature. The upper bound of the zone corresponds to the orange line, while the lower bound is the blue line. Points above the upper limit correspond to too hot thermal condition, while points below the lower limit represent cold discomfort.

Figure 12 shows the doctor house indoor temperature vs the outdoor temperature for both the cold (Figure 12a) and the warm (Figure 12b) periods. The comfort range is also shown in the figures. Most points are below the lower comfort limit in the cold period, especially the points corresponding to the days when the gas boiler was broken and the heating system of the doctor house was not working. In the warm period, the points are spread in a wide interval, and there is a considerable number of points outside the comfort temperature range, although in this case there are a few points also above the upper limit.



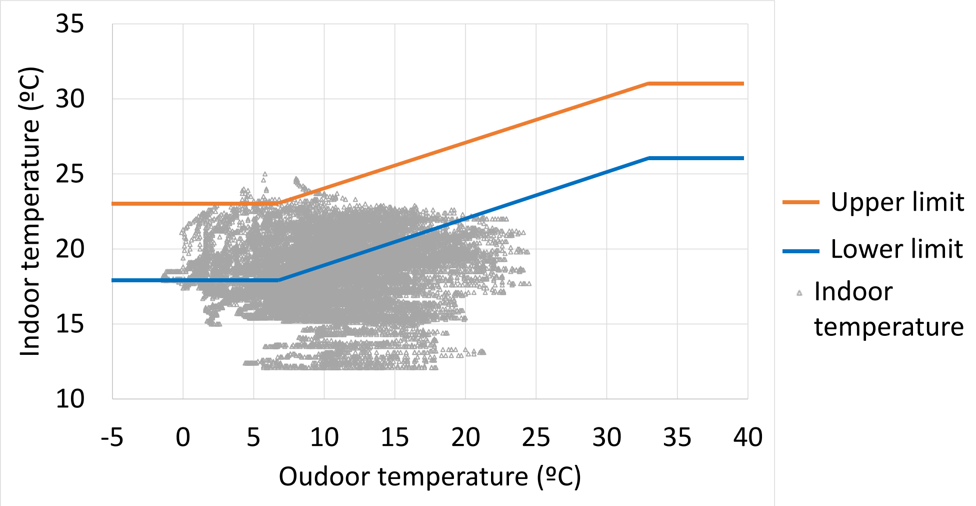

(a)



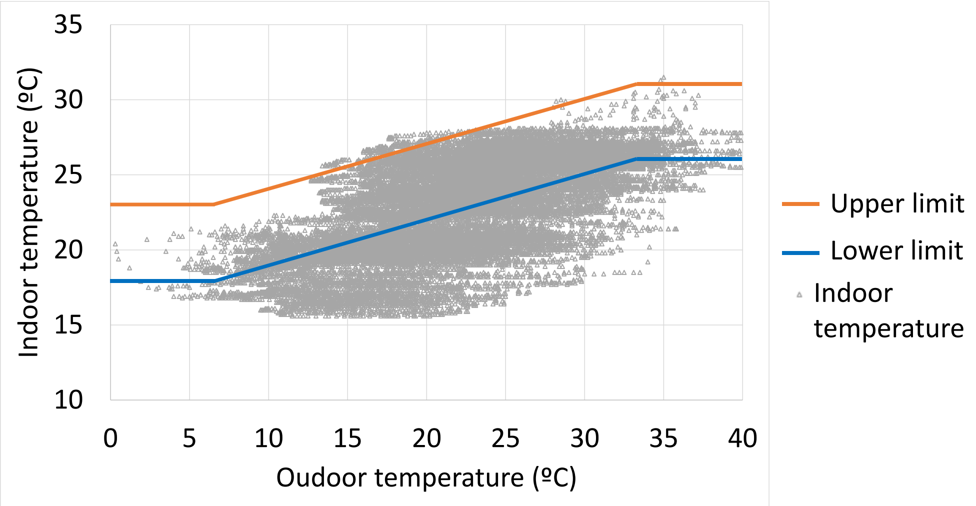

(b)

**Figure 12. Brager index at the doctor house during (a) the cold period and (b) the warm period**

Figure 13 shows the doctor office indoor temperature vs the outdoor temperature for both the cold (Figure 13a) and the warm (Figure 13b) periods along with the comfort range. During the cold period, around half of the points are within the comfort range, while the other half is below the lower limit of the comfort range. This is expected because the office is not heated all the time, but only during working hours. Therefore, during the night and during weekends or holidays, the temperature went down because of the colder outdoor temperature. Very few points are above the upper comfort limit. During the warm period, the situation is similar to the one shown in Figure 12b for the doctor house. Here again, there is a tendency towards zones below the lower comfort limit, and there are very few points above the upper limit.




(a)




(b)

**Figure 13. Brager index at the doctor office during (a) the cold period and (b) the warm period**

## 5.2 Aglantzia, Exhibition (Aglantzia, Cyprus)

### 5.2.1 Building analysis

#### *5.2.1.1 Site context and data*

The following table summarises the main features of the demo.

Table 6. Main features of the demo.

| Main features | Description |
|---|---|
| Address | In the square at Aglantzia core |
| Building typology | Multifunctional space |
| Surface | 140 $m^2$ |
| Number of floors | 1 |
| PV installation location | roof |
| Planned HYBUILD System | Mediterranean |
| Owner of the building | Municipality of Aglantzia |
| Occupancy | 20-60 depending on the building use |
| Building plans (floor plans, electrical network, ventilation network…) | _ |

#### *5.2.1.2 Main equipment existing in the building before the project*

Here we present a synthesis of the equipment existing in the Building (Heating /Ventilation/DHW/solar panels/number of electrical board) and energy used for each system. The table highlights also the existing possibilities for monitoring implementation.

The case study is a listed building located in the square at Aglantzia core. The building will serve as a benchmark for a permanent digital exhibition of renewable energy technologies and supportive equipment to serve as a space to inform society about the use of smart technologies in our homes to enable the transition to a low carbon economy and high levels of energy savings.

The building has been shut down in recent years without any electricity consumption. In order to improve the energy efficiency of the building envelope, it is necessary to take the appropriate steps in this direction before installing any system (PV panels, solar thermal collectors, heat pump, etc.). It is necessary before the integration of renewable energy sources to upgrade the roof of buildings. The sloped wooden roof included 3cm extruded polystyrene and it had been increased to 10 cm. Additionally, conventional bulbs will be replaced by LEDs. These measures are expected to offer a significant reduction in the building energy consumption and thus reduce the requirements for the hybrid system capacity to be installed.

Construction work is also being done inside the building (installation of partitions, demolition of walls to improve the functionality of the building, etc.). For this reason, the building does not currently have any heating - cooling system, only some ceiling fans which are to be replaced.

Table 7. Summary of the current equipment

| | Equipment | Energy used | Comments and possibilities of monitoring: |
|---|---|---|---|
| **Heating** | No heating system | --- | --- |
| **Cooling** | No cooling system | | |
| **DHW** | | --- | --- |
| **Ventilation** | No equipment | --- | --- |
| **Indoor Comfort** | --- | --- | --- |
| **Electricity consumptions** | --- | --- | Separate electricity meter on site |
| **Outdoor conditions** | --- | --- | Weather station with pyranometers, temperature sensors, relative humidity sensors, wind speed and wind direction sensors (feature to be defined) |

### 5.2.1.3 Main monitoring equipment installed for pre intervention

Table 8. Equipment used for the pre-intervention monitoring in Aglantzia Demonstration site.

| | Units | instrument | Data acquisition | COST |
|---|---|---|---|---|
| **Heating consumption** | - | - | - | - |
| **DHW consumption** | - | - | - | - |
| **Indoor Comfort** | - | - | - | - |
| **Electricity consumptions** | - | - | - | - |
| **Gas consumptions** | - | - | - | - |
| **Outdoor conditions** | (°C),<br>(%),<br>(W/m$^2$),<br>(m/s),<br>(°), | Rotronic HC2S3,<br>Rotronic HC2S3,<br>Kipp & Zonen CMP11,<br>NRG 40C,<br>NRG 200P | Ambient temperature,<br>Relative Humidity,<br>Solar irradiation,<br>Wind speed,<br>Wind direction | (Loggers were provided by the university and not financed by the project) |
| **Indoor temperature / Ground floor (recommended)** | (°C),<br>(%),<br>(m/s) | (1) ten UX100-003 HOBO data logger<br>(2) one LSI-Lastem Heat Shield base module with a Hot wire LSI Anemometer ESV125 | (1) air temperature (°C), relative humidity (%)<br>(2) a natural wet bulb, a dry bulb and globe Temperature, air velocity | (1) 2000 euro<br>(2) 5500 euro<br>(Loggers were provided by the university and not financed by the project) |

#### *5.2.1.4 Monitoring period*

The monitoring period reported in this deliverable covers the January 2019 to December 2019, collecting all the seasonal variations. The building is free of users and the shutters, where available, are closed.

### 5.2.2 Data collected

The UX100-003 HOBO data logger (DL) was placed to record building temperature and relative humidity with an accuracy of ±0.21°C from 0° to 50°C and ±3.5% from 25% to 85% including hysteresis at 25°C respectively. Specifically, 10 data loggers were placed in the building. The sensors were placed at a height of 1.1 m above floor level, which fairly corresponds to the height level of the head of sitting people (EN ISO7726: 2001). In addition, data loggers were placed in one selected position along different heights of the room, i.e. 1.1 m, 1.7 m, 2.3 m, 2.9 m. The intervals of the recordings of indoor environmental parameters were set at five minutes. The equipment was placed in selected locations, as shown in the plan and section below.

One LSI-Lastem Heat Shield base module (ELR610M) was employed to measure the operative temperature indoors. The equipment obtains a data logging interval of 10s, environmental limits between -20 and 60°C and includes a natural wet bulb, a dry bulb and globe thermometers reaching the accuracy of ±0.3°C, ±0.4°C and ±0.3°C respectively. In order to measure air velocity, a Hot wire LSI Anemometer ESV125 was used which produced measurements ranging between 0.01m/s and 20m/s with an accuracy of 0.01m/s. The equipment was placed in the middle of the space as shown in the plan and section below.

An outdoor weather station is installed in Aglantzia at the University of Cyprus at a height of 3-4 m above street level, at a small distance from the demo-site of Aglantzia (less than 1.8 km).

Below, Figure 14 and Figure 15 show the positions of measurement equipment in the building.


Figure 14. Plan of the building with positions of measurement equipment

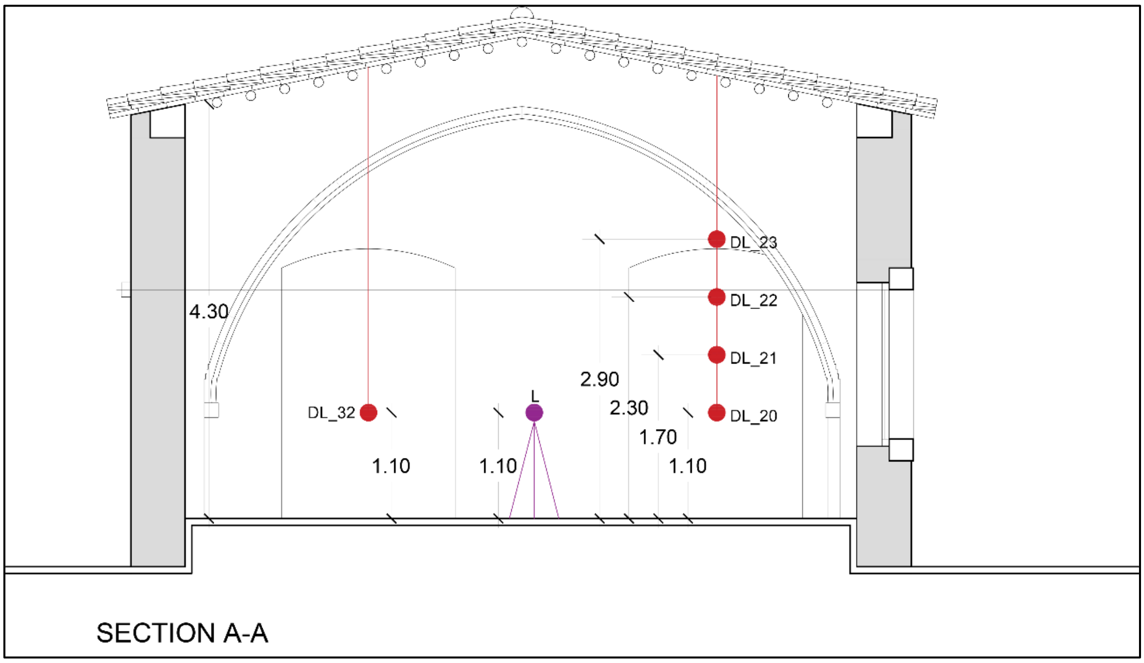



Figure 15. Section of the building with positions of measurement equipment in height.

Table 9. Data collected during the pre-intervention period.

| Data point | Physical correspondence | Units | Sample rate (min) | Data available |
|---|---|---|---|---|
| **Outdoor Temperature** | Outdoor Temperature | °C | 15 | 1/1/2019 |
| **Relative humidity outdoor** | Outdoor relative humidity | %RH | 15 | 1/1/2019 |
| **Wind speed** | Wind speed | m/s | 15 | 1/1/2019 |
| **Wind direction** | Wind direction | degrees | 15 | 1/1/2019 |
| **Inclined global irradiation** | Global non-corrected solar radiation in the plane of PV panels | W/m² | 15 | 1/1/2019 |
| **Corrected inclined global irradiation** | Global corrected solar radiation in the plane of PV panels | W/m² | 15 | 1/1/2019 |
| **Domestic hot water power and energy consumption** | Domestic hot water system electricity consumption | W, Wh | Not provided | Not provided |
| **Heater power and energy consumption** | Heater electricity consumption | W, Wh | Not provided | Not provided |
| **Indoor Temperature** | Indoor Temperature | °C | 5 | 9/1/2019 |

| | | | | |
|---|---|---|---|---|
| **Relative humidity indoor** | Indoor relative humidity | %RH | 5 | 9/1/2019 |
| **Wet bulb, Dry bulb and Globe Temperature** | Indoor Wet bulb, Dry bulb and Globe Temperature | °C | 1 | 9/1/2019 |
| **Air velocity** | Indoor air velocity | m/s | 1 | 9/1/2019 |

### 5.2.3 Energy consumption analysis

The building has been out of operation lately due to renovations being carried out inside and outside of the building. For this reason, there is no heating/cooling system in the building and no electricity consumption. Inside the building, sensors were installed at different points and heights to measure internal parameters (indoor temperature, humidity, etc.). Based on these data, the building internal conditions are evaluated compared to the external data (ambient temperature, humidity, etc.) obtained through the university weather station.

### 5.2.4 Indoor comfort conditions

Figure 16 shows the measured values of air temperature in all rooms of the building during the whole monitoring period for both weekdays and weekend. The results were presented in correlation to the external temperature as this factor can significantly affect the indoor conditions. The thermal comfort conditions are analysed in the section “Comfort rating in the building”. The analysis of the onsite recordings includes maximum, minimum, mean temperatures, standard deviation and diurnal fluctuation of different spaces of the building.

The outdoor temperature during the winter period i.e. December to February varies from -0.59°C to a peak of 23.06°C with a mean diurnal fluctuation of 11.43°C (Fig. 17). The outdoor mean average temperature during the winter period was 11.6°C. Based on the onsite recordings, mean average temperatures in all spaces are found to be low but stable and all rooms show similar behaviour in terms of temperature. Nevertheless, it is interesting to mention that, during the winter period, the building shows much higher temperatures compared to the outside conditions. Specifically, the mean average indoor temperatures in the building during winter period range from 12.1 to 16.3°C. The results indicate that the south-oriented spaces (kitchen/technical room (DL_47) and the permanent exhibition space (DL_34) exhibits generally slightly higher temperatures and diurnal temperature fluctuations compared to the north-oriented one. Specifically, the mean maximum temperature during the winter period in the multi-purpose area (DL_20, DL_32, DL_36, DL_37) ranges from 12.3 to 16°C with a mean diurnal fluctuation varying from 0.3°C to 0.5°C; while in the south-oriented space of the kitchen/technical room and permanent exhibition (DL_47 and DL_34) the mean maximum temperature range from 12.9°C to 16.3°C with mean diurnal fluctuation varying from 1 to 1.7°C. This variation in temperatures of spaces with different orientation is mainly attributed to the impact of direct solar radiation. It is worth noting that these spaces are also not shaded by external shutters. The mean maximum temperature in the spaces under study remains lower compared to the outdoor environment however, indoor temperature fluctuations indicate that temperatures in spaces remain fairly constant. Due to their high thermal stability, all spaces present a beneficial thermal effect during night-time hours when temperatures are minimal. Specifically, mean minimum temperatures in the building range from 11.8°C to 16.0°C while the mean minimum temperature in the outdoor environment is between 4.5°C-6.7°C (**¡Error! No se encuentra el origen de la referencia.**10).

The outdoor temperature during the intermediate spring period, i.e. March to May, varies from 2.8°C to a peak of 42.2°C with a mean diurnal fluctuation of 14.6°C (Figure 16). The outdoor mean average temperature during the mid-season period was 19.2°C. Regarding indoor temperatures, the highest temperatures are recorded again in south-oriented spaces i.e. kitchen/technical room (DL_47). The mean average indoor temperatures in the building ranges from 14.9°C to 15.5°C during March, from 17.4°C to 17.7°C during April and from 23.1°C to 23.7°C during May, i.e. a mean difference of 0.3-0.6°C between the spaces. It is worth mentioning that only during May the mean average temperature is within comfort levels. The building keeps thermal stability, having slightly higher mean diurnal fluctuation in each individual space, compared to the winter period ranging from 0.5 to 1.7°C. Again, the indoor mean minimum temperatures that appear during night-time are above the minimum outdoor temperatures. Specifically, the indoor mean minimum temperatures range from 14.6°C to 14.9°C during March, from 16.9°C to 17.2°C during April and from 22.7 to 23°C during May while the mean minimum temperature of the outdoor environment is 8.7°C, 11.8°C and 16.1°C respectively (Table 10).

The outdoor temperature during the summer period, i.e. June to August varies from 15.4°C to a peak of 41.1°C with a mean diurnal fluctuation of 15.1°C (Fig. 18). The outdoor mean average temperature during the summer period was of 28.8°C. Only during June and July, the average temperature of all spaces falls within the comfort zone. Regarding indoor temperatures, throughout the examined seasons, indoor maximum temperatures are, to a great extent, below maximum outdoor temperatures i.e. of 9-10°C lower and with small diurnal fluctuation i.e. from 0.7 to 1.8°C in different spaces. However, due to this low fluctuation, the indoor average temperature is always higher than the corresponding outdoor one during the whole summer period ranging from 27.7-31.7°C. The highest temperatures are again recorded in south-oriented spaces, i.e. kitchen/technical room (DL_47). Specifically, the mean maximum temperature in the kitchen ranges from 29°C to 32.8°C compared to the multi-purpose area (DL_20) that ranges from 28.6°C to 31.8°C. The indoor mean minimum temperatures that appear during night-time are, to a great extent, above the mean minimum outdoor temperatures i.e. 7.4-7.6°C during June, 7.7-8.1°C during July and 8.6-8.9°C during August, above the minimum outdoor temperature. Specifically, the indoor mean minimum temperatures range from 27.4°C to 27.6°C during June, from 29.8°C to 30.2°C during July and from 30.7 to 31°C during August while the mean minimum temperature in the outdoor environment is 20°C, 22.1°C and 22.1°C respectively.

The outdoor temperature during the intermediate autumn period i.e. September to November varies from 6°C to a peak of 15°C with a mean diurnal fluctuation of 14.3°C (Figure 16). The outdoor mean average temperature during the autumn period was of 21.8°C. The highest indoor temperatures are also recorded in south-oriented spaces i.e. kitchen/technical room (DL_47). The mean average indoor temperatures in the building range from 20.2°C to 30.1°C during autumn in all spaces. The average temperature indicates that the building is within the comfort levels most of the time. The mean diurnal fluctuation in each individual space ranges from 0.5 to 2.2°C. Again, the high thermal mass masonry construction leads to indoor mean minimum temperatures during night-time above the minimum outdoor temperatures, keeping the building warmer during night. Specifically, the indoor mean minimum temperatures range from 20.1°C to 29.4°C from September to November while the mean minimum temperature in the outdoor environment ranges from 10.4°C to 19.6°C (Table 10).

The results indicate that spaces with southern orientation could provide a warmer space during a cold, sunny winter day while spaces with northern aspect could offer greater thermal stability and a cooler space during a hot, summer day.

The results of different data loggers along different heights of the room show that during the winter period the difference is negligible (0.1°C) while during the summer period, the mean difference between the lower data logger at 1.1m and the higher data logger at 2.9m is about 0.5°C. Taking into account that the building has a mean height of 4.30m, the difference is expected to be much higher at the top. This shows the positive contribution of high ceilings, keeping indoor spaces cooler during the summer (Fig.19).

#### *5.2.4.1 Temperatures evolution in the building*

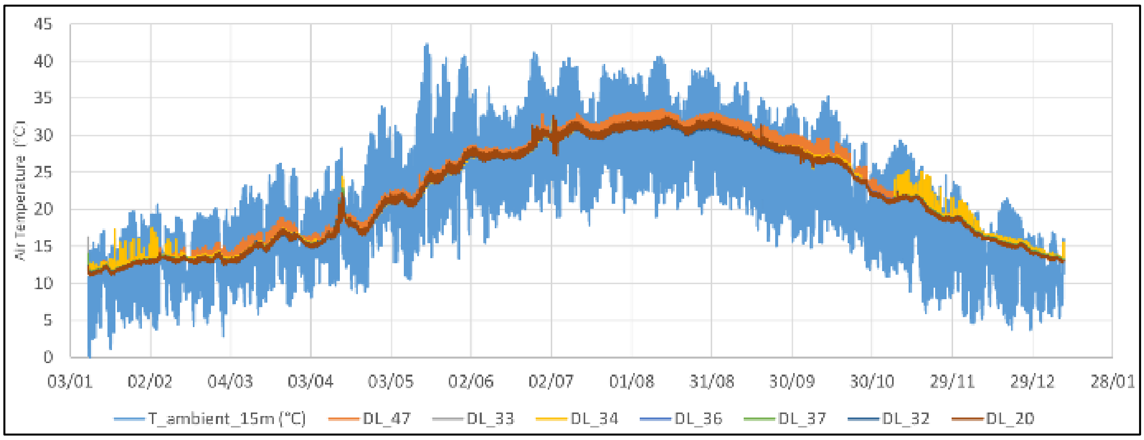



**Figure 16. Indoor temperatures evolution in the different rooms of the building and outdoor temperature**

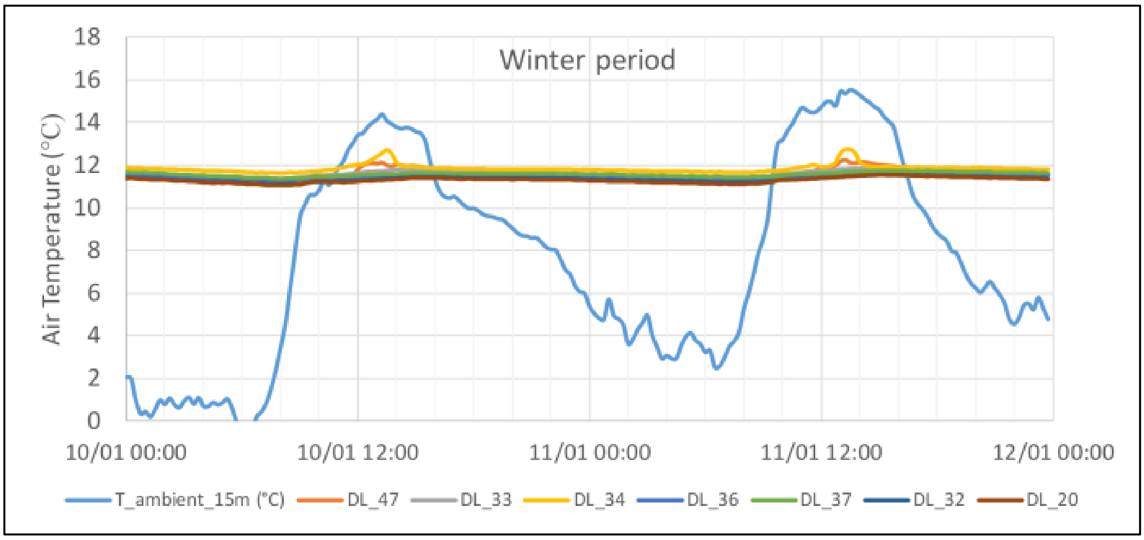



**Figure 17. Indoor temperatures evolution during the coldest week in the year**

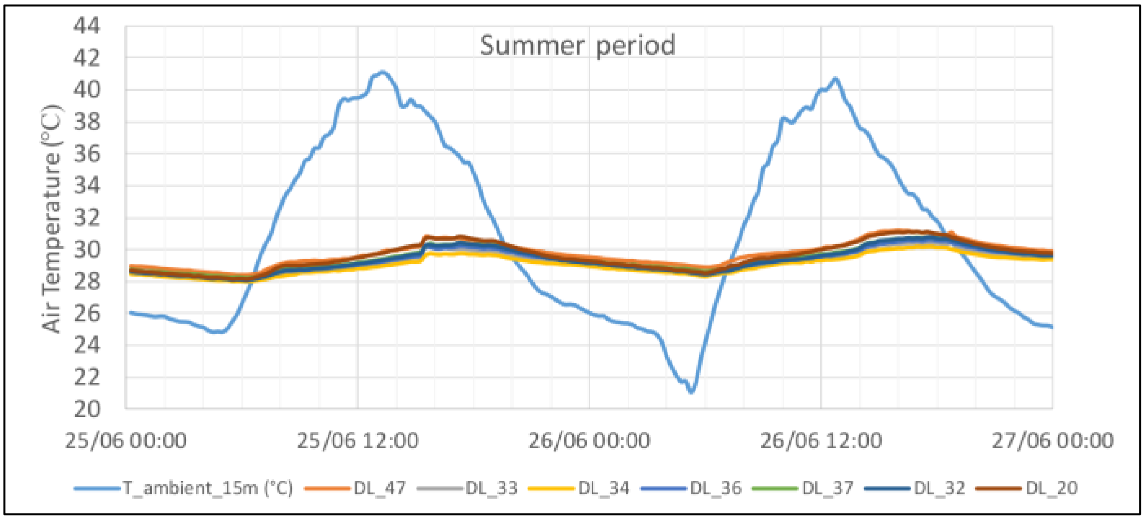



**Figure 18. Indoor temperatures evolution during the warmest week in the year**

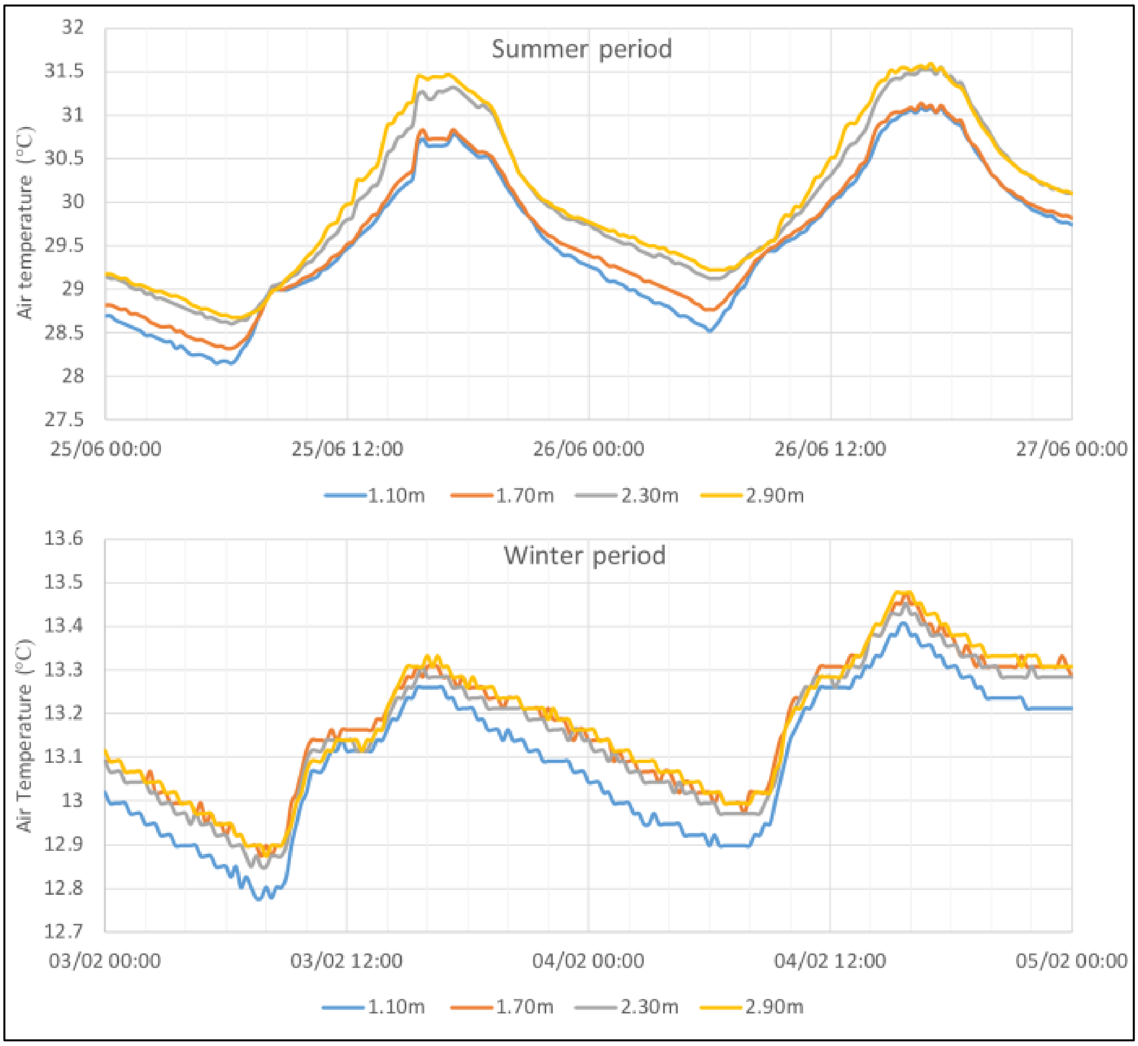



**Figure 19. Indoor temperatures evolution along different heights of the room, i.e. 1.1 m, 1.7 m, 2.3 m, 2.9 m during the winter and summer period.**

**Table 10. Synthesis table of all the recorded temperature values (°C) carried out for the investigation of thermal comfort from January to December 2019.**

| Months | Mean temp. | Outdoor | DL_47 | DL_33 | DL_34 | DL_36 | DL_37 | DL_32 | DL_20 |
|---|---|---|---|---|---|---|---|---|---|
| Jan | Min | 4.5 | 12.0 | 12.0 | 12.2 | 12.0 | 12.1 | 11.9 | **11.8** |
| | Max | 16.3 | 12.9 | 12.6 | **13.9** | 12.4 | 12.5 | 12.3 | 12.3 |
| | Average | 10.0 | 12.3 | 12.2 | 12.4 | 12.2 | 12.3 | 12.1 | 12.1 |
| | St. Dev. | 4.2 | 0.6 | 0.5 | 0.6 | 0.5 | 0.5 | 0.6 | 0.6 |
| | Diurnal flactuation | 11.8 | 1.0 | 0.6 | 1.7 | 0.3 | 0.4 | 0.4 | 0.4 |
| Feb | Min | 6.7 | 13.1 | 13.1 | 13.4 | 13.2 | 13.2 | **13.0** | **13.0** |
| | Max | 17.8 | **14.4** | 13.5 | **14.4** | 13.5 | 13.5 | 13.5 | 13.5 |
| | Average | 12.0 | 13.5 | 13.3 | 13.5 | 13.3 | 13.4 | 13.2 | 13.2 |
| | St. Dev. | 3.8 | 0.5 | 0.2 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 |
| | Diurnal flactuation | 11.1 | 1.3 | 0.5 | 1.1 | 0.3 | 0.3 | 0.5 | 0.5 |
| Mar | Min | 8.7 | 14.9 | 14.6 | 14.9 | 14.8 | 14.8 | **14.6** | 14.6 |
| | Max | 21.5 | **16.6** | 15.3 | 15.5 | 15.3 | 15.3 | 15.3 | 15.3 |
| | Average | 14.7 | 15.5 | 14.9 | 15.2 | 15.0 | 15.0 | 14.9 | 14.9 |
| | St. Dev. | 4.5 | 1.4 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| | Diurnal flactuation | 12.8 | 1.8 | 0.7 | 0.5 | 0.5 | 0.5 | 0.7 | 0.7 |
| Apr | Min | 11.8 | 17.1 | **16.9** | 17.2 | 17.1 | 17.1 | **16.9** | 17.0 |
| | Max | 24.9 | **18.7** | 17.9 | 18.1 | 18.0 | 18.1 | 18.0 | 18.0 |
| | Average | 18.1 | 17.7 | 17.4 | 17.5 | 17.4 | 17.5 | 17.4 | 17.4 |
| | St. Dev. | 5.2 | 1.7 | 1.6 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 |
| | Diurnal flactuation | 13.1 | 1.7 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.1 |
| May | Min | 16.1 | 23.0 | **22.7** | 22.8 | 22.8 | 22.9 | 22.8 | 22.9 |
| | Max | 33.9 | **24.6** | 23.7 | 23.5 | 23.7 | 23.8 | 23.8 | 24.0 |
| | Average | 24.9 | 23.7 | 23.1 | 23.1 | 23.2 | 23.3 | 23.2 | 23.4 |
| | St. Dev. | 6.7 | 2.1 | 2.0 | 2.0 | 2.0 | 2.1 | 2.1 | 2.1 |
| | Diurnal flactuation | 17.8 | 1.6 | 1.0 | 0.8 | 0.9 | 1.0 | 1.0 | 1.2 |
| Jun | Min | 20.0 | 27.6 | 27.4 | **27.4** | 27.4 | 27.5 | 27.4 | 27.5 |
| | Max | 34.8 | **29.0** | 28.3 | 28.1 | 28.3 | 28.4 | 28.4 | 28.6 |
| | Average | 27.1 | 28.2 | 27.8 | 27.7 | 27.8 | 27.9 | 27.8 | 27.9 |
| | St. Dev. | 5.0 | 1.1 | 1.1 | 1.0 | 1.2 | 1.1 | 1.1 | 1.1 |
| | Diurnal flactuation | 14.8 | 1.4 | 0.9 | 0.7 | 0.9 | 0.9 | 1.0 | 1.1 |
| Jul | Min | 22.1 | 30.2 | 30.0 | 30.0 | 29.9 | 30.0 | **29.8** | 29.9 |
| | Max | 37.1 | **32.0** | 30.9 | 30.8 | 30.9 | 31.0 | 31.1 | 31.2 |
| | Average | 29.4 | 31.0 | 30.4 | 30.3 | 30.4 | 30.4 | 30.4 | 30.5 |
| | St. Dev. | 5.1 | 0.8 | 0.5 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 |
| | Diurnal flactuation | 15.0 | 1.8 | 1.0 | 0.8 | 1.0 | 1.1 | 1.3 | 1.3 |
| Aug | Min | 22.1 | 31.0 | 30.8 | 30.9 | 30.8 | 30.8 | **30.7** | 30.9 |
| | Max | 37.5 | **32.8** | 31.4 | 31.4 | 31.5 | 31.5 | 31.6 | 31.8 |
| | Average | 29.5 | 31.7 | 31.1 | 31.1 | 31.1 | 31.2 | 31.1 | 31.2 |
| | St. Dev. | 5.0 | 0.7 | 0.3 | 0.3 | 0.4 | 0.2 | 0.4 | 0.4 |
| | Diurnal flactuation | 15.4 | 1.8 | 0.7 | 0.6 | 0.7 | 0.7 | 0.9 | 0.9 |
| Sept | Min | 19.6 | 29.4 | 29.2 | 29.3 | 29.1 | 29.1 | **29.0** | 29.2 |
| | Max | 34.0 | **31.3** | 29.7 | 29.9 | 29.7 | 29.7 | 29.7 | 30.0 |
| | Average | 26.5 | 30.1 | 29.5 | 29.5 | 29.4 | 29.4 | 29.3 | 29.5 |
| | St. Dev. | 4.7 | 1.2 | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 |
| | Diurnal flactuation | 14.4 | 1.9 | 0.5 | 0.6 | 0.6 | 0.6 | 0.7 | 0.8 |
| Oct | Min | 15.9 | 25.5 | 26.2 | 25.4 | 26.7 | 26.7 | 26.4 | **25.3** |
| | Max | 29.8 | **27.7** | 26.8 | 25.9 | 27.4 | 27.4 | 27.1 | 25.9 |
| | Average | 22.2 | 26.2 | - | 26.6 | 25.7 | 27.1 | 26.8 | 25.6 |
| | St. Dev. | 11.8 | 2.0 | - | 1.1 | 1.7 | 0.5 | 0.5 | 1.8 |
| | Diurnal flactuation | 13.8 | 2.2 | 0.7 | 0.5 | 0.7 | 0.7 | 0.7 | 0.7 |
| Nov | Min | 10.4 | 20.4 | 20.2 | 23.0 | 20.4 | 20.2 | **20.1** | 20.2 |
| | Max | 25.1 | **21.5** | 20.7 | 20.5 | 20.8 | 20.6 | 20.5 | 20.7 |
| | Average | 16.8 | 20.8 | 20.3 | 20.7 | 20.6 | 20.4 | 20.2 | 20.4 |
| | St. Dev. | 5.6 | 1.3 | 1.2 | 1.3 | 1.2 | 1.2 | 1.2 | 1.2 |
| | Diurnal flactuation | 14.8 | 1.1 | 0.4 | 2.0 | 0.3 | 0.3 | 0.3 | 0.5 |
| Dec | Min | 6.4 | 15.6 | 15.7 | 16.0 | 15.8 | 15.8 | 15.6 | **15.5** |
| | Max | 18.3 | 16.3 | 16.1 | **16.9** | 16.0 | 16.0 | 15.9 | 15.9 |
| | Average | 11.9 | 16.0 | 16.0 | 16.3 | 16.0 | 16.0 | 15.8 | 15.8 |
| | St. Dev. | 4.2 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| | Diurnal flactuation | 11.9 | 0.7 | 0.4 | 0.9 | 0.3 | 0.3 | 0.3 | 0.3 |

*Bold indicates the peak values

#### 5.2.4.2 Comfort rating in the building

The island of Cyprus has a typical Mediterranean climate featuring hot dry summers from mid-May to mid-September and rainy, rather variable, winters from November to mid-March. Summer and winter periods are intervened by short autumn and spring seasons of rapid change in weather conditions. According to the Department of Meteorology, in January and February - the coldest months of the year - mean temperatures reach 10.6°C with mean low temperature 5.2°C. In July and August - the hottest months of the year - mean temperatures reach 29.7°C while mean high temperatures reach 37.2°C. Daily temperature fluctuations range from 8 to 10°C during the cold months while they reach 16°C during the hot months. The annual mean precipitation is 342.2bmm.

Thermal comfort is assessed using the Adaptive Comfort Standard (ACS) which is incorporated in ASHRAE 55. The calculation of the ACS is based on the fact that the occupants of naturally ventilated spaces have different expectations of thermal comfort than those of technically supported indoor spaces, due to their adaptation to outdoor conditions. The Adaptive Comfort Standard was developed by de Dear & Brager, after a number of field research studies at a global scale. The acceptable indoor operative temperatures are determined during the 80% and 90% acceptability limits, calculated as a moving average of the mean daily outdoor air temperatures, using a seven-day moving average. This refers to the standard, i.e. the prevailing mean outdoor temperature (tpma(out)). In particular, the 80% acceptability limits are calculated as indicated in Eqs. (1) and (2), while the corresponding 90% acceptability limits result after subtracting1◦C from the upper 80% acceptability limit and adding 1◦C to the lower 80% acceptability limit.

$$\text{Upper 80\% acceptability limit} = 0.31t_{pma(out)} + 21.3 \quad (1)$$

$$\text{Lower 80\% acceptability limit} = 0.31t_{pma(out)} + 14.3 \quad (2)$$

It is noted that, in order to determine the acceptable thermal conditions, sedentary activities in residential spaces ranging from 1.0 to 1.3 met are taken into consideration. Moreover, typical clothing insulation for hot summer period of about 0.5 clo is expected to be used by occupants.

Depending on the external conditions, the thermal comfort zone ranges from 17.4°C-23.5°C to 24.4°C-30.5°C for 80% acceptability and from 18.4°C-24.5°C to 23.4°C-29.5°C for 90% acceptability (**¡Error! No se encuentra el origen de la referencia.**1.).

During January, February and March, the building fails to maintain indoor thermal comfort as no recorded time falls within 90% or 80% acceptability limits descripted by ASHRAE (Table 11). The maximum average temperature in the building during these three months is 15.47°C. However, it is interesting to mention that the mean minimum temperature indoor is about 7-7.5°C above the outdoor temperature. During April, the percentage within the 80% and 90% acceptability limit is only 10.3% and 3.1% of the time respectively. During May, the building is within the 80% and 90% acceptability limit for 61.7% and 52.9% of the time respectively, while during June the building achieved one of the highest percentages within the comfort zone compared to other months. Specifically, the operative temperature was within the 80% and 90% acceptability limit for 88.1% and 81.1% of the time. During July, the percentage within 80% acceptability limit drops to 46.8%. The percentage within the 90% acceptability limit drops to 4.6%. It is worth noting that the whole building fails to maintain indoor thermal comfort during August as none of the spaces exhibits temperatures within the comfort zone. However, it should be noted that although the outside temperature reaches up to about 40°C, the indoor temperature shows small temperature deviation from the acceptable limits in a range of 1 - 2.3°C difference from the 80% acceptability limit (Fig. 20). The building remained closed; therefore, the heat absorbed by the building could not be released to the outside environment leading to higher indoor temperatures. During September, the building is within the 80% and

90% acceptability limit for 50.4% and 28.6% of the time, while during October, the building is nearly all the time within the comfort zone with a percentage of 99.4% for the 80% acceptability limit. During November, the percentage is reduced to 69.8% and 60.7% for the 80% and 90% acceptability limit, while during December, the temperature falls out the comfort zone most of the time, being only 5.5% of the time within the 80% acceptability limit.

The onsite monitoring results during the winter period, and early intermediate period, show that the thermal comfort conditions of spaces are unsatisfactory and require a large amount of energy to keep indoor thermal comfort (Table 11). During the late intermediate period, and early summer period, the building provides acceptable indoor temperatures without the aid of an artificial system. However, the building requires much less energy for cooling. Specifically, the building needs 13 times less energy for cooling than for heating.

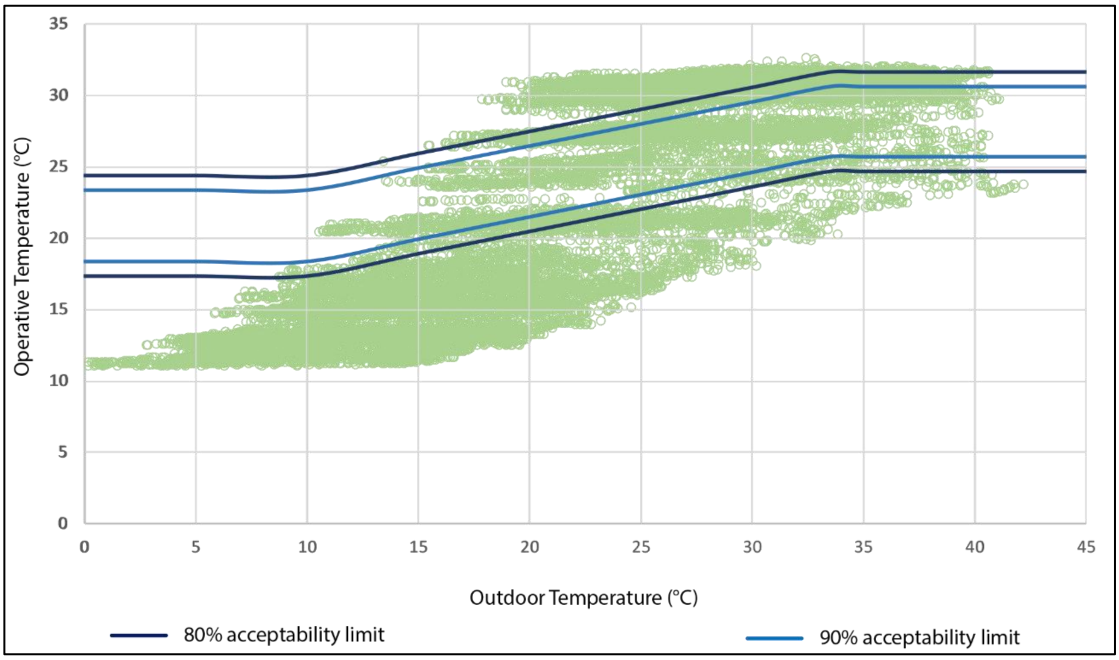



**Figure 20.** ***Brager Index of operative temperature in multi-operation area of the building*** **(DL_20)** ***from Jan. to Dec. 2019.***

**Table 11. Percentage of data within thermal comfort zone for the 80% and 90% acceptability limit and degree hours**

| | % of data within thermal comfort zone | | Degree hours | |
|---|---|---|---|---|
| | **80% acceptability** | **90% acceptability** | **heating** | **cooling** |
| **Jan.** | 0.0% | 0.0% | 2942.6 | 0.0 |
| **Feb.** | 0.0% | 0.0% | 3330.6 | 0.0 |
| **Mar.** | 0.0% | 0.0% | 3045.9 | 0.0 |
| **Apr.** | 10.3% | 3.1% | 1774.0 | 0.0 |
| **May** | 61.7% | 52.9% | 313.1 | 0.0 |
| **Jun.** | 88.1% | 81.1% | 0.0 | 25.0 |
| **Jul.** | 46.8% | 4.6% | 0.0 | 139.9 |

| | | | | |
|---|---|---|---|---|
| **Aug.** | 0.0% | 0.0% | 0.0 | 515.9 |
| **Sept.** | 50.4% | 28.6% | 0.0 | 314.7 |
| **Oct.** | 99.4% | 79.0% | 0.0 | 0.2 |
| **Nov.** | 69.8% | 60.7% | 157.1 | 0.0 |
| **Dec.** | 5.5% | 0.0% | 1687.8 | 0.0 |
| **Total** | | | 13251.0 | 995.7 |

The recorded data for relative humidity show that for most of the time (from May to December) the building totally meets the norms with values between 40-70%. During February and March, the building exhibits higher relative humidity due to lower indoor temperatures having only 20-30% of the data between acceptable limits (Table 12).

**Table 12. Summary of registered RH values throughout the year**

| | **Absolute values RH (%)** | | | **% of data in which RH=40-70%** |
|---|---|---|---|---|
| | **max** | **min** | **mean** | |
| **Jan** | 72.1 | 55.8 | 67.9 | 79 |
| **Feb.** | 76.8 | 64.3 | 71.6 | 21 |
| **Mar.** | 77.8 | 54.1 | 71.1 | 26 |
| **Apr.** | 79.2 | 53.6 | 69.3 | 54 |
| **May** | 79.2 | 53.6 | 69.3 | 100 |
| **Jun.** | 71.3 | 43 | 59.6 | 100 |
| **Jul.** | 61.8 | 44.1 | 54.1 | 100 |
| **Aug.** | 64.5 | 43.8 | 56.6 | 100 |
| **Sep.** | 63.5 | 39.8 | 56.8 | 100 |
| **Oct.** | 65 | 47.7 | 58.8 | 100 |
| **Nov.** | 66.8 | 52.4 | 61.1 | 100 |
| **Dec.** | 70.0 | 50.5 | 64.6 | 100 |

For the improvement of thermal comfort and energy performance, passive measures should be considered during the normal operation of the building. Based on the bioclimatic chart (**¡Error! No se encuentra el origen de la referencia.**), during the heating period, i.e. from November to April, passive solar systems and internal gains are required. During the intermediate period, i.e. October and May, the temperatures are mild and overlap the comfort zone for the greatest part of the day. During the cooling period, i.e. from June to September, a number of cooling strategies is proposed. June and September fall partially within comfort zone limits, whereas July and August exceed the upper comfort zone limits, maintaining high levels of temperature and relative humidity. The appropriate passive cooling design strategies are ventilation, night ventilation and evaporative cooling. Daytime ventilation should be carefully applied and restricted to the periods of the day when the exterior temperature is lower compared to the interior temperature.

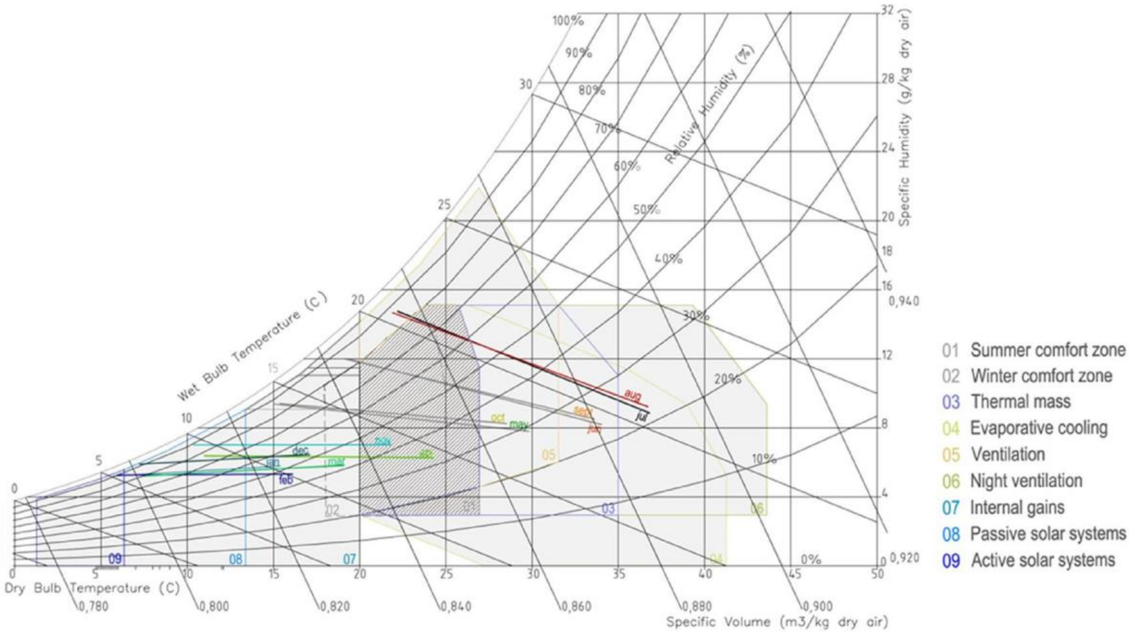



Figure 21. Plotting the Aglantzia's Weather Data_Givoni's chart

## 5.3 Bordeaux, Offices building (Talence, France)

### 5.3.1 Building analysis

#### *5.3.1.1 Site context and data*

Table 12. summarises the main features of the demo.

Table 12. Main features of the French demo site

| Main features | Description |
|---|---|
| Address | Talence 33400 - France |
| Current use of building | Office and experimental workshop, with a zone close to residential use |
| Surface | 100 m² (area related to HYBUILD project) / 600 m² total |
| Number of floors | 2 |
| PV installation location | Roof |
| Hybuild system in the site | Continental system |
| Owner of the building | ENSAM / CAMPUS |
| Occupancy | NBK / INEF4 |

| | |
|---|---|
| Building plans (floor plans, electrical network, ventilation network…) | See the descriptive of demo sites |
| Date of construction | 1960 |

#### 5.3.1.2 Main equipment existing in the building before the project

The building is on a campus and its heating system depends on the district heating system that is described below. The building is mainly supplied by the small district heating network. It is currently equipped with high temperature radiators that are fed with hot water coming from the district heating. They don’t have a thermostatic valve, and therefore, ambient temperature is controlled by the users. There is no cooling system. As the indoor temperatures are very high during the summer season, the discomfort is a big problem for the building users. Therefore, many fans are running nonstop during this period.

As the building has construction systems that do not allow good energy performances, the indoor winter temperature is quite low and users are complaining that the indoor temperatures are below comfort temperature.

Table 13. Main equipment on the French demo site

| | Equipment | Energy used | Comments and possibilities of monitoring |
|---|---|---|---|
| **Heating** | Gas boiler for Heating & DHW (heat network) | Gas | No gas meter present in the site |
| **Cooling** | No cooling system | --- | --- |
| **DHW** | Gas boiler for Heating & DHW (heat network) | Gas | No meters available neither for the energy nor for the DHW |
| **Ventilation** | Dual flow air handling unit | Electricity | No equipment |
| **Outdoor conditions** | --- | --- | Wireless weather station (problem of data loss in cloudy days). |

### *5.3.1.3 Main monitoring equipment installed for pre intervention*

To measure the energy consumption for space heating in the building, one flow meter is installed in the return pipe to measures the volume of 'Hot water' (V) and two temperature sensors are installed in the flow and return pipes to calculate the temperature difference (dT) (Figure 22).

$$\text{Heat Energy [kWh]} = V \times dT \times K^{*}$$

$^{*}$K: Thermal coefficient of the 'Hot Water'

**Figure 22. the temperature sensors (PT100) and the flowmeter to measure the energy consumption for heating**

A water meter (Figure 22) is installed to measure the volume of 'Hot water' [$m^3$], the energy consumption for the DHW is measured by the mean of an energy meter.


**Figure 23. Water consumption meter**

For the indoor comfort, one HOBO Temperature/Relative Humidity/Light/External Data Loggers is installed in each office in the first floor, one other datalogger is installed in the ground floor. The temperature and relative humidity sensors installed at 1.5 m of height from the floor, far enough from heat emitters and openings (doors, windows). Figure 24 shows the location of Hobo sensors in the ground floor and the 1st floor.

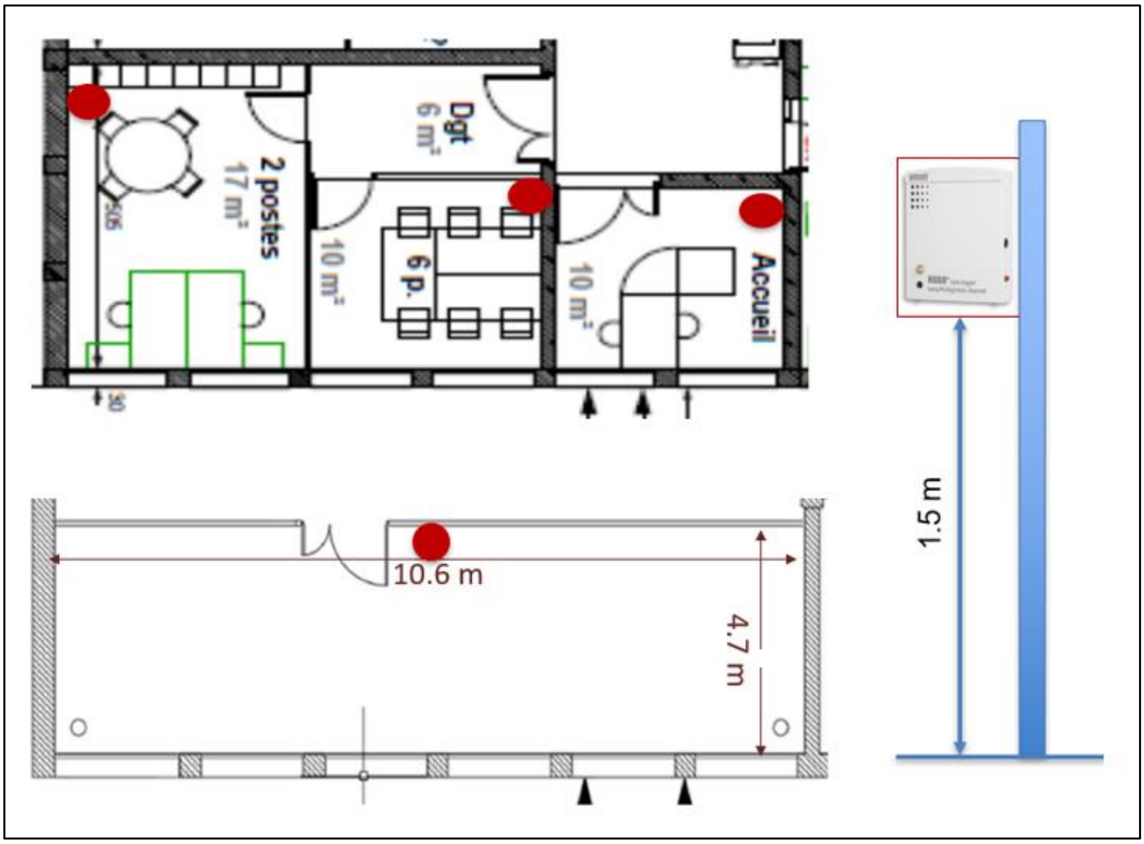



Figure 24. Location of hobos in the 1st floor (top), and in the ground floor (bottom)


Figure 25. Hobo sensor installed in the office to measure temperature and relative humidity

Figure 26. Weather station & pyranometer installed on the roof of the building.

For outdoor conditions measurements, the old wireless weather station installed on the roof of the building had a problem of data transmission. It was replaced by a wired weather station from DAVIS instruments. It measures the outdoor temperature, RH, wind speed and direction. A horizontal pyranometer (KIPP & ZONES) is also installed beside the weather station to measure the global irradiation (Figure 26).

#### 5.3.1.4 Monitoring period

The monitoring devices are installed in July 2018, one-year monitoring data is available and used for this study.

### 5.3.2 Data collected

The Hobos have an internal memory storage, they can store data for 3 months. A manual collection of data is needed to empty the internal memory. All other sensors are connected to the server of Nobatek/INEF4 by the mean of a datalogger connected to Nobatek/INEF4's network.

**Table 14. Data collected during the Pre-intervention period. All date acquisition is done with a 10 minutes time step for all sensors.**

| Data point | Device | Units | rate (min) | Data available |
|---|---|---|---|---|
| Outdoor Temperature | Weather station | °C | 10 | From 01/07/2018 Until now |
| Relative humidity outdoor | Weather station | %RH | 10 | |
| Wind speed | Weather station | m/s | 10 | |
| Wind direction | Weather station | degrees | 10 | |
| Global irradiation | Weather station | $W/m^2$ | 10 | |
| Energy consumption / DHW | Energy meter | kWh | 10 | |
| Energy consumption / Heating | Energy meter | kWh | 10 | |
| Domestic hot water / Volume | Water meter | $m^3$ | Daily | |
| Indoor temperature | HOBO | °C | 15 | |
| Indoor HR% | HOBO | % | 15 | |

### 5.3.3 Energy consumption analysis

The following table summarises the annual energy consumptions for heating, cooling, DHW, Energy/HDD, Energy/L and for DHW.

These values are based on the real needs of the building in kWh. Since there is no gas meter for the gas consumption in our building, the gas consumption was calculated using the following hypothesis:

- One $m^3$ of natural gas contains 11.8 kWh.
- Efficiency of gas boiler is 85%.
- Efficiency of district network is 95%.

**Table 15. Estimation of gas consumption**

| ALMATRET | Annual Gas consumptions for heating | | Energy / HDD | Annual Gas consumption for DHW | | DHW Consumption | Energy/L |
|---|---|---|---|---|---|---|---|
| **Unite** | kWh | M3 | kWh/HDD | kWh | M3 | Litre | Wh/l |
| **2018-19** | 6257 | 627.5 | 3.89 | 1761 | 176.6 | 34.633 | 50.85 |

### 5.3.3.1 *Analysis of heating needs*

The heating needs are calculated based on water flows and flow and return temperature (of the heating and cooling loop). The values of specific thermal capacity and density are considered as constant whatever the fluid temperature is.

$$P = \dot{m}_{eg} \times \rho_{eg} \times Cp_{eg} \times (Td_{eg} - Tr_{eg})$$

with $P$ as the power in [J/s], $\dot{m}_{eg}$ [l/h] as the flow in the heating and cooling loop, $\rho_{eg}$ [kg/m3] the density of water, $Cp_{eg}$ [J/kg.K] the mass thermal capacity of the fluid mix, $Td_{eg}$ and $Tr_{eg}$ the temperature of the flow and return fluid loop.

### 5.3.3.2 *Study of the building heating demand*

Figure 26 shows the heating demand of the building during the measurements period. It covers the October 2018 to April 2019 period. Figure 27 shows those results for a weekly time step.

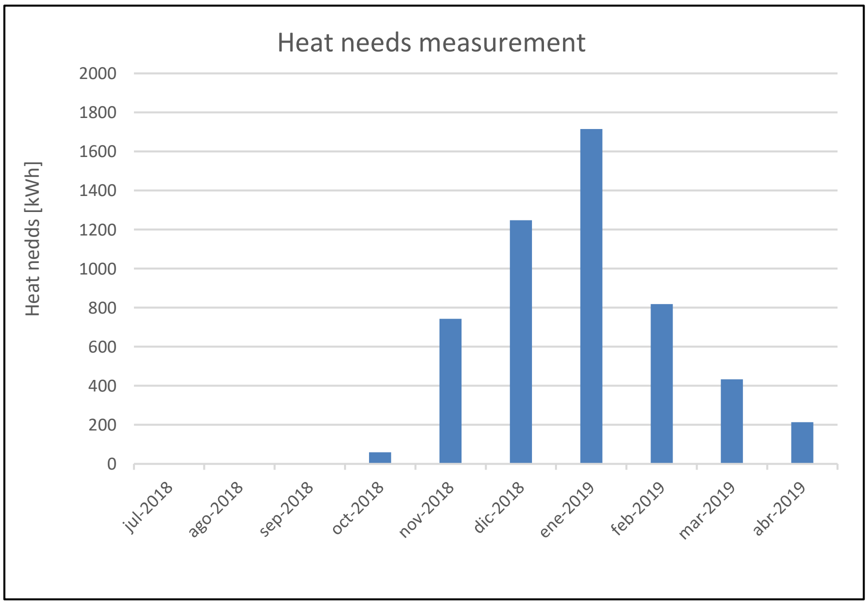



**Figure 27.** ***Monthly distribution of the heating demand***

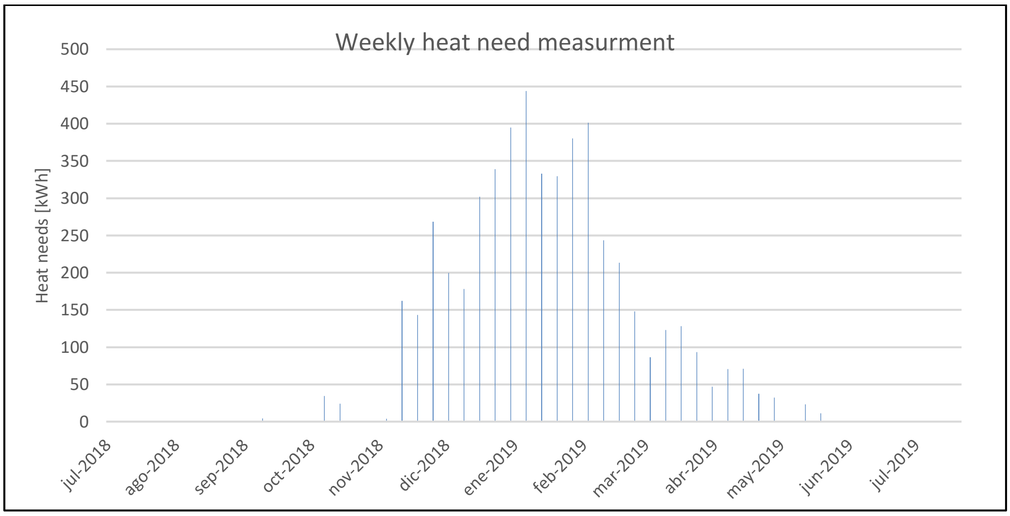



**Figure 28.** ***Weekly distribution of the heating demand***

Figure 28 shows the heating power needed for the building during an average day in wintertime. The calculation is carried out with a 10 min time step.

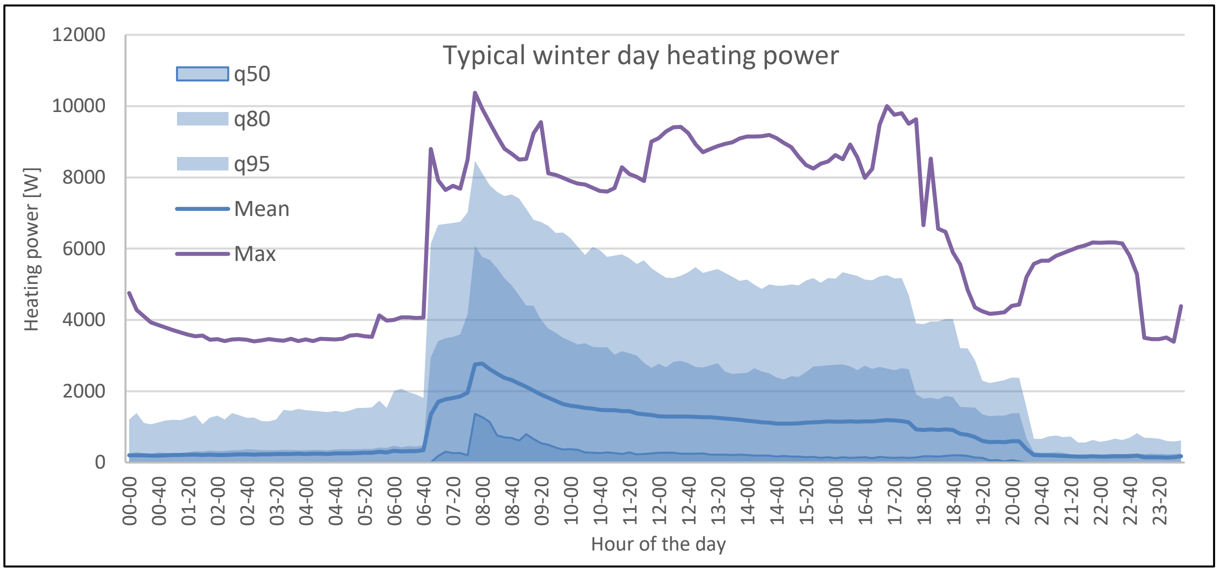



**Figure 29.** ***Heating power during a typical winter day***

The blue curb shows the average power required by the fan coils to maintain the set temperature in the corresponding areas. The yellow curb indicates the maximal power reached at each moment during the year. The light to dark blue surfaces shows the 50%, 80% and 95% quantiles. For each X quantile, the power is lesser or equal to the surface values X% of the time.

We observe a power demand peak at 7.00 am, when heating is starting. The needed power then decreases until reaching a nearly constant value. It is a stage corresponding to the conservation of the set temperature. Finally, the demand decreases strongly around 8.00 pm, when the set temperature changes form “comfort” to “reduced” mode.

The observation of the figure shows that the maximum power needed is about 10kW. A value of 8 kW is enough to satisfy the needs 95% of the time, and 6 kW 80% of the time. Finally, 50% of the time 2 kW is sufficient to satisfy the needs (between two seasons most probably).

The next figure shows similar results with a 1h time step.

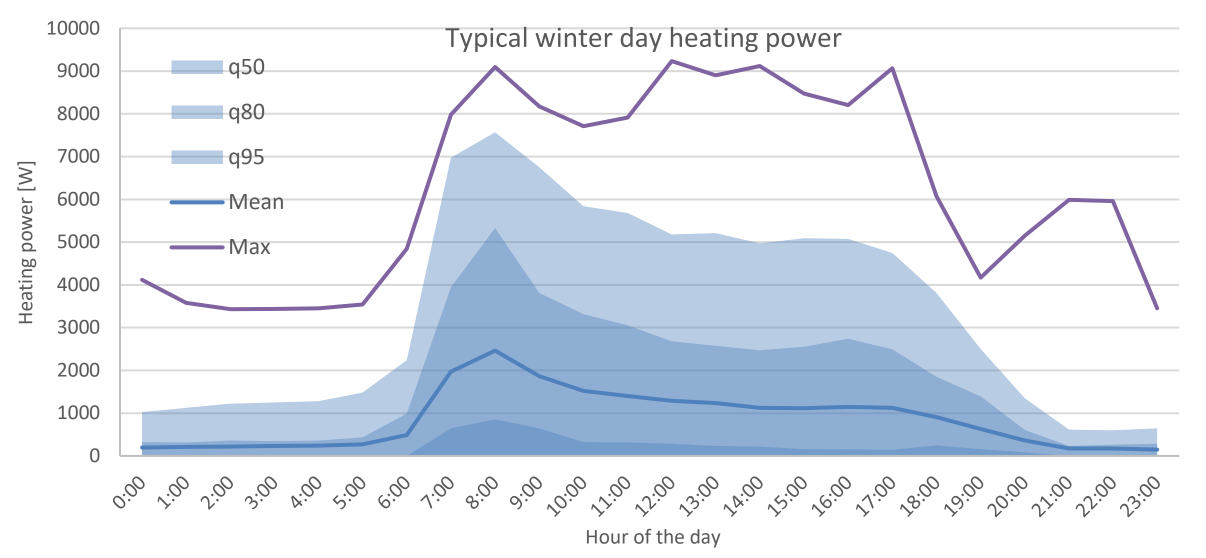



Figure 30. Heating power for a typical winter day

Figure 30 shows the evolution of the heating power and the outside/inside temperatures during the coldest week. That week is identified thanks to an HDD calculation: for every week, the sum of the differences hour by hour between 19°C and the outdoor temperature is calculated. The week which cumulates more HDD is considered as the coldest week. In our case this is the second week of January 2019. It corresponds to the week with the highest heating needs.

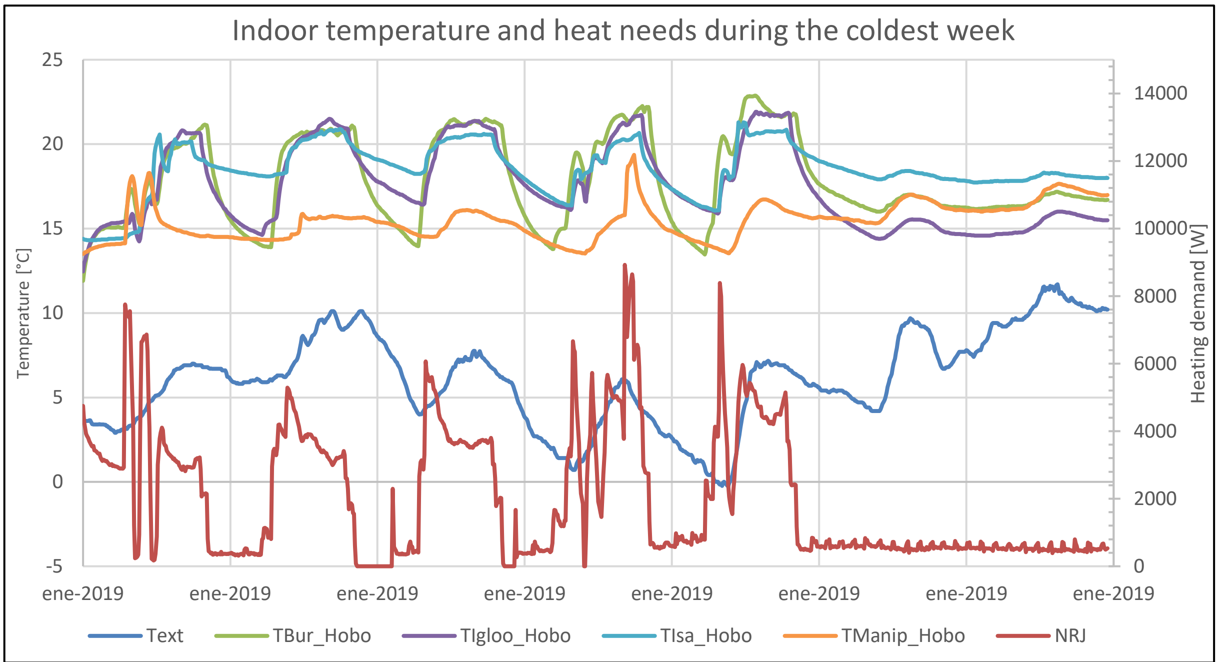



Figure 31. Coldest week / evolution of the temperature and the heating power

The observation of temperature in the different zones shows that the office or meeting rooms areas are heated at a temperature higher than 20°C during the hours with occupancy. Out of occupancy (night and weekends), the temperature decreases until 15°C, the lower set temperature. The speed of this decrease in temperature varies depending on the considered area. During that week the workshop area is maintained at the lower set temperature, 15°C, except on Wednesday afternoon when the comfort higher set temperature is programmed.

The observation of the heating power shows peaks during the reactivation of heating at the start of the day. These peaks can reach 9kW. The highest peak. The highest peak happens when the set temperature of the workshop is increased to 21°C.

Out of occupancy, a “residual” heating power of 1 kW is observed. It is necessary to keep the area at an acceptable reduced set temperature.

Figure 31 presents the evolution of the measurements during the week when the heating power peak is reached.

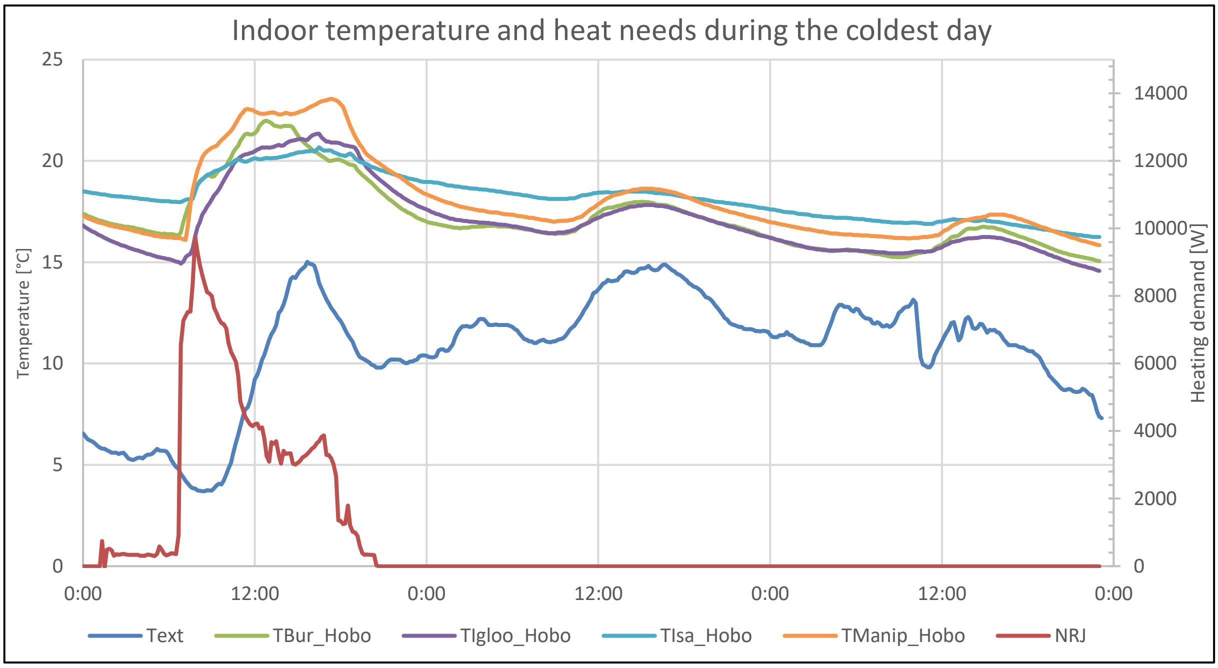



**Figure 32.** ***Day with the heating power peak / evolution of the temperature and heating power***

The highest heating measured peak happens on Friday 8 February 2019, when the external temperature is low (5°C) and when the set temperature passes from 15°C to 21°C for all the areas.

Similarly to the previously observed week, the system seems to face difficulties to heat the office on Monday morning when the outdoor temperature is low. We observe power variations, and the set temperature is only reached by the end of the day. These phenomena may be due to a problem with current installation.

Figure 32 shows the evolution of the measurements during the coldest day.

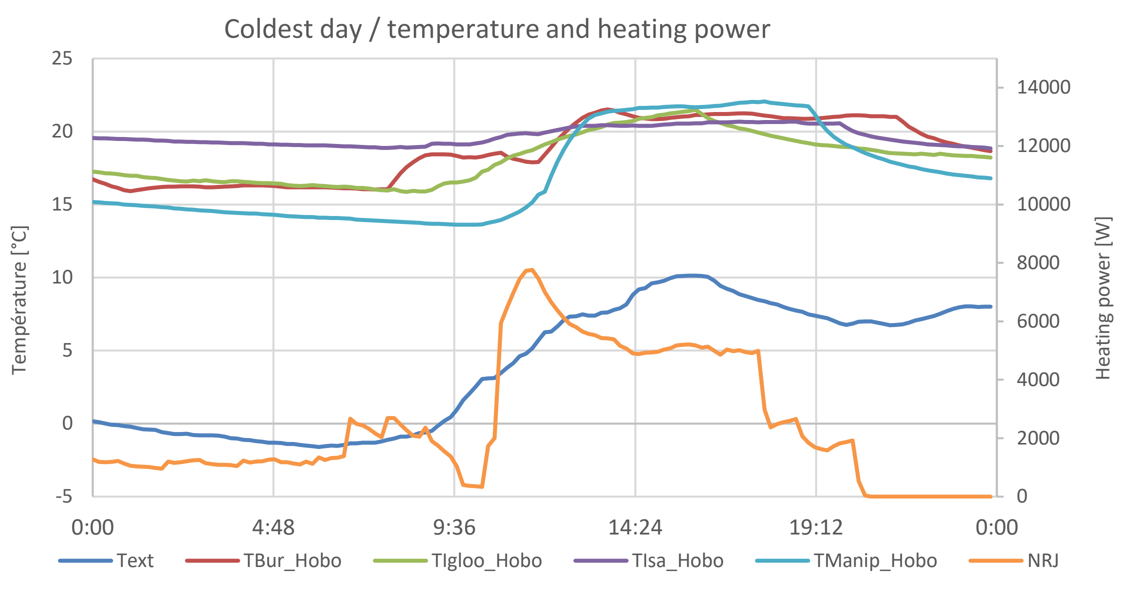



**Figure 33.** ***Coldest day/ evolution of the temperature and the heating power***

This graph presents a reasonable evolution of the measured variables. However, it is possible to observe that the "comfort" set temperature is activated earlier in the office area, which creates power load around 7:00 am. The second most important power peak happens around 11:50 am, when all the other areas change to "comfort" mode.

### *5.3.3.3 Modelling, energy signature of the building*

Based on the measured information, it is possible to build a static thermal model of the building. It is linear and does not consider the dynamic behaviour of the building. This type of model, called "energy signature" [4] has been proposed in this case.

Figure 33 shows the results of the modelling of the Talence building.

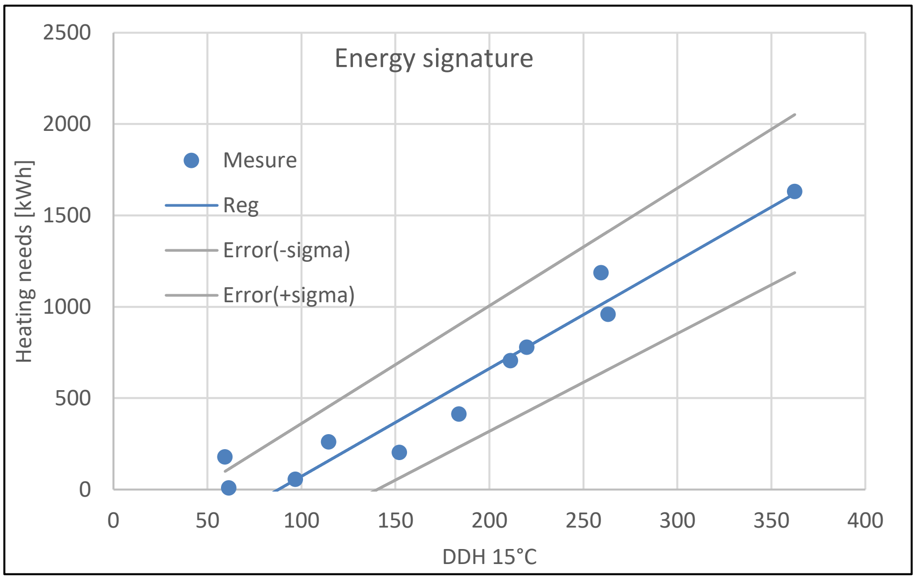



**Figure 34. Estimation of the heating demand of the building and energy signature**

The comparison between measurements and calculated values is presented in Figure 34.

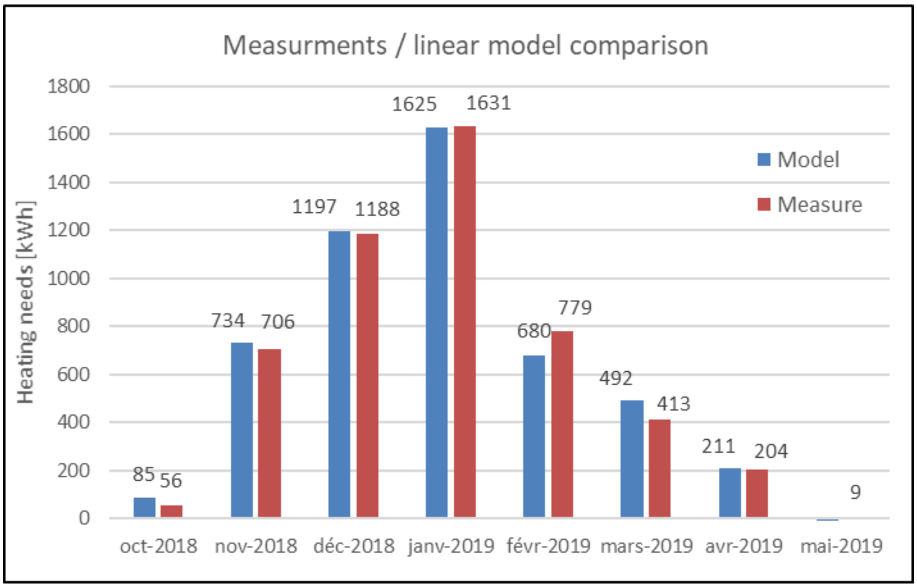



Figure 35. Estimation of heating needs, and energy signature of the building.

A Mean Average Error (MAE) of 38 kWh is obtained, that is 6% of the average monthly consumption. The coefficient of determination $R^2$ is 0.99, thus we consider that the calibration of the model is precise and reliable. Please pay attention that this result is not about the precision of the prediction! The number of training data is not sufficient to carry out an evaluation as regards this aspect.

#### *5.3.3.4 DHW Consumption*

Figures 35 and 36 show the monthly and weekly needs in kWh, to ensure the DHW production.

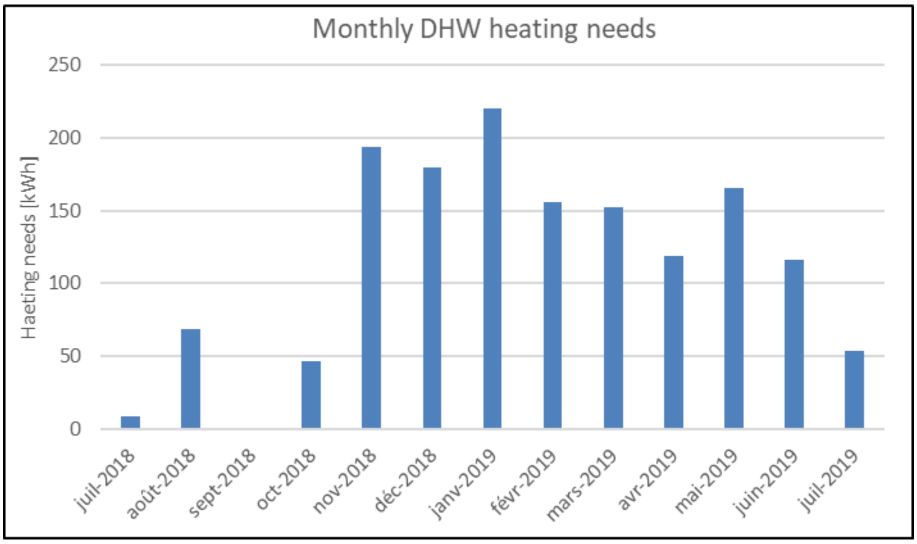



Figure 36. Monthly distribution of the DHW energy demand

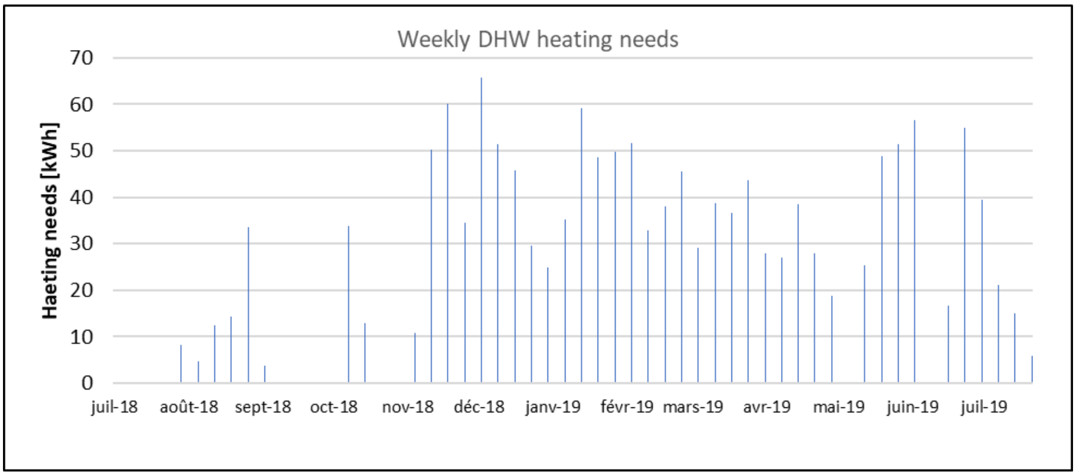



Figure 37. Weekly distribution of the DHW energy needs

For the considered period, the energy demand for DHW production is 2127 kWh, which correspond to a DHW annual need of around 1500 kWh.

The absence of observed consumption during September 2018 seems due to measurement errors. Please note that the energy needs fluctuate depending on the considered month. It seems higher during the winter period. It is very low during July and August, which correspond to the summer holiday period in France.

Figure 37 proposes a distribution of the heating power for DHW production during the day.

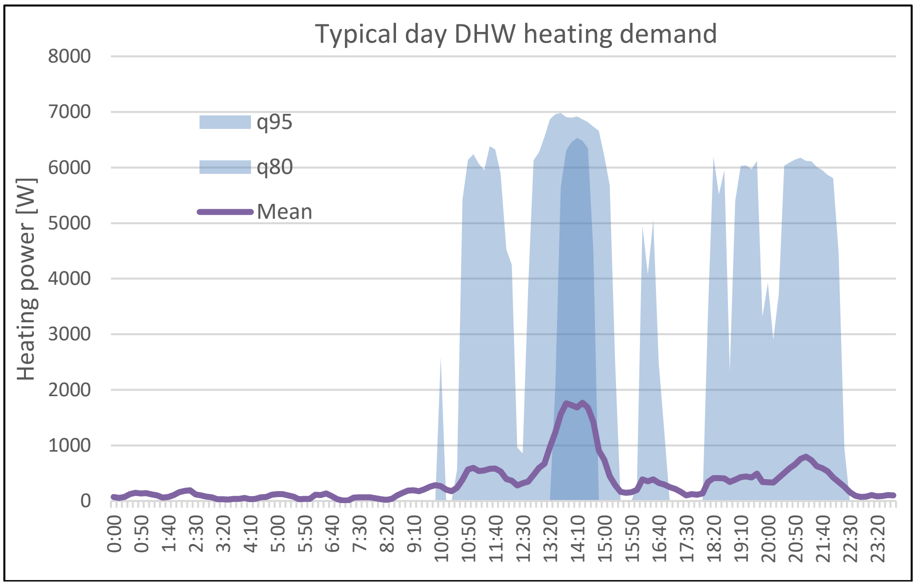



Figure 38. Distribution of the power for DHW production

The previous figure indicates that in 80% of the cases, the DHW production is carried out between 1:00pm and 3:00pm (when the demand for space heating is the lowest). However, in 20% of the cases the production can start at 10:30am, and finish by 5:00pm. During some days, DHW is heated during the evening (from 6:00pm to 11:00pm). The hours of DHW production can happen out of the hours of occupancy of the building.

As concerns the DHW heating power, in 95% of the cases, it is lower than 7 kW.

The DHW consumption measurements have been done starting from July 2018. Over the 217 measured days, the average daily DHW consumption is 159 l/day, it varies strongly with a standard deviation of 98 l. For 75% of the days, it is lower than 218 l. The maximum consumption over 1 day is 543 l.

Figure 38 shows the DHW consumptions, month by month.

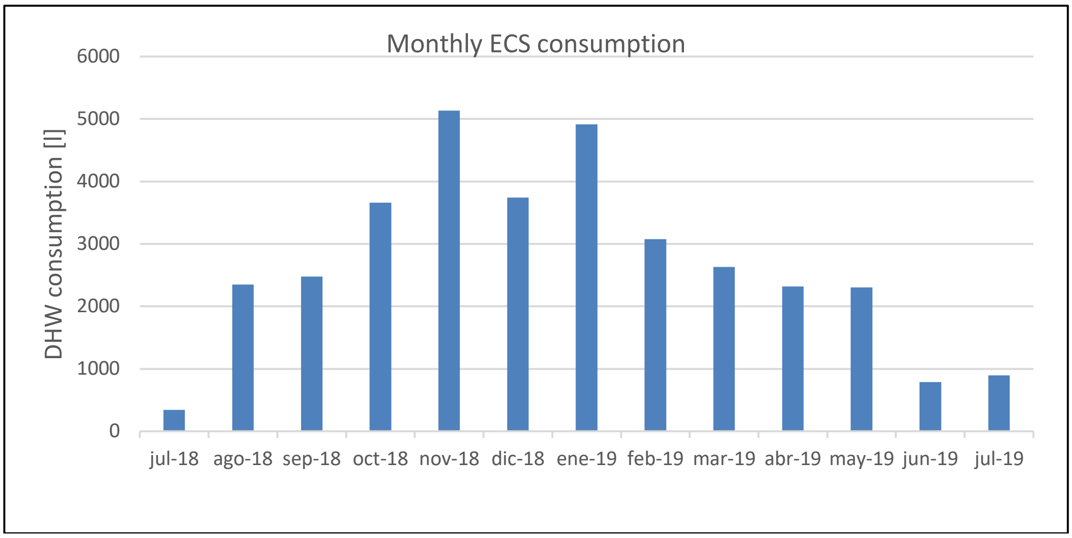



Figure 39. Monthly DHW consumption

#### 5.3.3.5 Summer comfort conditions

Figure 39 shows the evolution of the air temperature in the monitored zones as well as outside the building during the warmest week. The outdoor temperature reaches 36°C on Monday. This day, except the experimental zone, the temperature does not reach 35°C. During the week, the outdoor temperature decreases (it stays below 30°C), but the indoor temperature is still very high. These observations can be due to the heavy concrete structure of the building, which can store an elevated amount of energy. A night-time ventilation strategy could help mitigating this effect.

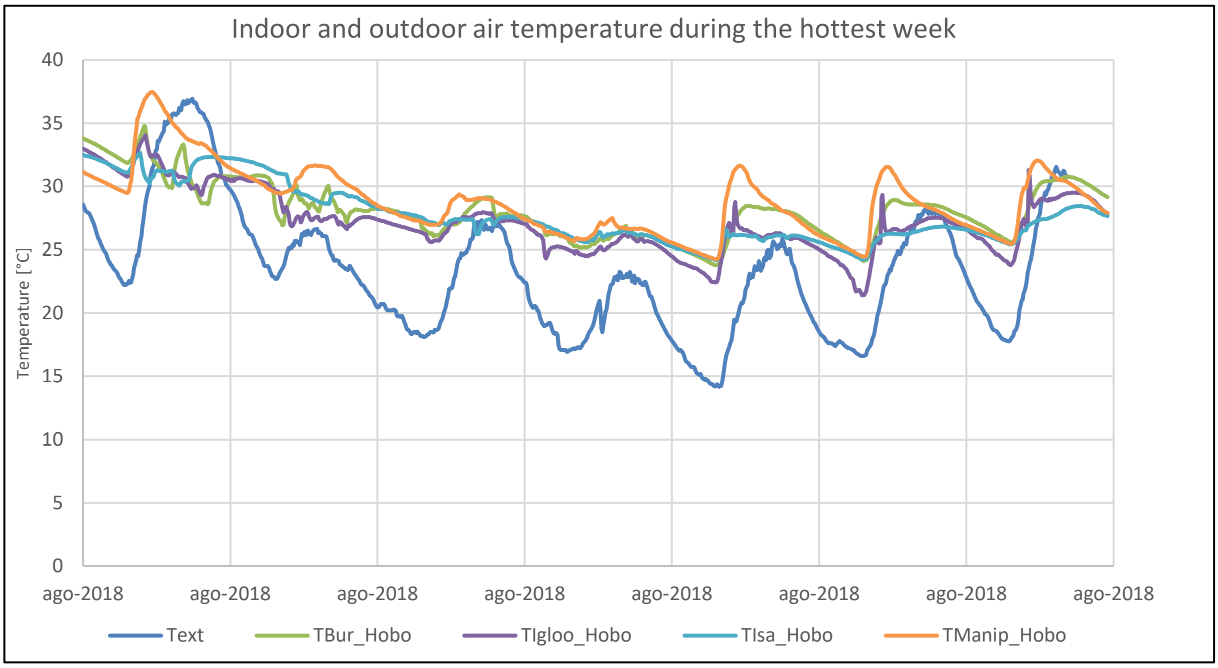



**Figure 40.** ***Temperature evolution during the hottest week***

#### 5.3.3.6 Comfort study as refers to Givoni

The hygrothermal comfort areas according to Givoni [3] have been developed in 1998. The objective is to offer passive thermal comfort during summer, for buildings which do not integrate any active cooling system. This method implies the assumption that the user has an appropriate clothing (typical of summer conditions) and can modify the thermal environment by controlling the air speed (fan).

Figures 40 to 43 show the projections of "indoor temperature / relative humidity" couples, as measured by HOBO in every room.

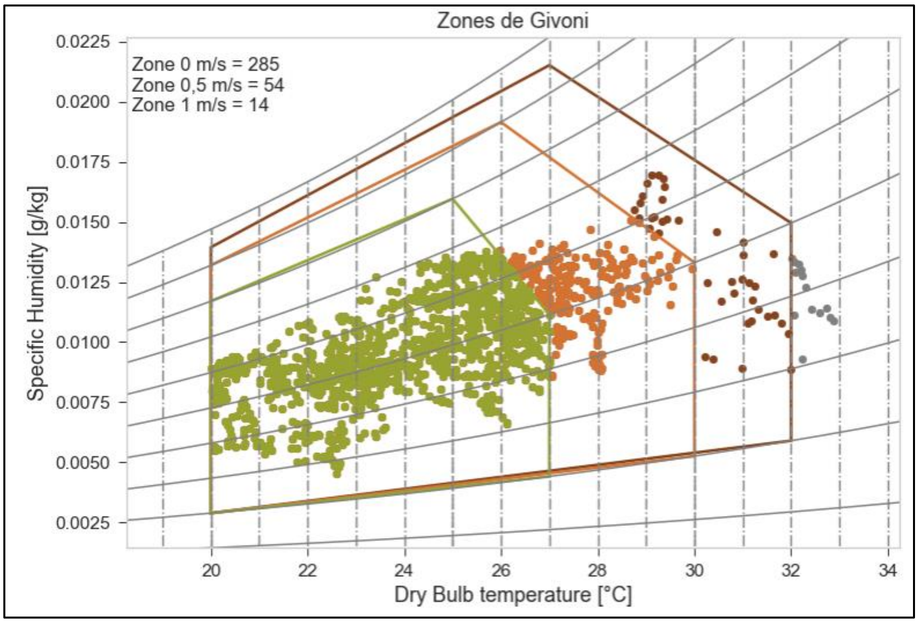



**Figure 41.** ***North office, Givoni zone***

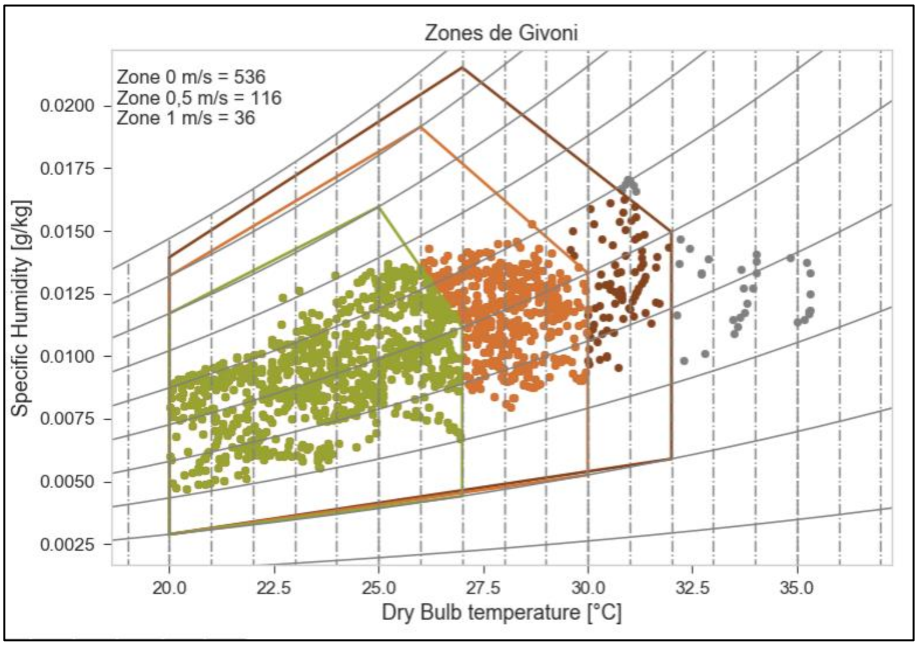



**Figure 42.** ***South office, Givoni zone***

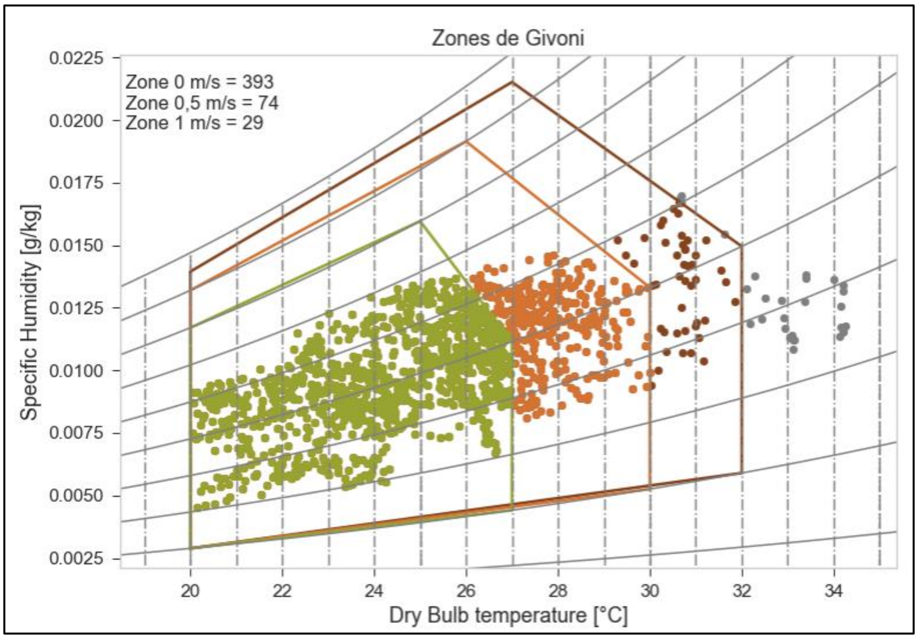



**Figure 43.** ***Meeting room, Givoni zone***

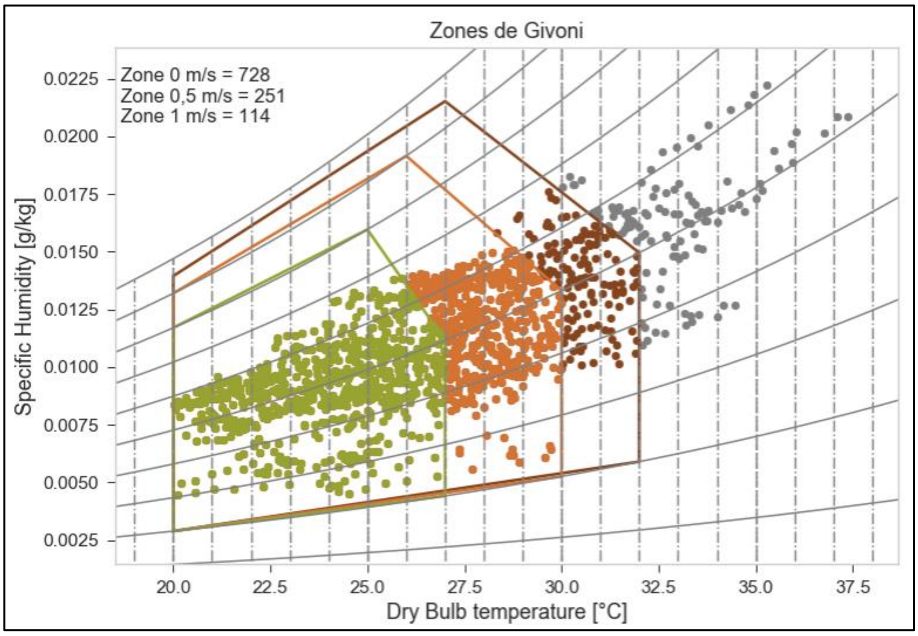



**Figure 44.** ***Workshop, Givoni zone***

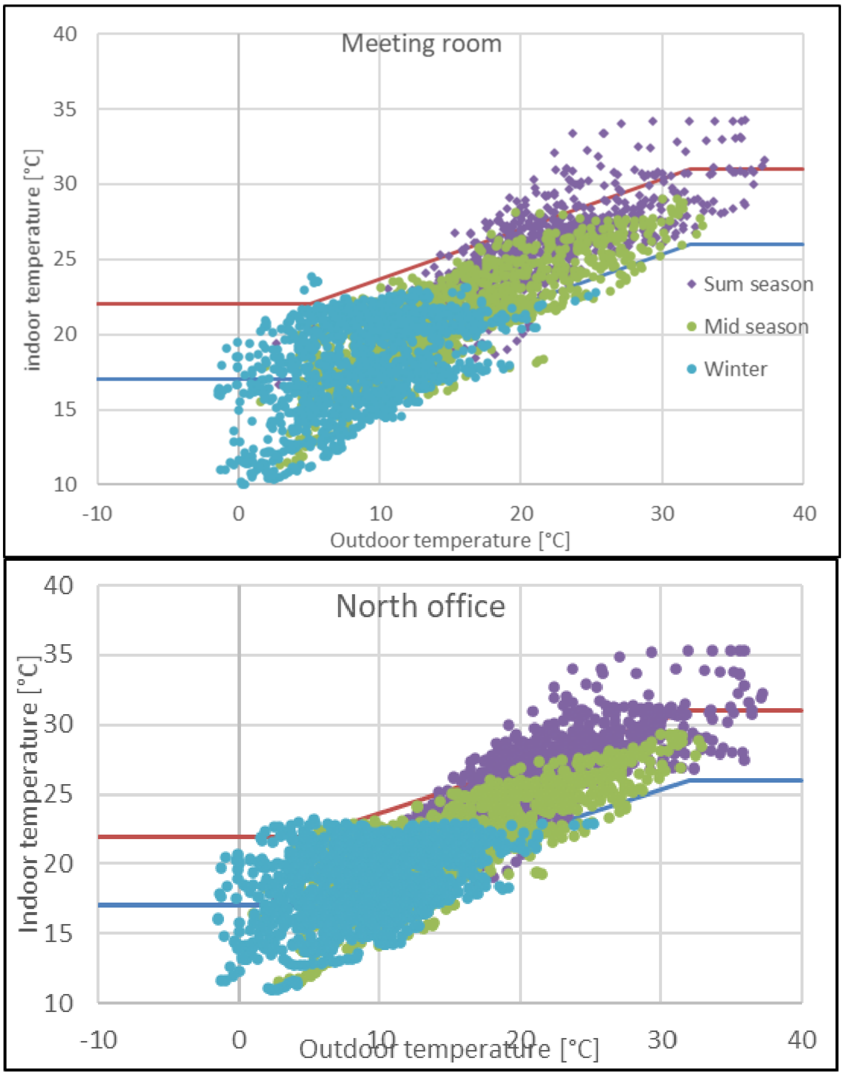
Whatever the considered area, these figures show a high risk about comfort in the building. The relative humidity level is contained, but the indoor temperature reaches values well beyond the comfort zones. Even if considering the use of individual fans, the users will have a difficult time to get thermal comfort sensation.

#### 5.3.3.7 Comfort rating in the building

Figure 47 shows the same behaviour concerning thermal comfort. During winter, a step in air temperatures can be seen at 21°C. It corresponds to the heating set point. Temperature below comfort zone correspond to the transient phases when the heating systems turned on, but air temperature did not reach comfort temperature.

With the exception of the experimental zone, most of the temperatures during the mid-season are in the comfort zone.

During the summer, in each room, the indoor temperature overshoots the comfort zone during many hours. It shows that despite the solar screens that reduce the amount of solar gain, high indoor temperatures are a major concern. The building would need active cooling solution to maintain thermal comfort during the hot season.



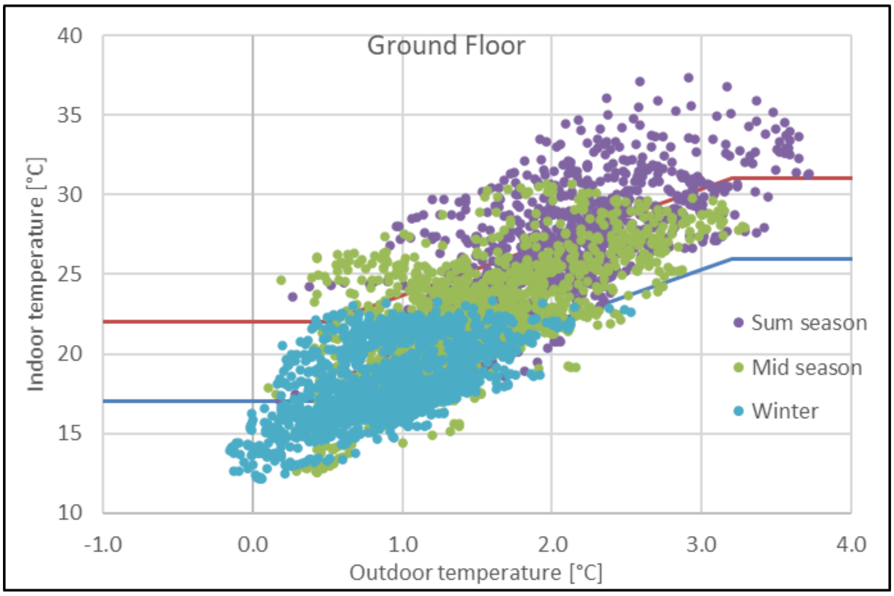



**Figure 45. Brager representation for the 3 areas of the French demo site**

## 5.4 Langenwang Office, storage and workshop building (Austria)

## 5.4.1 Building analysis

### *5.4.1.1 Site context and data*

Table 16 Main features if the demo sitesummarises the main features of the demonstration site.

**Table 16 Main features if the demo site**

| Main features | Description |
| --- | --- |
| Address | LANGENWANGT - Austria |
| Current use of building | Office, storage and workshop |
| Surface | 1000 m²total, relevant office section: 180m² |
| Number of floors | 1 |
| PV installation location | Roof of Production-hall |
| Hybuild system in the site | Continental system |
| Owner of the building | PINK |
| Occupancy | PINK |
| Building plans (floor plans, electrical network, ventilation network…) | Cf the description of the demo sites |
| Date of construction | 1960 |

### *5.4.1.2 Main equipment existing in the building before the project*

- **Building location & use**

Located close to the Semmering mountain at the eastern end of the Alps within the valley of the river Mürz, the edifice is an old building built around 1960s where no retrofitting operation has ever been carried out. A retrofit of the office section has been planned within 2020 with the objective of integrating recent technologies and to use it as a demonstration building. The building's area considered in the HYBUILD project is 180 m $^2$.

The studied building zone is used as offices (single and plan offices) and a meeting room. Though the use of this building is not residential, it has the advantage to be linked with the local biomass district heating. It does have DHW consumption as there is a changing room for the workers with showers. This changing room is located in a section of the building which is too far away to be directly connected with the pilot system.

However, within the retrofit actions it is planned to add a changing room with washing facilities near the toilets and social room of the office area, to benefit from real DHW consumption on the demonstrator.

- **Existing construction system**

As an old building, the existing construction systems offer poor thermal performances. The building does not integrate any insulation of the envelope (neither in the walls, nor the ceiling).

The ceiling is a partly plain, partly (60,91m $^2$) dropped ceiling (the total height is 2.9 m and the height under the dropped ceiling is 2,75 m).

- The floor is made of concrete with a 3cm XPS insulation layer, 2,5cm wooden chipboard and cover-layer.
- The envelope is made of concrete (the wall is 30 cm thick).
- The internal partitions are either concrete walls (20 cm thick) or plaster panels (10 cm thick).
- The windows are double glazing windows with PVC frame. The total surface area covered with windows and doors to ambient is 61,87m $^2$.
- The air tightness is poor.

- **Site plan**

The building location is visible in Figure 46 and Figure 47. The building zone connected to the HYBUILD project is visible in orange in the second one. The facades of the rooms considered are oriented north east and south east.

Figure 46:Detailed building location (satellite view)

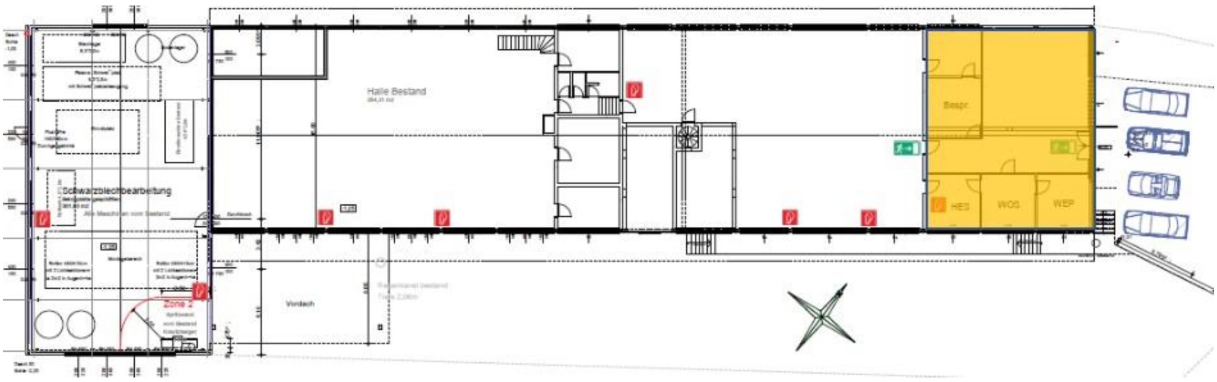



Figure 47 Site plan with the pilot building with the considered zone in orange

- **Building architectural plan**

The building zone studied in the scope of the HYBUILD project is visible in the next figure.

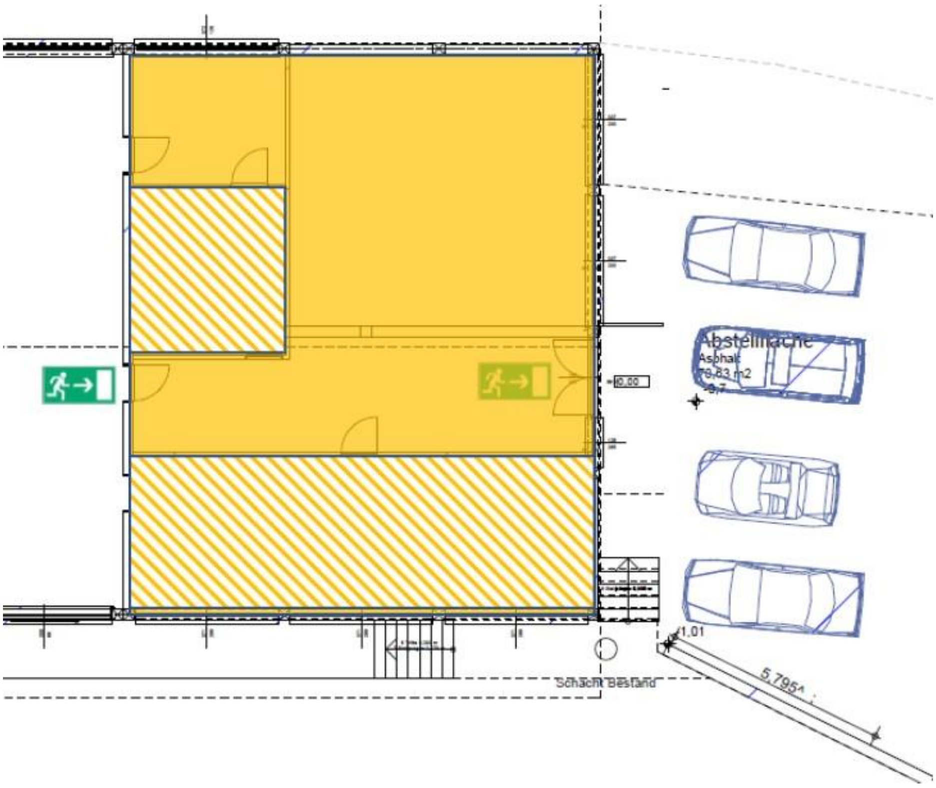



Figure 48 Building ground floor architectural plan with the considered zone

Photos of the current state of the building (Inside & outside) are shown in the next figure.

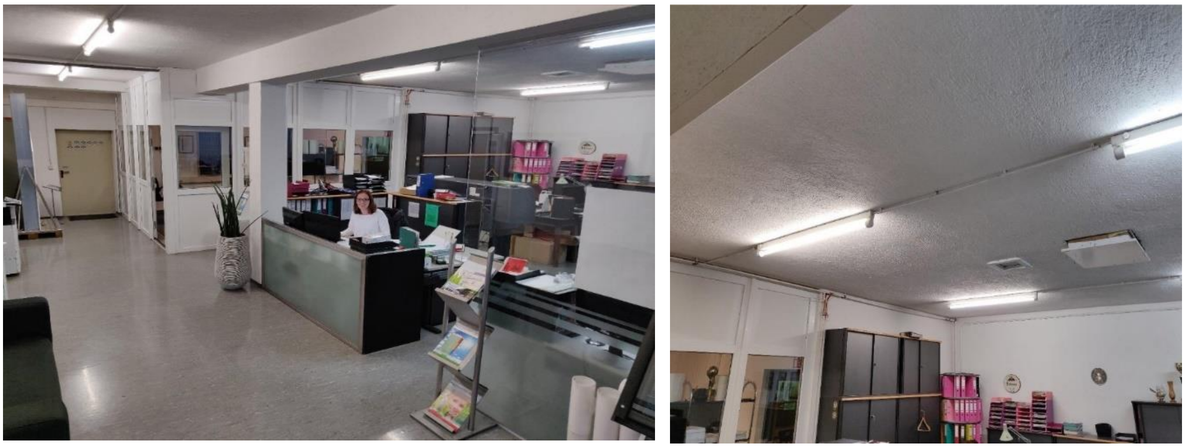


Figure 49 Plan office area with old ceiling

Figure 50 : Single office and meeting room with new (heating & cooling) ceiling

Figure 51 : Outside view of the demo building, office-area visible in the frontpresents an outside view of the building. A solar thermal installation situated at the tower surface to warm up the water for the pressure test of the tanks produced. The PV-installation on the container roof is only temporary (1,5kWp). Both solar systems are not coupled to the building's heating system.

Figure 51 : Outside view of the demo building, office-area visible in the front

- **Existing energy systems**

| | Equipment | Energy used | Comments and possibilities of monitoring |
|---|---|---|---|
| **Heating** | Coupled with the district heating system by a heat transfer station with a nominal power of 100kW | Biomass | Energy meter |
| **DHW** | Not directly related to the part of the building studied | -- | -- |
| **Cooling** | Cooling ceiling | Biomass | No meters available |
| **Ventilation** | -- | -- | -- |
| **Natural solar gains** | -- | -- | Directly exposed to the sun for certain hours on summer afternoons |

The whole building is connected to the local biomass-district heating system that is described below:

1. District heating system: For thermal energy supply, there is currently one boiler facility, equipped with three biomass boilers (1 MW, 1.5 MW and 2 MW). The district heating supplies a core area of Langenwang town, consisting of public buildings, schools, companies and residential houses (in total 287) with a total pipeline length of 15.060m.
2. Building heating and cooling system:
   - **Heating:** The building is coupled with the district heating system by a heat transfer station with a nominal power of 100kW. The production area (workshop) is partly using fan heaters and an underfloor heating system.
     The offices are currently using high temperature radiators, partly combined with heated ceiling to cover peak loads. Both are already controlled by a thermostatic valve using a daily and weekly time program for the temperature settings.
     As the building has construction systems that do not allow good energy performances, the indoor winter temperature is partly still low, and some users are complaining that the indoor temperatures are below comfort temperature. In order to improve their comfort, some electric space heaters are used. Because of the electric space heaters, the energy consumption is increased.
   - **Cooling**: The three single offices and the meeting room are already equipped with a cooling ceiling to improve the comfort during summer. The users in the not cooled

area of the office section are complaining about increased temperatures during the summer season.

#### *5.4.1.3 Main monitoring equipment installed for pre intervention*

At the moment, there is an internal monitoring equipment for the office section of the building installed. It consists of:

- 1 energy meter (temperatures, flow rate), and temperature prob.
- Temperature sensors:
  - 5 Room temperatures (3 single offices, 1 plan office, 1 meeting room).
  - 1 Ambient (outdoor) temperature.

**Figure 52 : Position of the ambient temperature sensor**

- 2 Buffer tank temperatures (top, bottom)
- 2 Primary flow temperatures of the feeding line of the radiator and ceiling circuit

#### *5.4.1.4 Monitoring period*

The measurement period is the year 2018.

### 5.4.2 Data collected

| Data point | Device | Units | Rate (min) | Data available |
|---|---|---|---|---|
| **Outdoor Temperature** | Senor on the north-west wall of our company | °C | 1 | From 01/01/2018 to 31/12/2018 |

| | | | | |
|---|---|---|---|---|
| **Energy consumption / Heating** | Energy meter | kWh | 1 | |
| **Energy consumption / Cooling** | Energy meter | kWh | 1 | |
| **Indoor temperature** | Sensors in the offices | °C | 1 | |

### 5.4.3 Energy consumption analysis

| Zone | Energy consumption | | | | Maximum power consumption | |
|---|---|---|---|---|---|---|
| | Heating | Heating | Cooling | Cooling | Heating | Cooling |
| | kWh/year | kWh/m²/year | kWh/year | kWh/m2/year | kW | kW |
| **Total** | 37.793 | 210 | 675 | 11 | 21 | 0,85 |

#### *5.4.3.1 Analysis of heating needs*

The heating needs are calculated based on water flows and flow and return temperature (of the heating and cooling loop). The values of the specific thermal capacity and density are considered as constant whatever the fluid temperature is.

$$P = \dot{m}_{eg} * \rho_{eg} * Cp_{eg} * (Td_{eg} - Tr_{eg})$$

with $P$ as the power in [J/s], $\dot{m}_{eg}$ [l/h] as the flow in the heating and cooling loop, $\rho_{eg}$ [kg/m3] the density of water, $Cp_{eg}$ [J/kg.K] the mass thermal capacity of the fluid mix, $Td_{eg}$ and $Tr_{eg}$ the temperature of the flow and return fluid loop.

#### *5.4.3.2 Study of the building heating demand*

Next figure shows the heating demand of the building during the measurements period. It covers the January 2018 to December 2018 period. The following figure shows those results for a weekly time step.

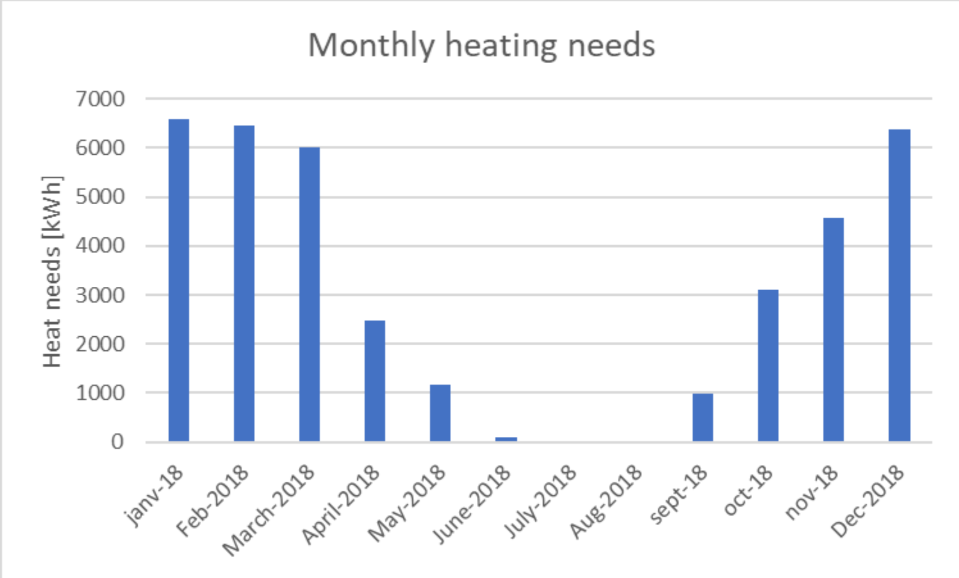



**Figure 53 : Monthly distribution of the heating demand**

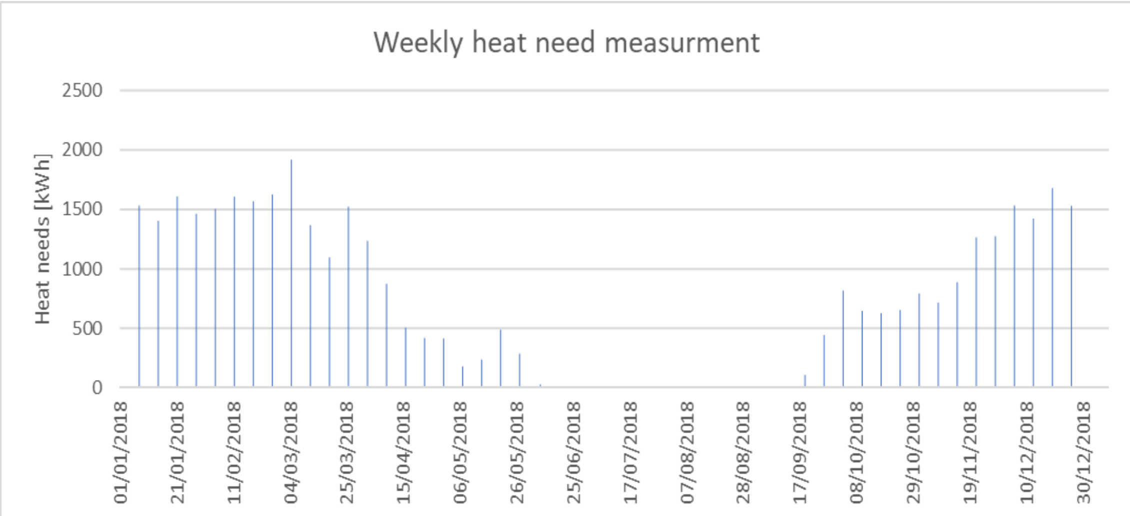



**Figure 54 : Weekly distribution of the heating demand**

The monthly heating consumption reaches 6000 kWh for the three months of winter, which is a high value but predictable given the age of the building.

Next figure shows the evolution of the heating power and the outside/inside temperatures during the coldest week. That week is identified thanks to an HDD calculation: for every week, the sum of the difference's hour by hour between 19°C and the outdoor temperature is calculated. The week which cumulates more HDDs is considered as the coldest week. In our case this is the last week of February 2018. It corresponds to the week with the highest heating needs.

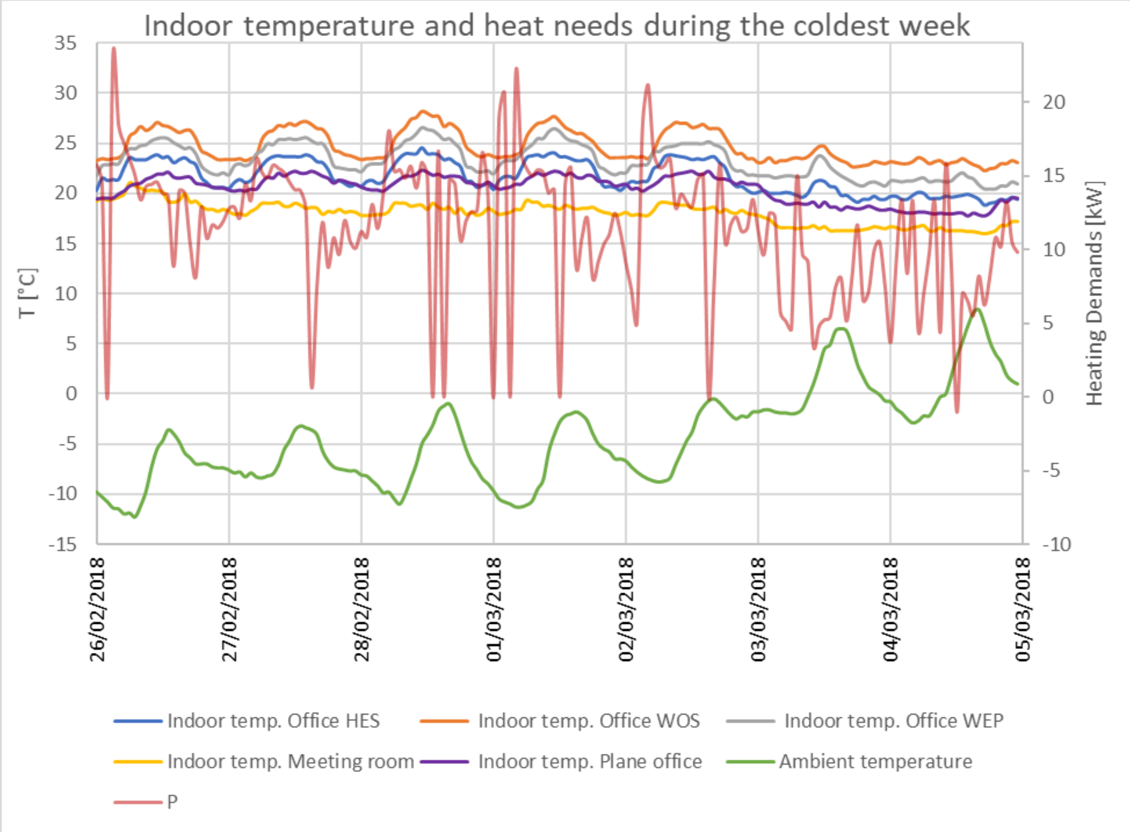



Figure 55 Coldest week / evolution of the temperature and the heating power

The observation of the temperature in different zones shows that the thermal behaviour is roughly similar in each room, except for the meeting room. The indoor temperature regularly exceeds 20°C during the hours with occupancy. The temperature even remains above 20°C most of the time the nights and reached 17°C during the weekend. The temperature of the meeting room is always between 15 and 20°C. A slight overheating is observed in the rooms considered. This overheating can be explained by the presence of an additional electric radiator, supplementing the standard heating system. According to the users, comfort would not be achieved without these electric radiators, revealing a problem of sizing the heating system. This is reflected in the temperatures in the meeting room, which has no supplementary heating and rarely reaches 20°C during this coldest week.

The observation of the heating power shows peaks at the start of the day. These peaks can reach 24kW. The highest peak happens when the coldest day.

Next figure presents the evolution of the measurements during the week when the heating power peak is reached.

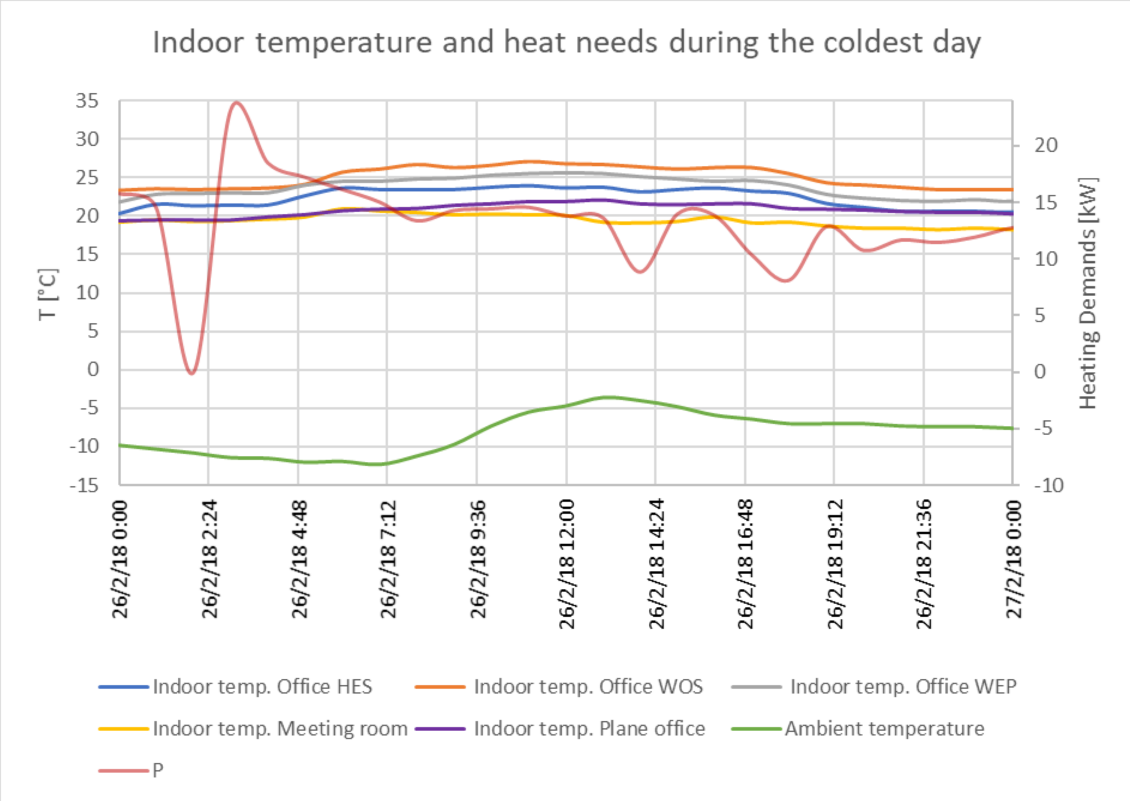



Figure 56 Day with the heating power peak / evolution of the temperature and heating power

The highest measured heating peak happens on Monday 26 February 2018, when the external temperatures is low (-10°C) and after the weekend when heating demand is lower. This day is the coldest day and provides information about the heating power requirements. To reduce this peak, it would be possible to stagger the morning heating period, especially after the days of non-use at weekends.

### *5.4.3.3 Summer comfort conditions*

The next figure shows the cooling demand of the building during the measurement period. It covers the period from January 2018 to December 2018. The following figure shows these results for a monthly time step.

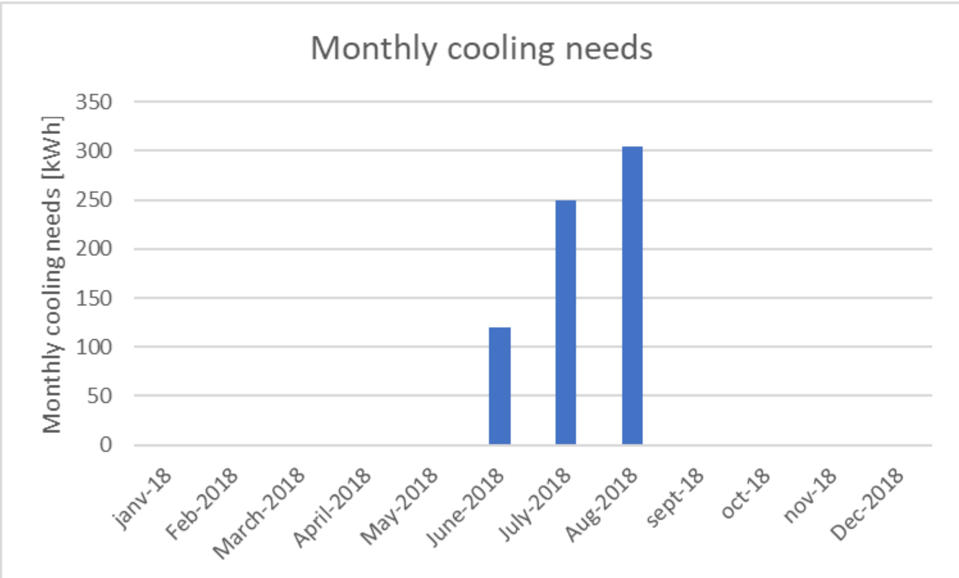



Figure 57 Monthly distribution of the cooling demand

Not surprisingly, the demand for cooling is for the summer months and reaches a maximum consumption of 300 kWh in August.

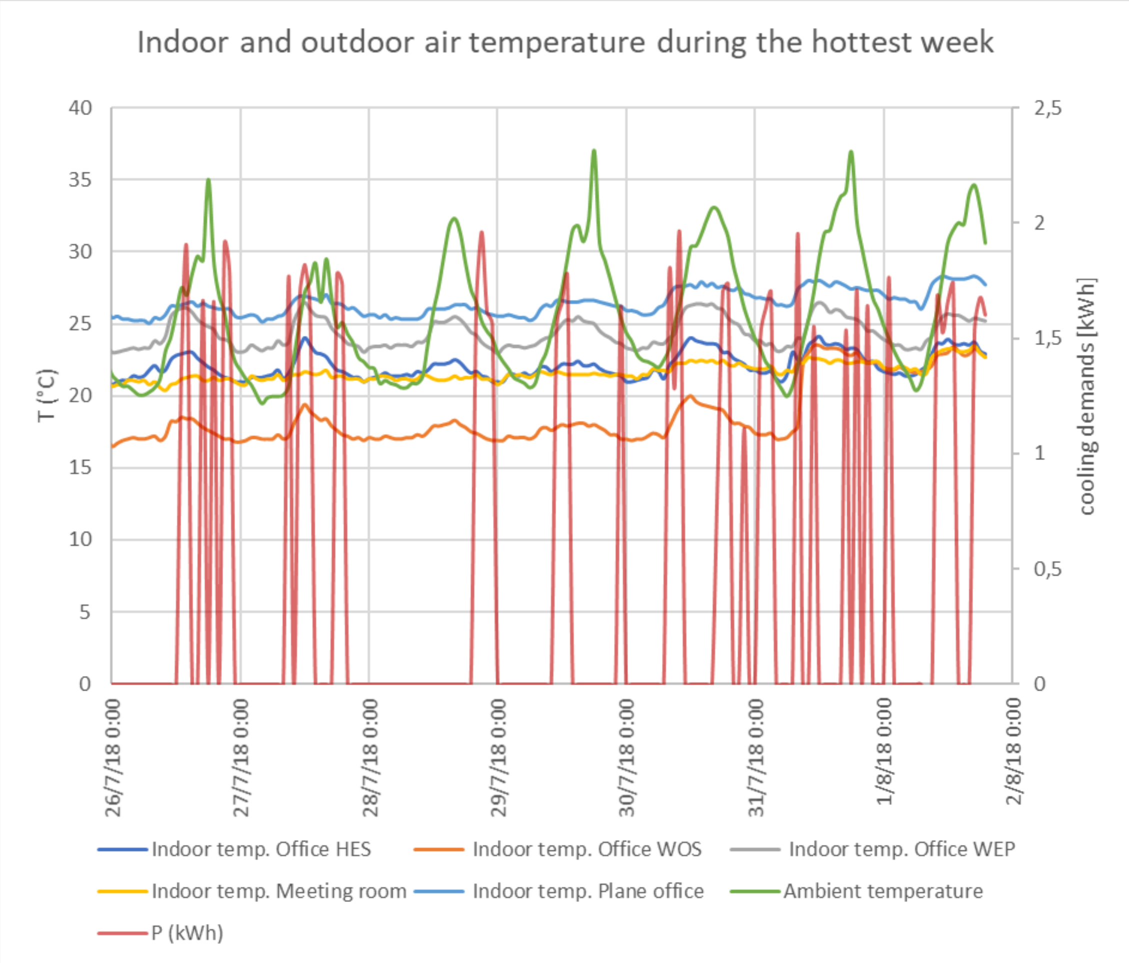



**Figure 58 : Temperature evolution during the hottest week**

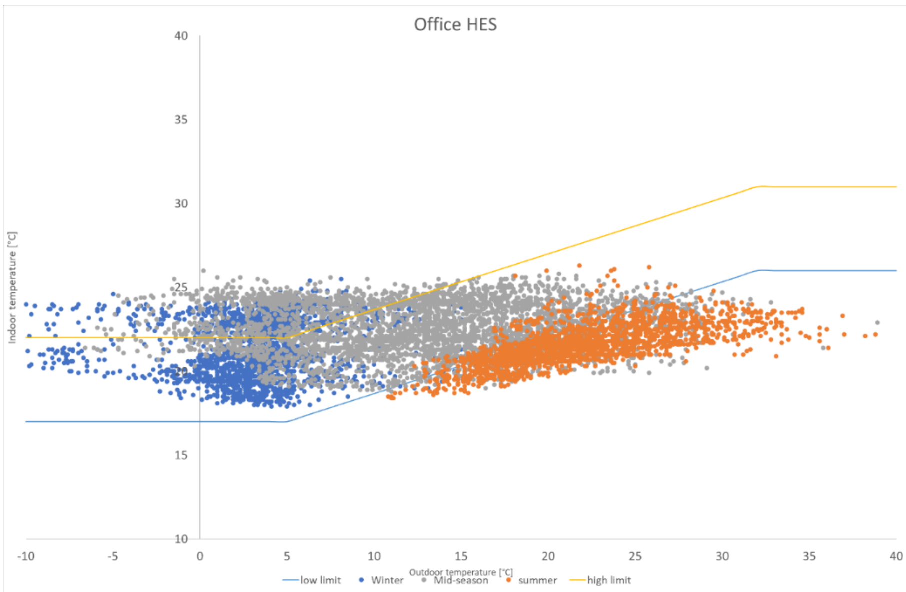
Firstly, it should be noted that the observed outdoor temperature peaks are due to the partial exposure of the collector to the sun. This exposure takes place around 4pm during the summer period.

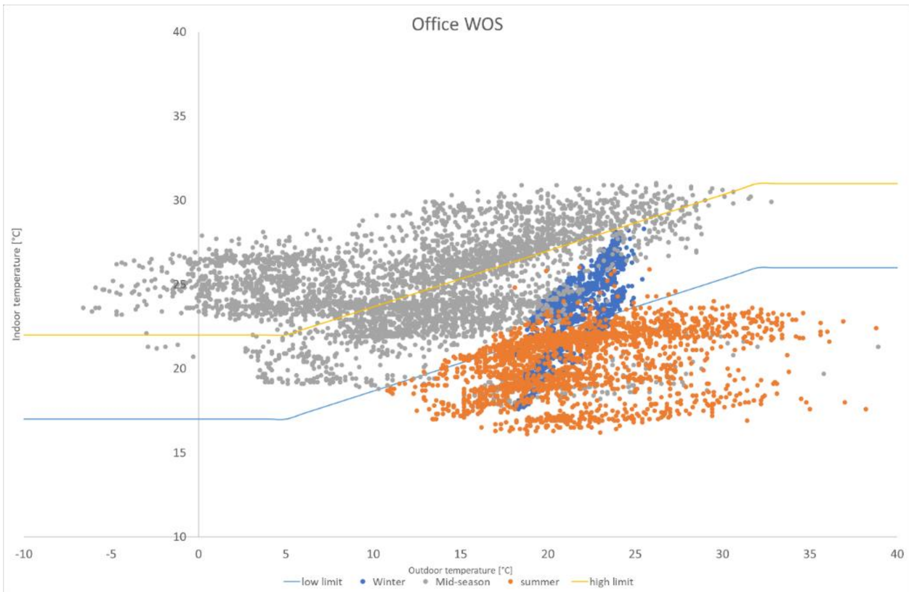
Figure 58 shows the evolution of the temperature inside and outside the building during the warmest week. Despite outdoor temperatures exceeding 30°C, the temperature inside the premises remains below 28°C, which is a reasonable threshold for comfort.

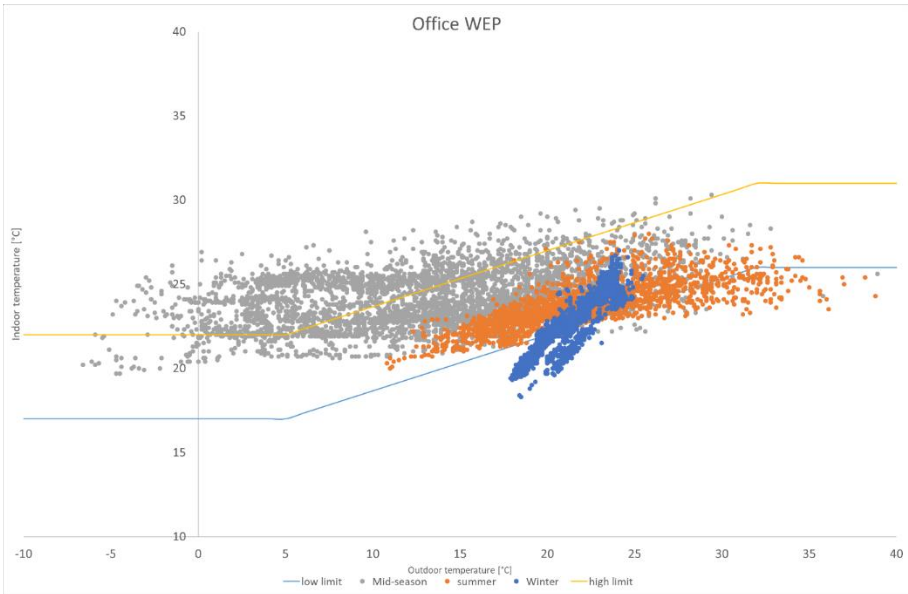
The existing system meets the need in the rooms where it is installed but would need to be extended to all user areas.

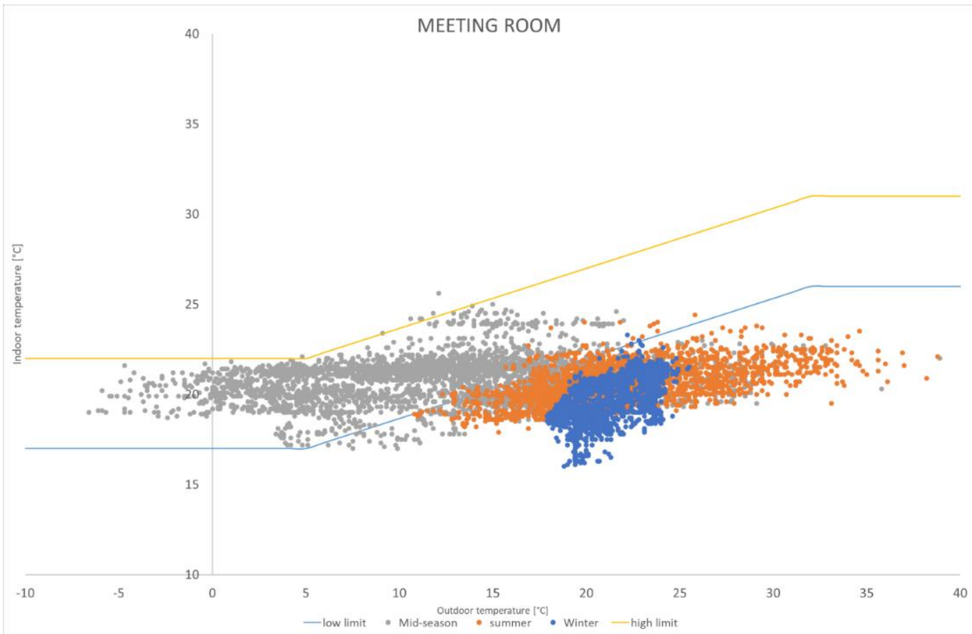
#### *5.4.3.4 Comfort rating in the building*

The next figures show Brager representations of comfort conditions in 5 different locations of the building. Each point represents a pair of simultaneous measurements: indoor temperature and outdoor temperature. Each graph corresponds to a different location/room of the building. In each figure the data represented correspond to a complete year, and the different seasons are represented with different colours. The area between the blue and the yellow line is considered to be representative of comfort conditions according to Brager criteria. The major concern for the building is the low indoor temperature in winter conditions, mainly observable for the "Meeting Room", the "plane office" and to a lesser extent for the "Office WOS" and "Office WEP". In summer conditions, the measured data points are often "below" the Brager zone, thus indicating low indoor temperatures but not necessarily generating a comfort problem (higher indoor temperatures in summer are a more common issue in summer for most of the buildings). High indoor temperatures potentially causing discomfort are observed during mid-season in the "Office WOS", this is where the main potential cooling needs are observed.




Office WEP
Indoor temperature [°C]
40
35
30
25
20
15
10
-10
-5
0
5
10
15
20
25
30
35
40
Outdoor temperature [°C]
low limit
Mid-season
summer
Winter
high limit


MEETING ROOM
Indoor temperature [°C]
40
35
30
25
20
15
10
-10
-5
0
5
10
15
20
25
30
35
40
Outdoor temperature [°C]
low limit
Mid-season
summer
Winter
high limit

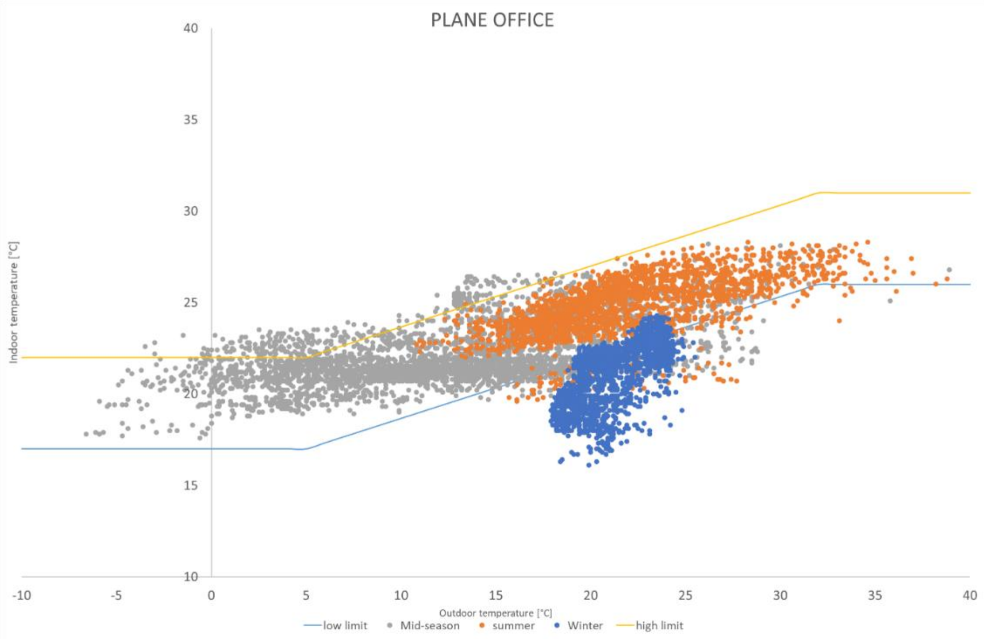



Figure 59. Brager representation for the 5 areas of the demo site

# 6 Conclusions

An energy demand analysis was carried out for the three demo sites, in the conditions prior to the installation of the demonstration systems.

This analysed baseline will be crucial at the moment of assessing the performance of the HYBUILD systems.

The consideration of Heating Degree Days will make possible to compare the results (before and after the implementation of the HYBUILD systems) on the basis of different meteorological conditions, resulting in different environmental parameters for the baseline period and the observation period.

A detailed analysis of the comfort conditions has also been done using advanced analysis tools such as the Brager and Givoni zones. These elements will allow to pay simultaneously attention to the energy consumptions and outputs, and to the corresponding service provided, i.e. the consideration of hygrothermal conditions in the buildings of the demo sites.

# 7 References

[1] David Palinkas, Merche Polo, Alvaro Picatoste and Sergio Costa, 2018 : Requirements for M&V plan for demo sites. Overview of IPMVP Methods. Report for HyBuild project, T6.1

[2] G. S. Brager et R. de Dear, *Center for the Built Environment*, 2001

[3] GIVOINI, Baruch, 1991 : Comfort, climate and building design guidelines, Energy and building, 18 (1992) 11-23.

[4] Vesterberg, Jimmy, Andersson, Staffan, 2016 : A single-variate building energy signature approach for periods with substantial solar gain In: Energy and Buildings, ISSN 0378-7788, E-ISSN 1872-6178, Vol. 122, p. 185-191

# 8 Annexes

## 8.1 Annex 1: Almatret, Doctor house (Almatret, Spain)

Figure 60 to Figure 62 show the location of the site at different scales.


Figure 60. Location of Almatret municipality, located in the province of Lleida within Spain


Figure 61. Location of the building within Almatret municipality


Figure 62. Zoom of the location of the building and neighbouring area

## Building architectural plan with dimensions (m²)

Figure 63 shows the schematic representation of the main area where the demo will be installed. Building 1 is a neighbouring building where another demo will be installed for another H2020 project (Innova MicroSolar), while Building 2 is the building where the demo of HYBUILD project will be installed. The two demos will share the area where the solar collectors will be places, and also the machine room.

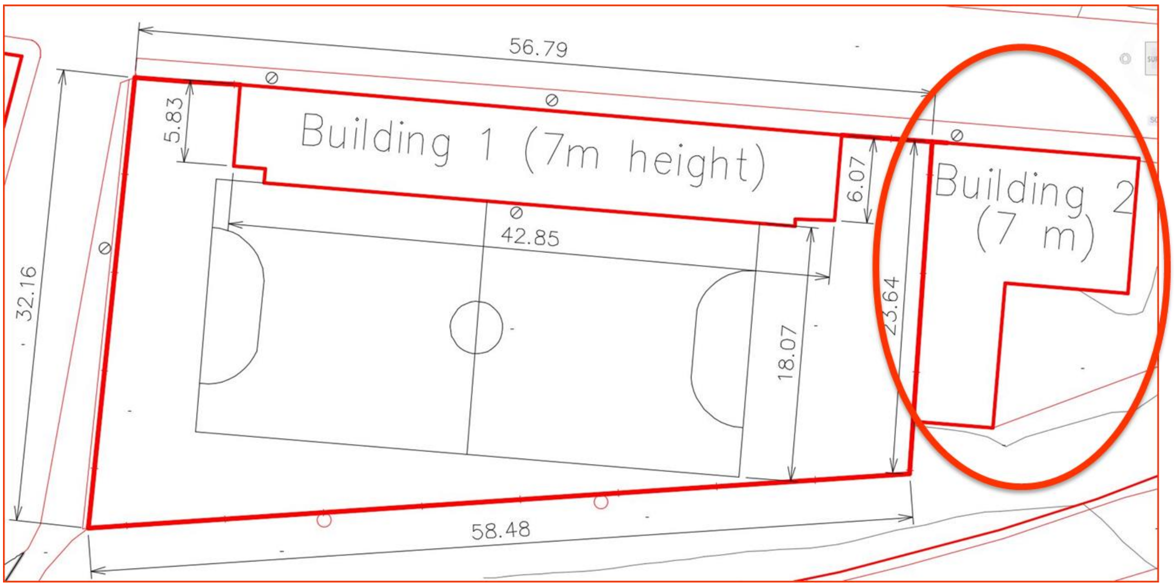



Figure 63. Schematic of the building (Building 2) and other neighbouring areas

The plans of the first floor of the building, which is where the HYBUILD system will be tested, are shown in Figure 64 and Figure 65 below.

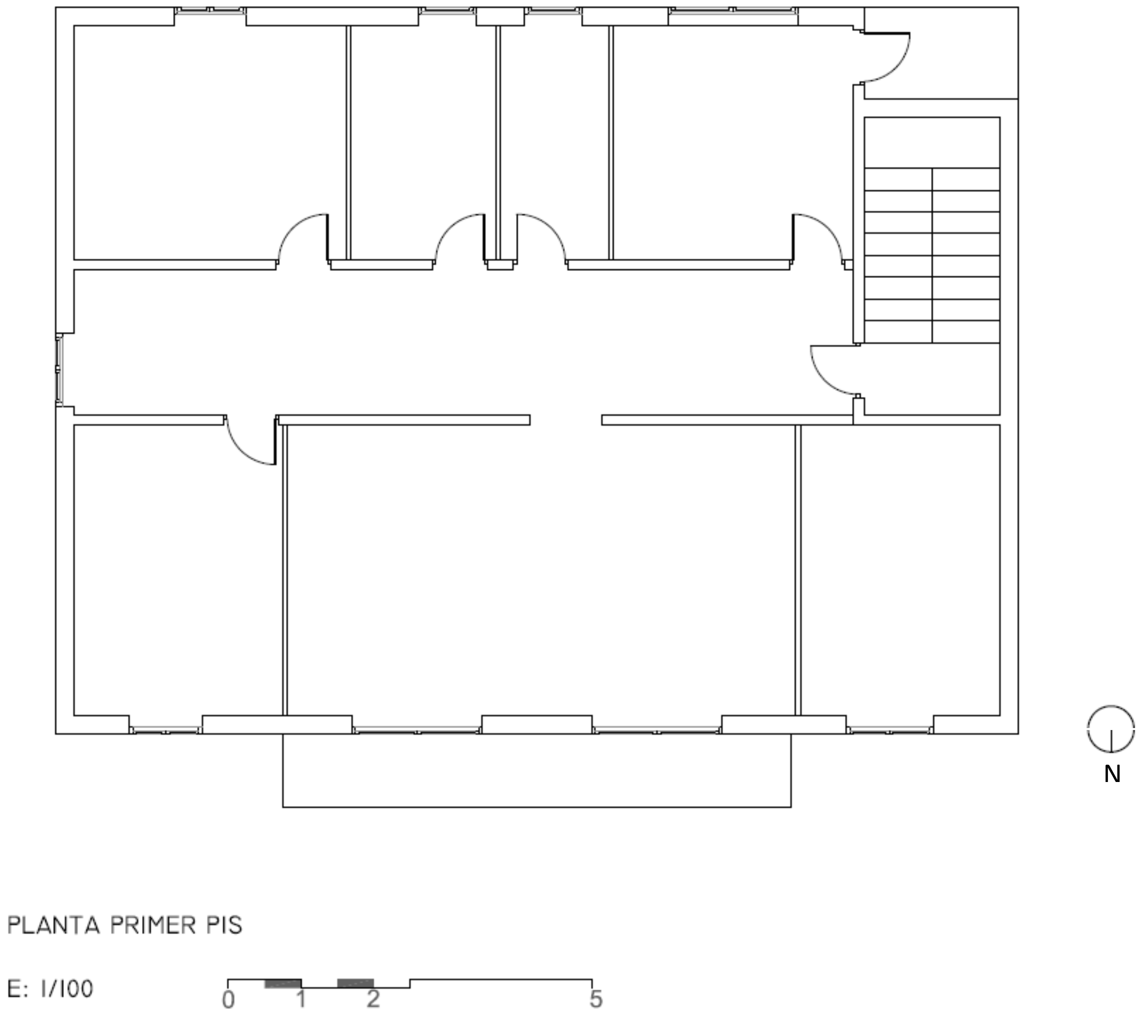



Figure 64. Plan of the first floor

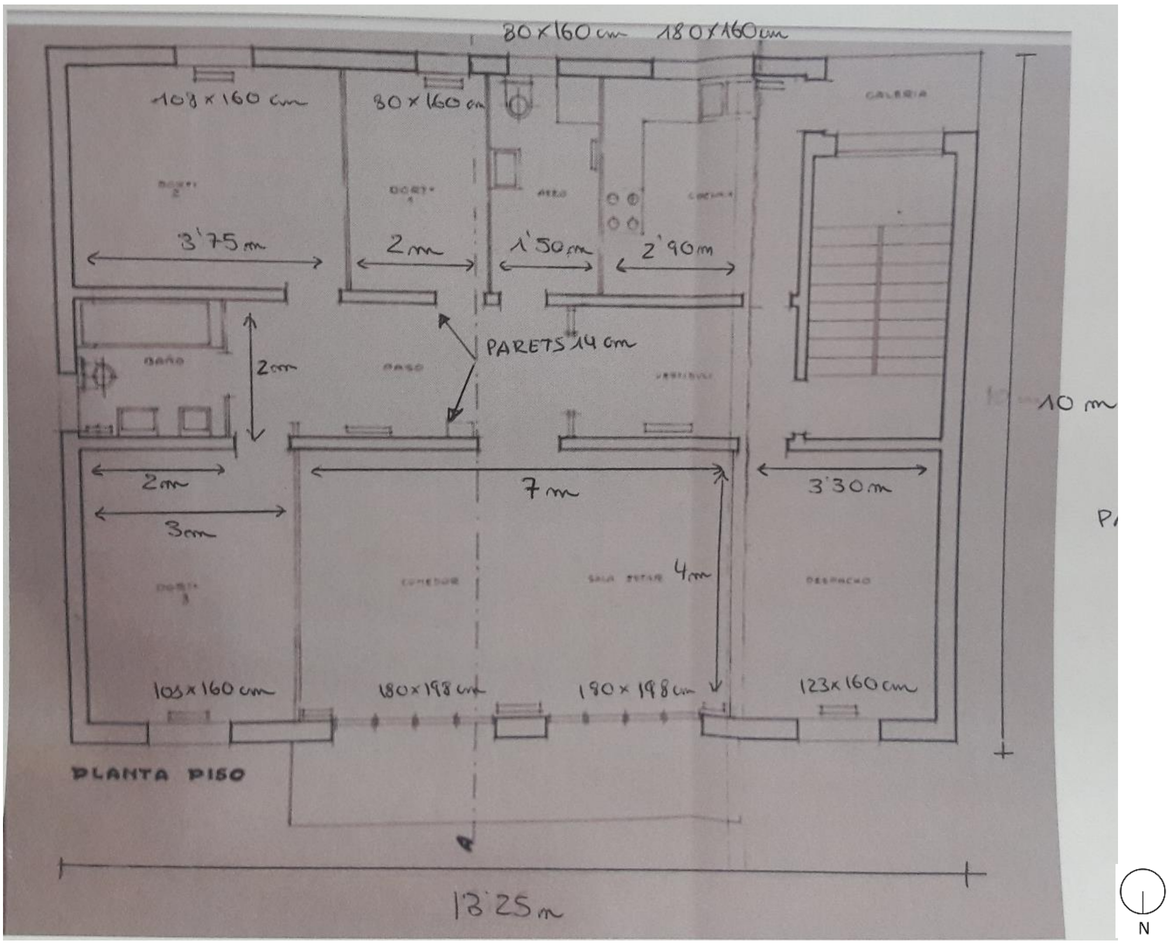



**Figure 65. Plan of the first floor, with details on the dimensions of rooms and windows**

A section through the entire house is shown in Figure 66, while a schematic of the house elevation is shown in Figure 67.

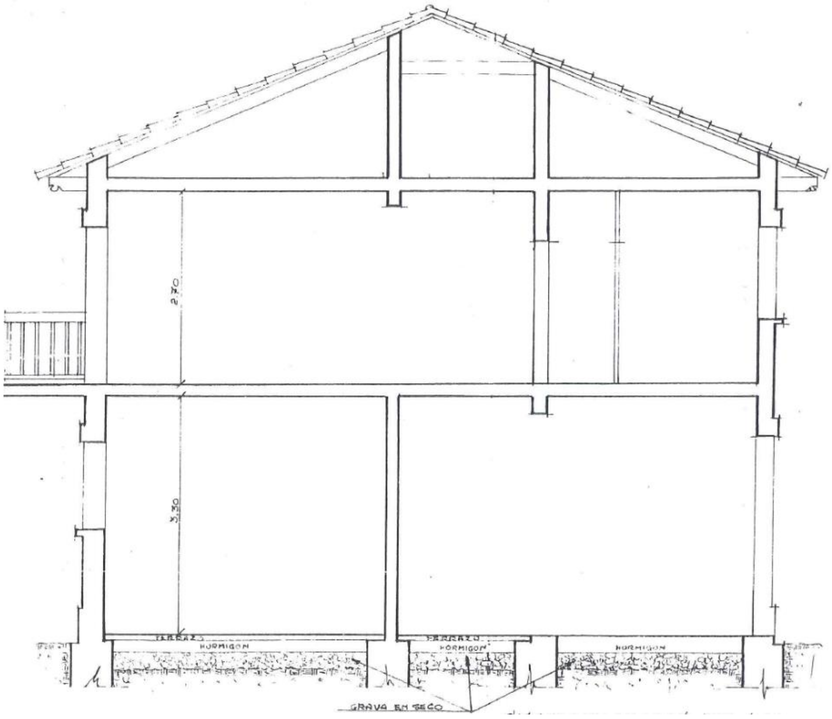


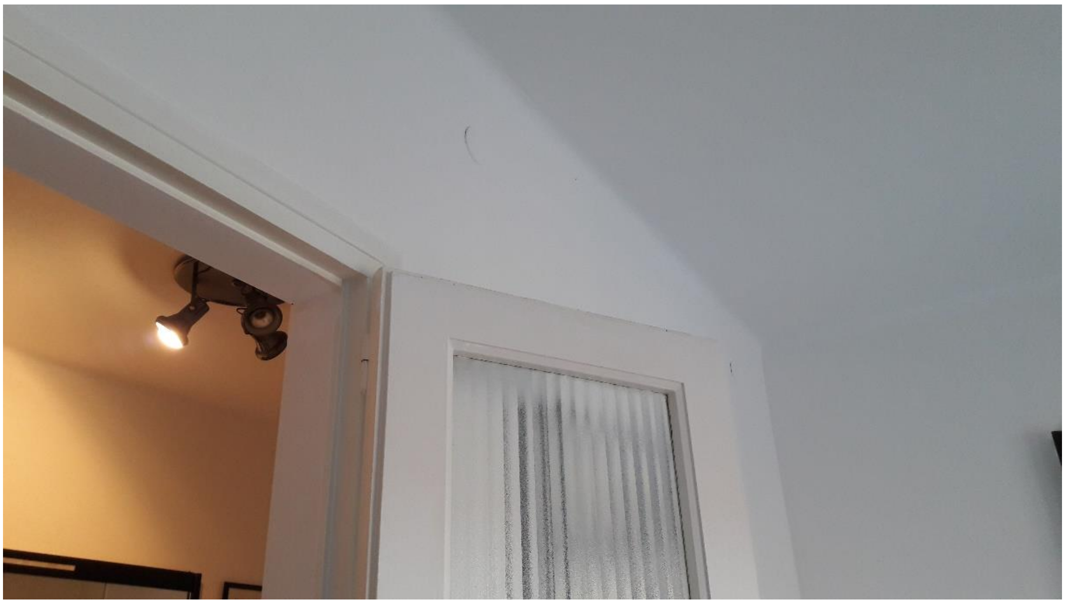
Figure 66. Schematic of the house section

Figure 67. Schematic of the house elevation

## Photos of the current state of the building (Inside & outside)

A few photos of the building are shown in the next few pages below, both of the outside and of the inside of the building.


CENTRE
MEDIC



## 8.2 Annex 2: HYBUILD KPIs and monitoring system

In this document, the KPIs selected by the project partners considering the HYBUILD main objective were summarized. This document can only be considered as an overview of the link between the KPIs and the monitoring phase. For the complete description of the KPIs, the authors refer to the final version of D1.3. To evaluate the link between the KPIs and the monitoring system, the authors referred to the scheme reported in Annex A.

### 8.2.1 Continental system

#### KPI 1: Thermal energy storage density, application level L1

Parameter description: D1.3 par. 5.1
Available from datasheet

Connected measurement:
1) State of charge of the energy storage
   Sensors:
   a) SoC108 connected to thermal controller

#### KPI 2: Seasonal Energy Performance

Parameter description: D1.3 par. 5.2
Seasonal average of the instantaneous values calculated from measurements

#### Compression chiller – L2, sub-system level

Connected measurements:

1) Cooling thermal energy
   Sensors:
   a) Inlet temperature: TT101
   b) Outlet temperature: TT107, TT102
   c) Mass flow rate: FTI104
   Sensors connected to the thermal controller

2) Electrical energy consumed by the compression chiller
   Sensors:
   a) Power: Power meter 3
   Sensor connected to the electrical controller

#### HYBUILD system – L3, system level

Connected measurements:

1) Total energy delivered to the building
   Sensors:
   a) Inlet temperature: TT302
   b) Outlet temperature: TT307
   c) Mass flow rate: FTI308
   Sensors connected to the thermal controller

2) Electrical energy consumed by the overall system
   Sensors:

a) Power: Power meter 3, Power meter 4, Power meter 5
b) Eventually: other power meters directly connected to the grid
Sensor connected to the electrical controller

## KPI 3: Share of renewable and self-consumption

Parameter description: D1.3 par. 5.3
Calculated from measurements

## PV sub-system– L2, sub-system level (DC side)

Connected measurements:

1) Renewable energy and self-consumption
Sensors:
a) PV power: Power meter 1
b) Battery power: Power meter 2
c) Power to compression chiller: Power meter 3
Sensor connected to the electrical controller

2) Energy demand
Sensors:
a) Power to compression chiller: Power meter 3
Sensor connected to the electrical controller

## HYBUILD system– L3, system level

Connected measurements:

1) Renewable energy
Sensors:
a) PV power: Power meter 1
b) Battery power: Power meter 2
c) Power to compression chiller: Power meter 3
d) Auxiliary resistances for DHW: Power meter 4, Power meter 5
e) Eventually: other power meters directly connected to the grid
Sensor connected to the electrical controller

2) Energy demand
Sensors:
a) Power to compression chiller: Power meter 3
b) Auxiliary resistances for DHW: Power meter 4, Power meter 5
c) Eventually: other power meters directly connected to the grid
Sensor connected to the electrical controller

## KPI 4: Energy savings and $CO_2$ emissions savings

Parameter description: D1.3 par. 5.4
Calculated from measurements

## PV sub-system– L2, sub-system level (DC side)

Connected measurements:

1) Renewable energy
Sensors:
a) PV power: Power meter 1
b) Battery power: Power meter 2
c) Power to compression chiller: Power meter 3
Sensor connected to the electrical controller

## HYBUILD system– L3, system level

Connected measurements:

1) Thermal energy
   Sensors:
   a) Inlet temperature: TT302
   b) Outlet temperature: TT307
   c) Mass flow rate: FTI308
   Sensors connected to the thermal controller

2) Electrical energy
   Sensors:
   a) PV power: Power meter 1
   b) Battery power: Power meter 2
   c) Power to compression chiller: Power meter 3
   d) Auxiliary resistances for DHW: Power meter 4, Power meter 5
   Sensor connected to the electrical controller

## KPI 5: Compactness

Parameter description: D1.3 par. 5.5
Calculated from datasheet

## KPI 6: Flexibility capacity index

Parameter description: D1.3 par. 5.6

## PV sub-system– L2, sub-system level (DC side)

Connected measurements:

1) Renewable energy and self-consumption
   Sensors:
   a) PV power: Power meter 1
   b) Battery power: Power meter 2
   c) Power to compression chiller: Power meter 3
   Sensor connected to the electrical controller

2) Energy demand
   Sensors:
   a) Power to compression chiller: Power meter 3
   Sensor connected to the electrical controller

## HYBUILD system– L3, system level

Connected measurements:

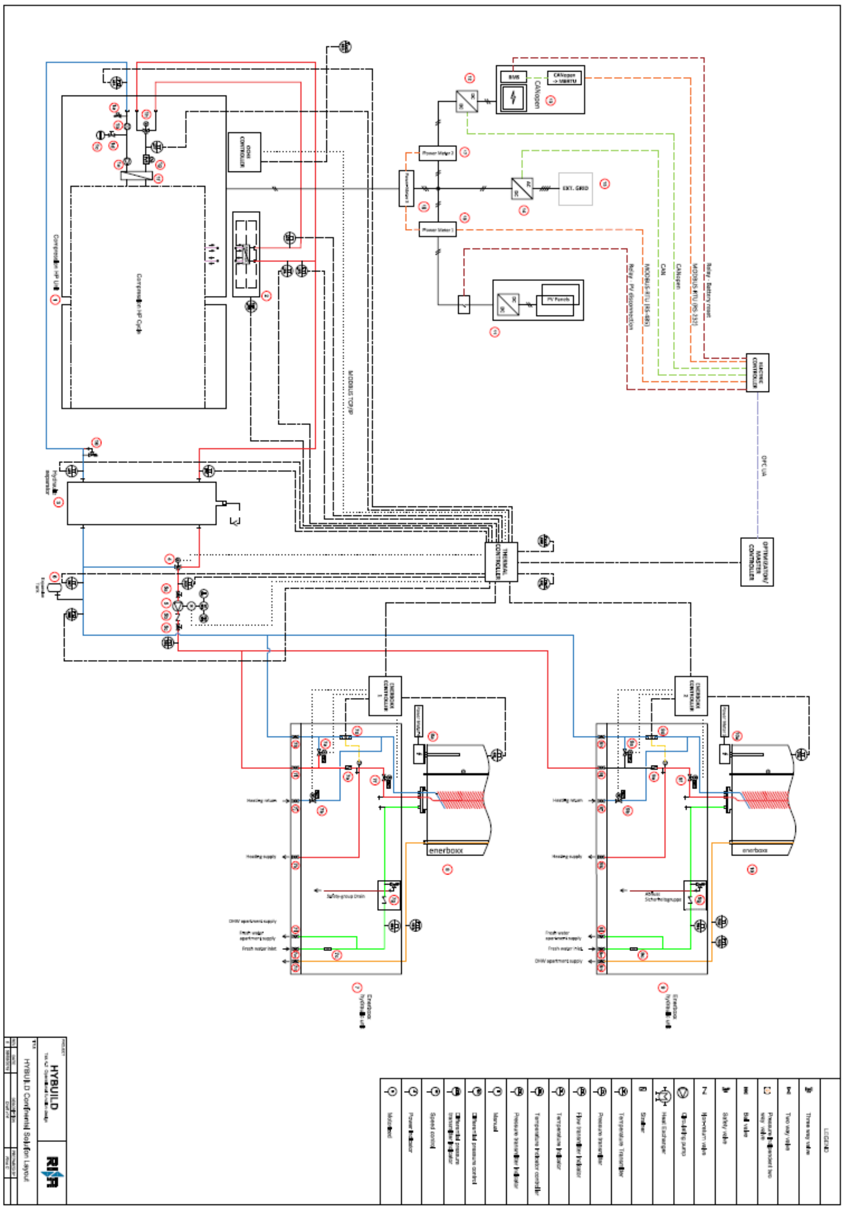
1) Renewable energy
   Sensors:
   a) PV power: Power meter 1
   b) Battery power: Power meter 2
   c) Power to compression chiller: Power meter 3
   d) Auxiliary resistances for DHW: Power meter 4, Power meter 5
   e) Eventually: other power meters directly connected to the grid
   Sensor connected to the electrical controller

2) Energy demand
   Sensors:
   a) Power to compression chiller: Power meter 3
   b) Eventually: other power meters directly connected to the grid
   Sensor connected to the electrical controller

## KPI 7: Return on investment

Parameter description: D1.3 par. 5.7

1) Primary energy savings
   Sensors:
   a) as for KPI 3 and 4



### 8.2.2 Mediterranean system

#### KPI 1: Thermal energy storage density, application level L1

Parameter description: D1.3 par. 5.1
Available from datasheet

Connected measurement:
1) State of charge of the energy storage
Sensors:
a) SoC1101 connected to thermal controller

#### KPI 2: Seasonal Energy Performance

Parameter description: D1.3 par. 5.2
Seasonal average of the instantaneous values calculated from measurements

#### Sorption module - L1, component level

Connected measurements:

1) Sorption module input thermal energy
Sensors:
a) Inlet temperature: TT401
b) Outlet temperature: TT403
c) Mass flow rate: FTI402

2) Sorption module output thermal energy
Sensors:
a) Outlet temperature: TT802
b) Inlet temperature: TT801
c) Mass flow rate of pump P17

All the sensors are connected to the thermal controller

#### Compression chiller – L2, sub-system level

Connected measurements:

1) Cooling thermal energy
Sensors:
a) Inlet temperature: TT1007
b) Outlet temperature: TT1009
c) Mass flow rate: FTI1008
Sensors connected to the thermal controller

2) Electrical energy consumed by the compression chiller
Sensors:
a) Power: Power meter 3
Sensor connected to the electrical controller

#### HYBUILD system – L3, system level

Connected measurements:

1) Cooling thermal energy
Sensors:
a) Inlet temperature: TT902
b) Outlet temperature: TT903

c) Mass flow rate: FTI901
Sensors connected to the thermal controller

2) Electrical energy consumed by the overall system
Sensors:
a) Power: Power meter 3
b) Eventually: other power meters directly connected to the grid
Sensor connected to the electrical controller

### KPI 3: Share of renewable and self-consumption

Parameter description: D1.3 par. 5.3
Calculated from measurements

### PV sub-system– L2, sub-system level (DC side)

Connected measurements:

1) Renewable energy and self-consumption
Sensors:
a) PV power: Power meter 1
b) Battery power: Power meter 2
c) Power to compression chiller: Power meter 3
Sensor connected to the electrical controller

2) Energy demand
Sensors:
a) Power to compression chiller: Power meter 3
Sensor connected to the electrical controller

### HYBUILD system– L3, system level

Connected measurements:

1) Renewable energy
Sensors:
a) PV power: Power meter 1
b) Battery power: Power meter 2
c) Power to compression chiller: Power meter 3
d) Eventually: other power meters directly connected to the grid
Sensor connected to the electrical controller

2) Energy demand
Sensors:
a) Power to compression chiller: Power meter 3
b) Eventually: other power meters directly connected to the grid
Sensor connected to the electrical controller

### Solar thermal sub-system– L2, sub-system level (DHW)

Connected measurements:

1) Renewable energy
Sensors:
a) Inlet temperature: TT101
b) Outlet temperature: TT104
c) Mass flow rate: FTI103
Sensors connected to the Fresnel system controller

2) Cooling energy demand
   Sensors:
   a) Inlet temperature: TT504
   b) Outlet temperature: TT502
   c) Mass flow rate: FTI503
   Sensors connected to the building datalogger controller

## Solar thermal sub-system– L2, sub-system level (SHC)

Connected measurements:

1) Renewable energy
   Sensors:
   a) Inlet temperature: TT101
   b) Outlet temperature: TT104
   c) Mass flow rate: FTI103
   Sensors connected to the Fresnel system controller

2) Cooling energy demand
   Sensors:
   a) Inlet temperature: TT902
   b) Outlet temperature: TT903
   c) Mass flow rate: FTI901
   Sensors connected to the thermal controller

## Solar thermal system– L3, system level

Connected measurements:

1) Renewable energy
   Sensors:
   a) Inlet temperature: TT101
   b) Outlet temperature: TT104
   c) Mass flow rate: FTI103
   Sensors connected to the Fresnel system controller

2) Cooling energy demand
   Sensors:
   a) Inlet temperature: TT902
   b) Outlet temperature: TT903
   c) Mass flow rate: FTI901
   Sensors connected to the thermal controller

   a) Inlet temperature: TT504
   b) Outlet temperature: TT502
   c) Mass flow rate: FTI503
   Sensors connected to the building datalogger controller

## KPI 4: Energy savings and $CO_2$ emissions savings

Parameter description: D1.3 par. 5.4
Calculated from measurements

## PV sub-system– L2, sub-system level (DC side)

Connected measurements:

2) Renewable energy
   Sensors:
   a) PV power: Power meter 1
   b) Battery power: Power meter 2
   c) Power to compression chiller: Power meter 3
   Sensor connected to the electrical controller

## HYBUILD system– L3, system level

Connected measurements:

3) Thermal energy
   Sensors:
   a) Gas meter measurement with **HYBUILD** system
   b) Inlet temperature: TT101
   c) Outlet temperature: TT104
   d) Mass flow rate: FTI103
   Sensors connected to the Fresnel system controller

4) Electrical energy
   Sensors:
   a) PV power: Power meter 1
   b) Battery power: Power meter 2
   c) Power to compression chiller: Power meter 3
   Sensor connected to the electrical controller

## KPI 5: Compactness

Parameter description: D1.3 par. 5.5
Calculated from datasheet

## KPI 6: Flexibility capacity index

Parameter description: D1.3 par. 5.6

## PV sub-system– L2, sub-system level (DC side)

Connected measurements:

1) Renewable energy and self-consumption
   Sensors:
   a) PV power: Power meter 1
   b) Battery power: Power meter 2
   c) Power to compression chiller: Power meter 3
   Sensor connected to the electrical controller

2) Energy demand
   Sensors:
   a) Power to compression chiller: Power meter 3
   Sensor connected to the electrical controller

## HYBUILD system– L3, system level

Connected measurements:

1) Renewable energy
   Sensors:
   a) PV power: Power meter 1
   b) Battery power: Power meter 2
   c) Power to compression chiller: Power meter 3
   d) Eventually: other power meters directly connected to the grid
   Sensor connected to the electrical controller

2) Energy demand
   Sensors:
   a) Power to compression chiller: Power meter 3
   b) Eventually: other power meters directly connected to the grid
   Sensor connected to the electrical controller

## Solar thermal sub-system– L2, sub-system level (DHW)

Connected measurements:

1) Renewable energy
   Sensors:
   a) Inlet temperature: TT101
   b) Outlet temperature: TT104
   c) Mass flow rate: FTI103
   Sensors connected to the Fresnel system controller

2) Cooling energy demand
   Sensors:
   a) Inlet temperature: TT504
   b) Outlet temperature: TT502
   c) Mass flow rate: FTI503
   Sensors connected to the building datalogger controller

## Solar thermal sub-system– L2, sub-system level (SHC)

Connected measurements:

1) Renewable energy
   Sensors:
   a) Inlet temperature: TT101
   b) Outlet temperature: TT104
   c) Mass flow rate: FTI103
   Sensors connected to the Fresnel system controller

2) Cooling energy demand
   Sensors:
   a) Inlet temperature: TT902
   b) Outlet temperature: TT903
   c) Mass flow rate: FTI901
   Sensors connected to the thermal controller

## Solar thermal system– L3, system level

Connected measurements:

1) Renewable energy
   Sensors:
   a) Inlet temperature: TT101
   b) Outlet temperature: TT104

c) Mass flow rate: FTI103
Sensors connected to the Fresnel system controller

2) Cooling energy demand
Sensors:
a) Inlet temperature: TT902
b) Outlet temperature: TT903
c) Mass flow rate: FTI901
Sensors connected to the thermal controller
a) Inlet temperature: TT504
b) Outlet temperature: TT502
c) Mass flow rate: FTI503
Sensors connected to the building datalogger controller

## KPI 7: Return on investment

Parameter description: D1.3 par. 5.7
1) Primary energy savings
Sensors:
a) as for KPI 3 and 4