Project Title:

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

Project Acronym:

## HYBUILD

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**Collaborative Project**

# Deliverable Report

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| CI | Classified, information as referred to in Commission Decision 2001/844/EC. | |

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## Publishable executive summary

HYBUILD is an EU Horizon 2020-funded project, led by COMSA Corporación, which will develop two innovative compact hybrid electrical/thermal storage systems for stand-alone and district connected buildings.

The aim of this report is first to characterize a limited number of concerned climates to be taken as reference in the analysis of the HYBUILD solution, considering the different climatic conditions as well as the different habits and constrains in energy consumption. The second purpose is to classify and characterize the most representative residential building typologies in Europe, identifying potential candidates for the HYBUILD technologies application.

The building typologies characterization is carried out starting from the analysis of two tools developed in the context of former European projects (FP7) related to building characterization: TABULA/EPISCOPE (http://EPISCOPE.eu) and INSPIRE(http://inspirefp7.eu/retrofit-solutions-database/).

A methodology to assess the technology applicability, define the sizing of the HYBUILD solutions and to assess their performance in given conditions (climates, building typology, user scenarios) is proposed. It allows for evaluating if the HYBUILD technologies can be applied in the different building typologies and climates and under which conditions.

Another objective is to define user scenarios and boundary conditions consistent with the building typologies, serving as an input in the energy simulations used to define loads profiles for heating, cooling and Domestic Hot Water (DHW). In this way it is possible, given a set of boundary condition and uses scenarios, to assess the performance in the different climates. Load profile and peak load for each building and climate are defined to be used in further energy simulations that will be carried out in the upcoming activities of the project to evaluate the HYBUILD system performance. The boundary conditions refer to the standard internal gains, the infiltration and ventilation of the building, the shading elements and the setpoint temperatures to be considered in the simulations, as well as the scheduling for heating and cooling systems. The user scenarios comprehend additional cases of heating and cooling setpoint temperatures, in order to have a wider evaluation of the performance.

The reference climates have been identified and characterized within chapter 2, considering different parameters such as ambient temperature, humidity, solar irradiation, HDDs (Heating Degree days) and CDDs (Cooling Degree days). HDDs and CDDs are weather-based technical indexes designed to describe the need for the heating and cooling energy requirements of buildings (Eurostat, the Statistical Office of the European Union).

Five reference climates have been selected among the seven European climates defined in INSPIRE project considering the differences in temperature, humidity and degree days. In particular a variation of +/- HDDs among the reference cities has been considered in the definition of the different climates. The five reference climates chosen in HYBUILD are Nordic, Continental, Southern Continental, Southern DRY and Mediterranean, covering hot, warm and cold climates. Five reference countries have been selected and a reference city has been identified for each country: Stockholm (Sweden, Nordic Climate), Stuttgart (Germany, Continental climate), Lyon (France, Southern Continental climate), Madrid (Spain, Southern Dry climate), Athens (Greece, Mediterranean climate). The climatic parameters of the reference cities have been collected from Meteonorm database.

In the HYBUILD project three demo sites have been selected to demonstrate the performance of the HYBUILD system: Aglantzia (Nicosia district, Cyprus), Almatret (Spain) and Bordeaux (France). The specific climatic data for the three locations have been collected in order to perform detailed energy analysis of the demo sites.

For each city characterized, the hourly profile of temperature, humidity and solar irradiation have been collected and used as inputs for the calculation of load profiles and peak loads.

In chapter 3, an analysis of the data available in TABULA/EPISCOPE and INSPIRE European projects, concerning building characterization, has been carried out. The analysis highlighted the large number of data available related to the building stock. The information available has been used for the identification and characterization of the building typologies, described in chapter 4. In particular in the TABULA web tool, four residential building categories have been investigated and characterized for 20 European countries: Single-Family House (SFH); Terraced House (TH); Multi Family House (MFH); Apartment Block (AB). Each typology has been investigated for different construction periods. For each building category and country, several data points on the building envelope characteristics and on the systems used are available. Moreover the energy demand and consumption for heating and DHW are presented as average annual values for all the building typologies considered.

When it comes to INSPIRE database, two building typologies have been investigated for the seven European climates identified: SFH and MFH. The database available online is divided into 3 sections: Building Stock Statistics, Reference Building Simulations, and Target Building Simulations. The most relevant section for the building typology characterization is the Building Stock Statistic section, containing information from statistics related to energy demand and consumption for heating, cooling and domestic hot water on annual bases. When it comes to the information on the building envelope performance (i.e. the typical U values), average values are present in the INSPIRE report D2.1a and D2.1c downloadable from the project website (Kuhn T., 2014) (Dipasquale C., 2014), but it is not included in the online database.

The reference building typologies have been identified and characterized in chapter 4. SFH and MFH belonging to the construction period 80’-90’ have been chosen as reference typologies.

According to the EU Building Database (European Commission, 2018), residential buildings cover approximately 22.7 billion m$^2$ of floor area in 2014. The residential mix between SFH and MFH, varies among the different countries, but the age of construction for the two typologies is distributed homogeneously (Birchall S., 2014). This allows for choosing a common reference period for all the climates considered. The aim is, for each climate, to characterize the two typologies (SFH and MFH) with standard building characteristics referring to one chosen reference period. In particular, the period **1980-1989** has been chosen. According to the EU Building database (European Commission, 2018) it represents the 12.54% of the EU28 building stock varying from the 10.16% in Sweden to the 19.44% in Cyprus, as shown in Table 23. The choice has been done considering that in the climates selected the energy performance of buildings starts to increase in the 1970s and 1980s, while in the previous years the energy performance was generally of low quality.

A common geometrical definition of the reference building for all countries (i.e. net area, surface/volume rate, building width/depth, Ceiling/Floor height, number of zones, glazing ration) has been defined, differentiating SFHs from MFHs. On the contrary, the typical U values of walls, floors, ceilings and windows of each reference country have been considered.

In chapter 5 a method to be followed for assessing the applicability of the HYBUILD technology and the performances of the HYBUILD solutions in the different condition is presented, in order to determine which type of building can use the systems to be developed and under which climatic conditions.

The main steps to perform time dependent simulations are described in order to achieve the above mentioned results, highlighting how the tools analysed in chapter 3 could be used to provide important data to perform the analysis. The steps identified are:

- **climatic characterization**;
- **building characterization** (carried out thanks to the above-mentioned tools);
- definition of the **boundary conditions** and user scenarios;
- definition of heating and cooling **peak loads and energy demand profiles**;
- **Sizing of the systems** according to the conditions defined;
- **Calculation of KPIs** for the evaluation of the technologies as a function of the context of application.

In chapter 6, boundary conditions to be considered in the energy simulations for the definition of the load profiles of the reference buildings in the different climates have been defined. The boundary conditions definition included the definition of internal gains, infiltration and ventilation, shading elements, temperature set point and appliances usage schedules.

Heating and cooling demands are assessed assuming ideal capacity of the conditioning system in a way that the internal temperature is maintained between two temperature set points: 20°C during winter; 25°C during summertime.

Then in chapter 6.2 the user scenarios have been defined, adding new combinations of temperature set points with respect to the standard ones. In particular six combinations have been defined, with the winter temperature set points varying from 19 °C to 22 °C, and the summer temperature set points varying from 24 °C to 26 °C.

The chapter 6.3 reported an analysis of the energy demands for heating and cooling of the reference building identified and their related peak load, considering the different climatic conditions. The profiles have been calculated on hourly-basis. In particular in this report, data regarding heating and cooling energy demands and specific heating and cooling peak values are reported for each analysed climate, building typology and temperature set points in yearly basis. Monthly values are also presented for one set point combination: 20°C winter and 25°C summer.

When it comes to the heating demand, the highest load profile has been found in Madrid. This is because, despite warmer external conditions with respect to the Nordic , Continental  and South continental climates, the lower building insulation with respect to those climates results in a higher heating demand. Regarding the Cooling demand, as expected the higher values have been found in Mediterranean climate, in particular in Athens. Also the coldest climates account for (low) cooling demand. However, thanks to the low temperatures during the night, the cooling load in these climates can be reduced though night-cooling strategies.

## Acronyms and Abbreviations

All acronyms and abbreviations (AAs) used in the report are listed in alphabetical order in the table below (other than symbols for units of measurement):

Table 1 Acronyms and Abbreviations

| | |
|---|---|
| AA | Acronyms and Abbreviations |
| CA | Consortium Agreement |
| CDD | Cooling degree day |
| DHW | Domestic Hot Water |
| DL | Deadline |
| Dh | Diffuse horizontal radiation |
| EC | European Commission |
| EU | European Union |
| FP7 | Framework Programme 7 (EU) |
| GA | Grant Agreement |
| Gh | Global horizontal radiation |
| HDD | Heating degree day |
| HP | Heat Pump |
| MFH | Multi Family House |
| PC | Project Coordinator |
| PO | Project Officer |
| PV | Photovoltaic |
| RH | Relative Humidity |
| SFH | Single Family House |
| $T_{amb}$ | Ambient temperature |
| $T_{base}$ | Base temperature |
| U | Thermal Transmittance [$W/m^2K$] |

# 1 Introduction

## 1.1 Aims and objectives

The aim of this report is first to characterize a limited number of concerned climates to be taken as reference in the analysis of the HYBUILD solution, considering the different climatic conditions as well as the different habits and constraints in energy consumptions. The second purpose is to classify and characterize the most representative residential building typologies in Europe, identifying potential candidates for the HYBUILD technologies application.

The building typologies characterization is carried out starting from the analysis of two of the several tools developed in the context of European projects (FP7) related to the building characterization: TABULA/EPISCOPE (EPISCOPE FP7 EU funded Project, 2012-2016) and INSPIRE (INSPIRE FP7 EU funded Project, 2016). The choice to focus the attention on these web tools has been made and agree among the partners during HYBUILD KoM of 18th and 19th of October 2017 as reported in the minutes of WP1 – WP2 – WP3 meeting.

A methodology to assess the technology applicability, define the sizing of the HYBUILD solutions and to assess their performance in given conditions (climates, building typology, user scenarios) is proposed. It allows for evaluating if the HYBUILD technologies can be applied in the different building typologies and climates and under which conditions.

Another objective is to define user scenarios and boundary conditions consistent with the building typologies, serving as input in the energy simulations used to define loads profiles for heating, cooling and DHW. In this way it is possible, given a set of boundary conditions and uses scenarios, to assess the performance in the different climates. Load profile and peak loads for each building and climate are defined to be used in further energy simulations that will be carried out in the upcoming activities of the project to evaluate the HYBUILD system performance.

Boundary conditions refer to the standard internal gains, the infiltration and ventilation of the buildings, the shading elements and the temperature set points to be considered in the simulations, as well as the scheduling for heating and cooling systems. The user scenarios comprehend additional cases of heating and cooling temperature set points, in order to have a wider evaluation of the performance.

## 1.2 Relations to other activities in the project

The work reported in this deliverable, carried out within task 1.1 and task 1.3 serves as an input for other tasks and work packages:

- Climates, building typologies and user scenarios identified serve as reference in the analysis of the system performance carried out in WP4.
- Dynamic conditions will be taken into account in the assessment of the component and sub-systems performance during the designing phase in WP2 and WP3.
- The proposed methodology serves in WP6 (pilots) for the definition of the proper sizing of the solution to be applied.

## 1.3 Report structure

Chapters 2 to 5 report on the activities carried out in task 1.1, while chapter 6 is related to the activities of task 1.3. The topics reported in each chapter are described below.

In chapter 2 the reference climates are identified and characterized, considering different parameters such as ambient temperature, humidity, solar irradiation, HDD and CDD. The data have been collected from Meteonorm database. For each climate, one reference country (and city) has been identified, to be considered representative for the whole climate.

In chapter 3, an analysis of two tools concerning building characterization, available among the ones developed in the framework of European Projects, is carried out. The two tools analysed are TABULA EPISCOPE tool and INSPIRE tool.

In chapter 4 the reference building typologies are identified and characterized. Typical U values for each reference country are defined, while the geometrical definition (i.e. net area, surface/volume rate, building width/depth, Ceiling/Floor height, number of zones, glazing ratio, etc.) is common in the reference building of all the climates.

In chapter 5 a methodology to assess the applicability of the HYBUILD technology and its performance in the different considered conditions is described. The main steps include:

- Definition of the climatic conditions (**climatic characterization**);
- Definition of the characteristics related to geometrical and thermal features for each building typologies investigated (**building characterization**);
- Definition of the **boundary conditions** in terms of internal temperature set point, internal gains, shading elements, air infiltrations;
- Definition of a User Scenario by selecting among different temperature set-points;
- Definition of heating and cooling **peak load and energy demand profile**;
- **Sizing of the systems** according to the condition defined;
- **Calculation of KPIs** for the evaluation of the technology as a function of the context of application.

Chapter 6 is related to Task 1.3. It defines first (chapter 6.1) the boundary conditions to be considered in the energy simulations for the definition of the load profiles of the reference buildings in the different climates. The boundary conditions definition includes the definition of internal gains, infiltration and mechanical ventilation, shading elements, temperature set points and scheduling of the appliances. Then in chapter 6.2 the user scenarios are defined, adding new combinations of set point temperatures with respect to the standard ones described in chapter 6.1. Chapter 6.3 reports an analysis of the energy demand for heating and cooling of the reference buildings identified in chapter 4, considering the different climatic conditions defined in chapter 2. Chapter 6.3.1 reports monthly energy demand, defining the load profiles in the standard boundary conditions. Chapter 6.3.2 shows the analysis of yearly demand considering the different user scenarios, with different cooling and heating set point.

## 1.4 Contributions of partners

**NTUA** provided an analysis of the TABULA/EPISCOPE database related to the building typologies, used in chapter 3. NTUA provided climatic data for Athens (Greece reference cities) and contributed in the energy simulations in Greek climates.

**UCY** helped in defining which climatic parameter and building related parameters should be defined to carry out the analysis of HYBUILD technologies, analysing at building level which are the key parameters influencing or influenced by the technologies.

**UDL** provided information related to the building typologies characterization coming from TABULA/EPISCOPE project.

**EURAC** provided information coming from INSPIRE related to the climates and building characterization. EURAC as leader of task 1.3 contributed to chapter 6 related to Dynamic User integration, defining boundary condition, user scenarios and carrying out an energy analysis to define the load profiles of the reference buildings.

**RINAC** (as third party of STRESS) as leader of task 1.1 and responsible for D1.1, collected the contributions from the other partners, finalized the buildings and climates characterization (chapter 2 and chapter 4), and the existing tools analysis (chapter 3). RINAC developed the methodology described in chapter 5.

## 2 Climates identification and characterization

The aim of this chapter is to characterize a limited number of climates where the future HYBUILD systems could be operated, accounting for different and representative climatic conditions as well as different uses, habits and constraints in energy consumptions.

European climate varies depending on different factors such as latitude, distance from major bodies of water, altitude, etc. According to the EC-funded project INSPIRE, Europe can be divided into 7 reference climates, Southern Dry; Mediterranean; Southern Continental; Oceanic; Continental; Northern Continental; Nordic. The analysis done in the context of Inspire Project was based on the Meteonorm 7 repository and data more than 300 weather stations. It provides several climatic data such as air temperature, humidity, atmospheric pressure, solar radiation and other parameters, for a typical meteorological year of the location selected, based on data collected over the period 2000-2009.

The 7 reference climates (and 7 reference cities) have been identified on the basis of temperature and humidity data. In Table 2, the 7 European climate definitions are shown (Kuhn T., 2014).

Table 2 HYBUILD relevant climates being considered in the analysis

| Climate | Description |
|---|---|
| **Southern Dry** | Dry climate zone with extreme summer temperatures and high yearly temperature amplitudes. Summer is very warm and dry, with a seasonal relative humidity under 60%. This climate zone includes main part of Spain and Portugal, Turkey and part of Greece |
| **Mediterranean** | Relatively warm climate zone with relative mild summer and winter seasons, due to the regulating influence of the Mediterranean Sea. It includes Italia and the other countries surrounding the Adriatic Sea (Croatia, Montenegro, Albania, West of Greece, Cyprus), as well as South of France and North-East of Spain |
| **Southern continental** | Climate zone with summer as warm as Mediterranean summers, but with winters much colder. It includes most part of France, North Italia, Slovenia, Serbia and Bulgaria |
| **Continental** | Inner land climate zone with high yearly temperature amplitudes between cold winters and hot summers. It includes Central Europe (Germany, Austria, Czech Republic, Slovakia, and Hungary) as well as parts of Ukraine, Poland and Romania |
| **Oceanic** | Humid and mild climate zone with low yearly temperature amplitudes, due to the regulating influence of Atlantic Ocean. It includes the Britannic islands, Benelux, North-West of France and the extreme North-West of Spain (Galicia) |
| **Northern continental** | Climate zone with a mild summer and a cold winter not as extreme as the Nordic climate. It includes Countries at the South of the Baltic Sea (Denmark, Poland, and Lithuania) |

| | |
|---|---|
| **Nordic** | Climate zone with extreme winter temperatures and mild summer temperatures. It includes Scandinavian countries, North of Russia, Estonia and Latvia. The reference city considered is Stockholm |

HDDs (Heating Degree days) and CDDs (Cooling Degree days) are weather-based technical indexes designed to describe the need for the heating and cooling energy requirements of buildings (Eurostat, the Statistical Office of the European Union).

A variation of +/- 250 heating degree days (HDDs) among the reference cities of each climate is considered.

The calculation of these indexes depends on the base temperature, i.e. the external temperature below which a building is assumed to need heating or above which a building is assumed to need cooling. Different base temperatures and calculation methods can be used depending on the target application and temperature data frequency:

- Mean degree-hours method: calculated from the hourly temperature data;
- Mean daily temperatures methods: used by USA and European standards (EN ISO 15927-6), and by Eurostat. Different versions of this method exist: for example Eurostat, differently from EN ISO 15927-6, consider in the calculation the set point temperature of the building in addition to the base temperature.
- Daily maximum and minimum temperatures method (used by the French and English national Meteorological Offices, and now adopted by the European Environment Agency).

In HYBUILD, the mean daily temperatures method is considered, as it is the one proposed by the European standards and it is commonly used and recognized both in the industrial and scientific worlds. The equations used to calculate HDDs and CDDs are presented below:

$$HDD_{Tbase} = \sum_{d=1}^{365}\left(T_{base} - \overline{T_{amb}(d)}\right) \quad \text{for the days “d” when} \quad \overline{T_{amb}(d)} < T_{base}$$

$$CDD_{Tbase} = \sum_{d=1}^{365}\left(\overline{T_{amb}(d)} - T_{base}\right) \quad \text{for the days “d” when} \quad \overline{T_{amb}(d)} > T_{base}$$

Where:

$T_{base}$ is the base temperature;

$HDD_{tbase}$ are the heating degree days having base temperature ‘$T_{base}$’ (e.g. $HDD_{15}$ are HDD calculated with a $T_{base}$ of 15 °C);

$CDD_{tbase}$ are the cooling degree days having base temperature ‘$T_{base}$’ (e.g. $CDD_{21}$ are CDD calculated with a $T_{base}$ of 21 °C);

$T_{amb}$ is the ambient temperature;

d is the day of the year.

$T_{base}$ can be fixed at different values, depending in principle on several factors associated with the building and the surrounding environment. Generally, the heating base temperature varies between 15 and 18°C. The European Environment Agency (EEA) considers 15.5 °C as reference value (European Environment Agency), while Eurostat consider a $T_{base}$ of 15 °C (Eurostat, the Statistical Office of the European Union). When considering highly insulated building, a lower heating $T_{base}$ of 12 °C could be considered (Kuhn T., 2014).

When it comes to the Cooling Degree Days calculation, the range of base temperatures are quite large, from 12 °C (for commercial buildings with large windows) to more than 20°C depending strongly on the building usage (Kuhn T., 2014). In INSPIRE project, the cooling base temperature of 21 °C has been considered to evaluate the cooling demand in Europe, while Eurostat consider a $T_{base}$ of 24 °C in its calculation and the EEA consider a $T_{base}$ of 22 °C.

In this document, a heating base temperature of 15 °C and a cooling base temperature of 21 °C have been considered.

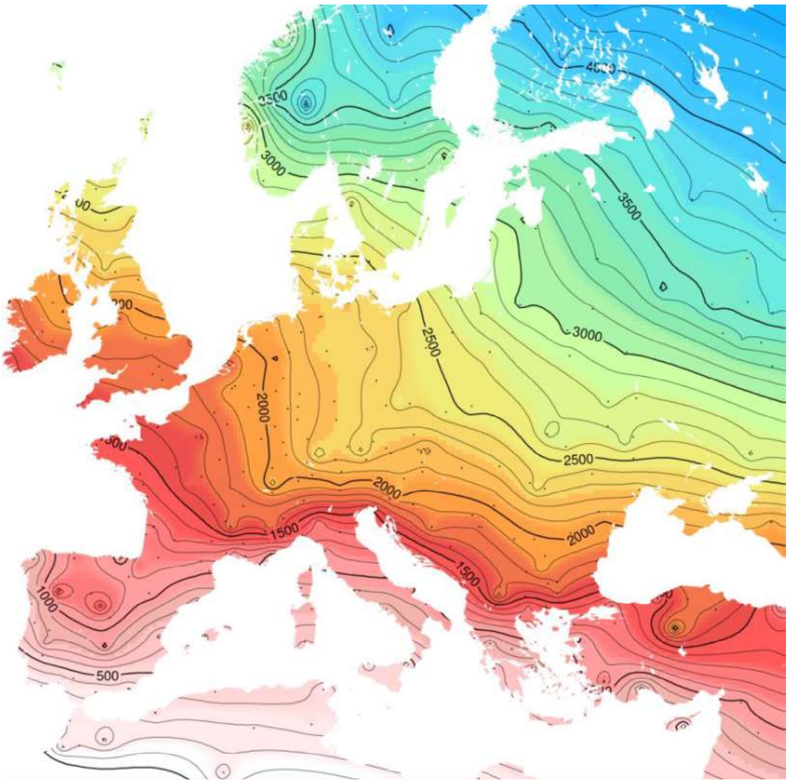


Figure 1 Heating degree days base 15 in Europe based on Meteonorm data (Kuhn T., 2014)

Two different hybrid storage concepts will be developed in HYBUILD, the ‘Mediterranean’ concept and the ‘Continental’ concept. Despite both solutions can cover both heating and cooling demand, the ‘Mediterranean’ concept is meant for cooling energy provision, while the ‘Continental’ concept is meant for climate where the energy for heating is the main need.

Since one of the objectives of the project is to investigate the applicability of the solutions under different conditions (in this case, climatic conditions), five reference cities and countries have been selected, covering hot, warm and cold climates in Europe.

In order to investigate the applicability in hot climates, two reference countries have been considered: Spain, with the reference city of Madrid and the demo site in Almatret; Greece, with the reference city of Athens. In addiction climatic characterization of Nicosia (Cyprus) has been carried out as representative of the demo site in Aglantzia, located in Nicosia District. The characterization of these climates is meant mainly to investigate the behaviour of the HYBUILD Mediterranean solution.

When it comes to the warm climate, France (south continental climate) has been considered as representative country, including the reference city of Lyon and the demo site location of

Bordeaux. In this warm climate it will be interesting to analyse the behaviour of both the HYBUILD Mediterranean and Continental solution.

Sweden and Germany, with the reference city of Stockholm and Stuttgart, have been chosen as representative respectively of Nordic and Continental climates, which are the targeted climates of the HYBUILD Continental solution.

In Table 3 the climates, countries and cities considered are reported:

Table 3 HYBUILD relevant climates being considered in the analysis

| Climate | Country | City |
|---|---|---|
| **Nordic** | Sweden | Stockholm |
| **Continental** | Germany | Stuttgart |
| **South continental** | France | Lyon |
| | | Bordeaux (demo site) |
| **Southern dry** | Spain | Madrid |
| | | Almatret (demo site) |
| **Mediterranean** | Greece | Athens |
| | Cyprus | Aglantzia (demo site) |

In the following sections, the climates of the cities identified above are characterized taking into account different parameters such as ambient temperature, humidity, solar irradiation, HDD and CDD. The data have been collected from the Meteonorm database (Meteonorm v7) for all reference cities, with the exception of the Almatret demo site, where the hourly ambient temperature profile for a reference year has been created with data coming from the nearest weather stations.

The data, exported from Meteonorm with .tm2 format, have been used as input for the energy demand analysis carried out thanks to dynamic simulations (see chapter 6). The files collected contain several meteorological data on an hourly basis. They represent the typical meteorological year of the different locations. The typical year is based on data belonging to the period 1991-2010 for the solar radiation, and to the period 2000-2009 for temperature and humidity.

For each location, relevant weather information has been stored in a database (excel file): the hourly values for external temperature, relative humidity, Global horizontal radiation (Gh), and Diffuse horizontal radiation (Dh) are shown and used to characterize the climate defining monthly values as well as yearly maximum and average data. HDD and CDD are calculated starting from the temperature data using the formulas defined above.

In the following paragraphs, the climate characterizations of the 6 reference cities and of the 3 demo sites are shown.

## 2.1 Nordic Climate: Stockholm

Stockholm is the capital of Sweden, located on the Baltic Sea near the 60th North parallel. It is the reference city for the Nordic climate. The annual mean temperature is equal to 7.9°C, while the minimum and maximum temperature varies from -16.4°C to 29.7°C. The winter is very cold, with the minimum temperature going below zero from October to April and having a mean temperature of 2.4 °C in that period. The summer is warm, with the average temperature not reaching the 20 °C.

When it comes to the relative humidity, it varies from 60% to 83%, with the mean annual humidity ratio is 73%, typical of a northern climate.

In Table 4, monthly and annual data of temperature, relative humidity and solar radiation are presented.

Table 4 Stockholm Climatic data (Meteonorm 7)

| | $T_{amb}$ mean | $T_{amb}$ min | $T_{amb}$ max | RH | Gh | Dh |
|---|---|---|---|---|---|---|
| | °C | °C | °C | % | kWh/m2 | kWh/m2 |
| **Jan** | -1.1 | -16.4 | 7.8 | 83 | 10 | 7 |
| **Feb** | -1.6 | -14.0 | 7.6 | 81 | 25 | 16 |
| **Mar** | 1.1 | -10.9 | 12.8 | 71 | 64 | 35 |
| **Apr** | 6.6 | -3.2 | 19.3 | 63 | 110 | 55 |
| **May** | 11.8 | 0.4 | 23.5 | 60 | 162 | 64 |
| **Jun** | 15.6 | 3.4 | 27.2 | 61 | 168 | 82 |
| **Jul** | 18.9 | 9.0 | 29.7 | 67 | 162 | 76 |
| **Aug** | 17.8 | 7.2 | 26.4 | 71 | 125 | 68 |
| **Sep** | 12.8 | 2.5 | 23.0 | 75 | 79 | 40 |
| **Oct** | 7.7 | -2.8 | 16.0 | 81 | 37 | 22 |
| **am** | 3.5 | -7.1 | 12.2 | 85 | 12 | 8 |
| **Dec** | 0.8 | -12.8 | 9.6 | 83 | 6 | 4 |
| **Annual** | 7.9 | -16.4 | 29.7 | 73 | 959 | 478 |

The following figure (Figure 2) shows the trend of the ambient temperature over one year in Stockholm, while Figure 3 and Figure 4 show the hourly profile of the colder month (February) and the hotter (July).

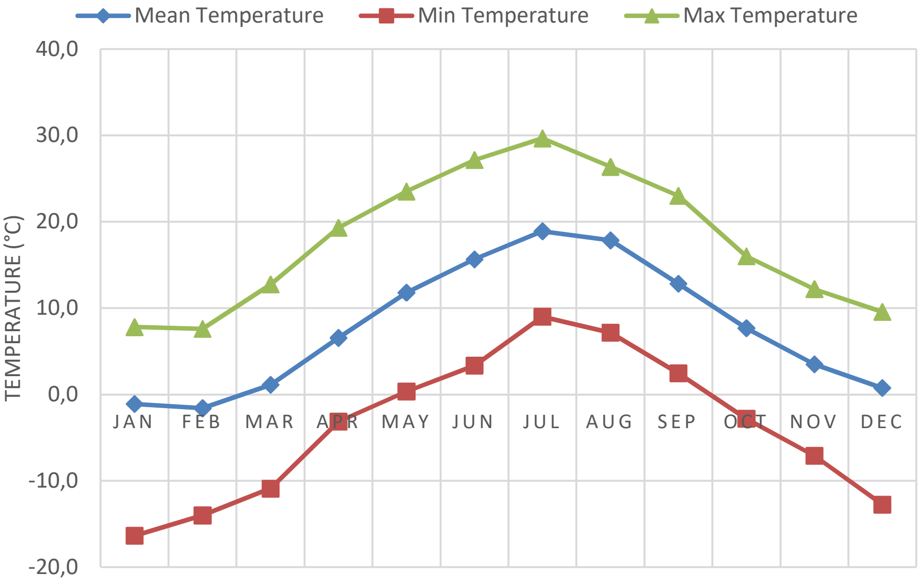


Figure 2 Monthly Ambient Temperature in Stockholm (Meteonorm 7)

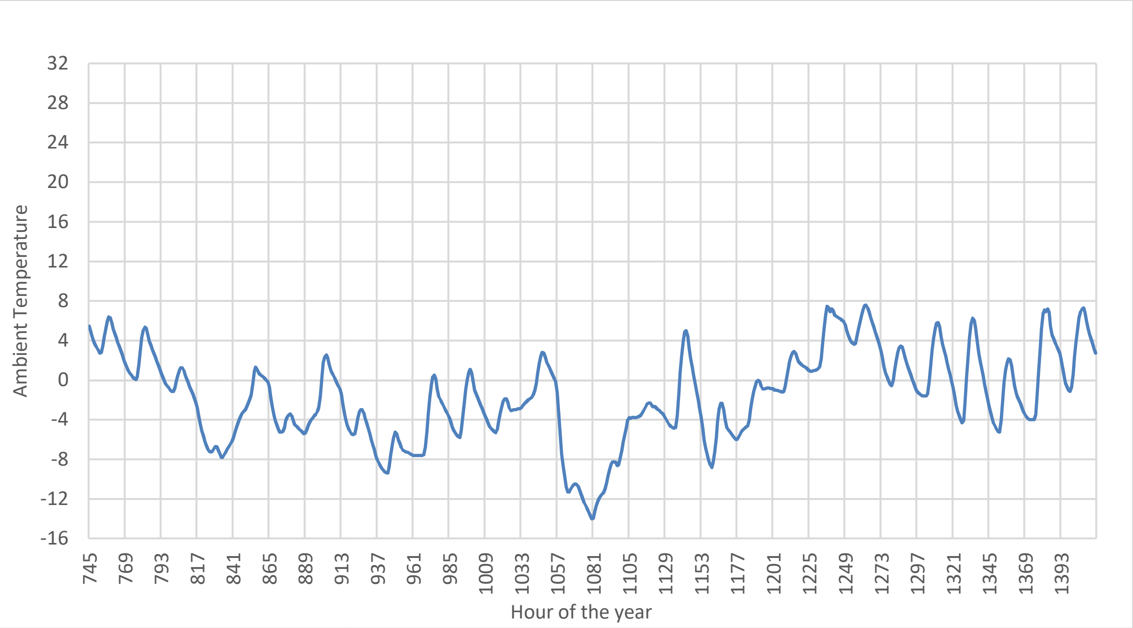


Figure 3 Ambient temperature hourly profile of February in Stockholm (Meteonorm 7)

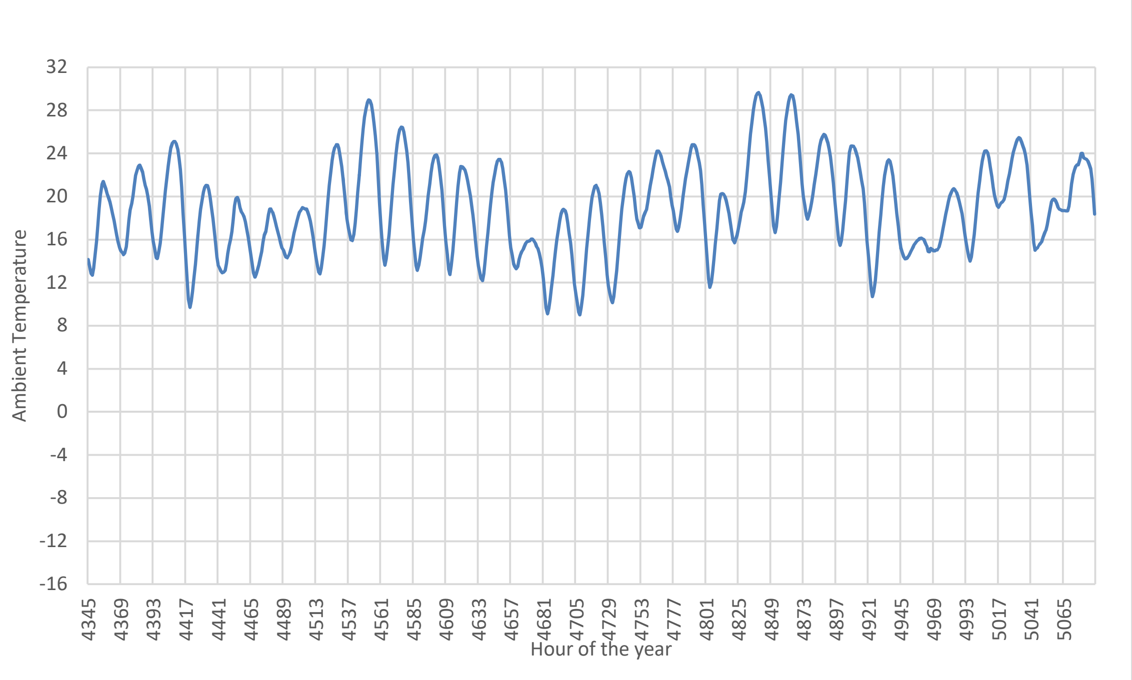


Figure 4 Ambient temperature hourly profile of July in Stockholm (Meteonorm 7)

Heating degree days and cooling degree days for Stockholm are shown in Table 5. As it can be seen, the annual HDDs are very high (2874 HDD15), representing a high heating demand. In fact, the heating period last almost 9 months, from mid-September to mid-May. No cooling demand is needed (annual CDDs equal to 16).

Table 5 Stockholm Heating and Cooling degree days

| | **HDD15** | **CDD21** |
|---|---|---|
| **Jan** | 499 | 0 |
| **Feb** | 465 | 0 |
| **Mar** | 430 | 0 |
| **Apr** | 253 | 0 |
| **May** | 106 | 0 |
| **Jun** | 26 | 0 |
| **Jul** | 1 | 12 |
| **Aug** | 4 | 4 |
| **Sep** | 76 | 0 |
| **Oct** | 227 | 0 |
| **Nov** | 345 | 0 |
| **Dec** | 442 | 0 |
| **Annual** | 2874 | 16 |

## 2.2 Continental Climate: Stuttgart

Stuttgart is located in the German state of Baden-Württemberg, in the south west of the country. Its geographical position, far from any sea in the middle of Europe at 245m above sea level, sets Stuttgart in a typical continental climate. The ambient temperature varies from the annual min of 12.5 °C to the annual max of 32.4 °C, with an average temperature of 10 °C. The winter is cold, with minimum temperatures below or near to 0 °C for seven months in the year. On the contrary, the summer is hot, with June, July and August having mean temperature around 18 °C and maximum temperature above 30°C.

Relative humidity varies from 67% in the spring and summer period to 80% in winter.

Table 6 shows monthly and annual values for temperature, humidity and solar radiation in Stuttgart.

Table 6 Stuttgart Climatic data (Meteonorm 7)

| | $T_{amb}$ **mean** | $T_{amb}$ **min** | $T_{amb}$ **max** | **RH** | **Gh** | **Dh** |
|---|---|---|---|---|---|---|
| | °C | °C | °C | % | kWh/m$^2$ | kWh/m$^2$ |
| **Jan** | 0.8 | -12.5 | 12.5 | 80 | 29 | 17 |
| **Feb** | 2.3 | -9.3 | 14.1 | 75 | 45 | 26 |
| **Mar** | 5.5 | -5.3 | 19.8 | 72 | 82 | 44 |
| **Apr** | 9.8 | -3.2 | 22.1 | 66 | 119 | 62 |
| **May** | 14.4 | 3.0 | 28.7 | 67 | 153 | 81 |
| **Jun** | 17.6 | 5.5 | 30.4 | 67 | 165 | 87 |
| **Jul** | 18.9 | 8.3 | 32.4 | 66 | 166 | 76 |
| **Aug** | 18.6 | 9.3 | 31.5 | 68 | 142 | 71 |
| **Sep** | 14.1 | 4.1 | 26.7 | 76 | 98 | 51 |
| **Oct** | 10.2 | 0.1 | 20.8 | 80 | 60 | 36 |
| **Nov** | 5.1 | -2.9 | 16.5 | 82 | 32 | 18 |
| **Dec** | 1.6 | -7.9 | 11.4 | 82 | 22 | 13 |
| **Annual** | 10.0 | -12.5 | 32.4 | 73 | 1112 | 581 |

In the following figures the yearly trend of the ambient temperature (Figure 5) and the hourly profiles of the colder and hotter month in Stuttgart are shown. (Figure 6; Figure 7)

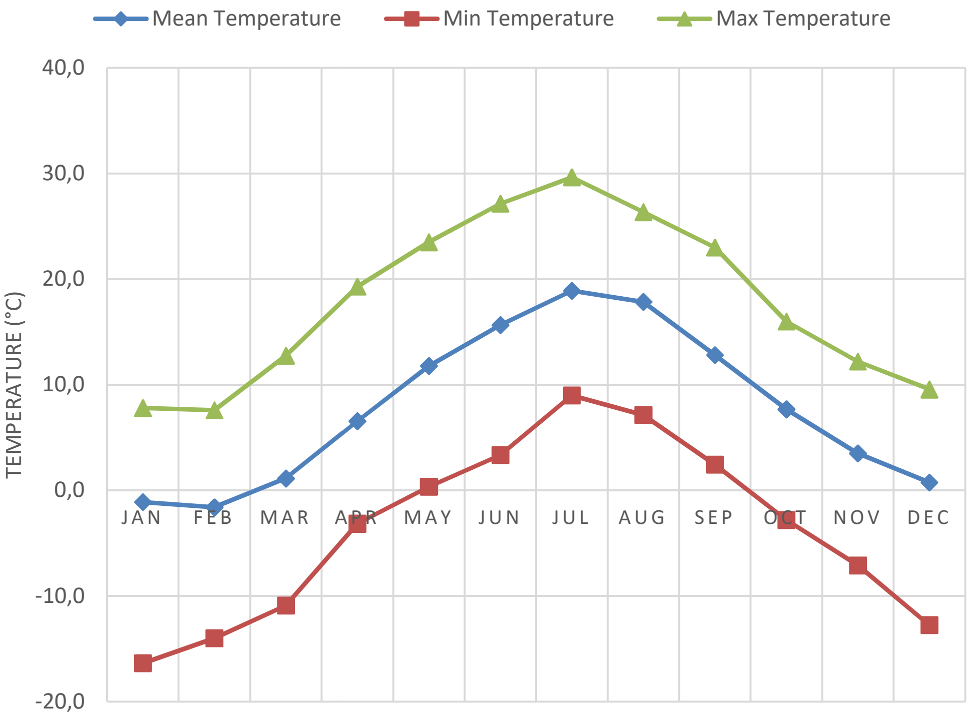


Figure 5 Monthly Ambient Temperatures in Stuttgart (Meteonorm 7)

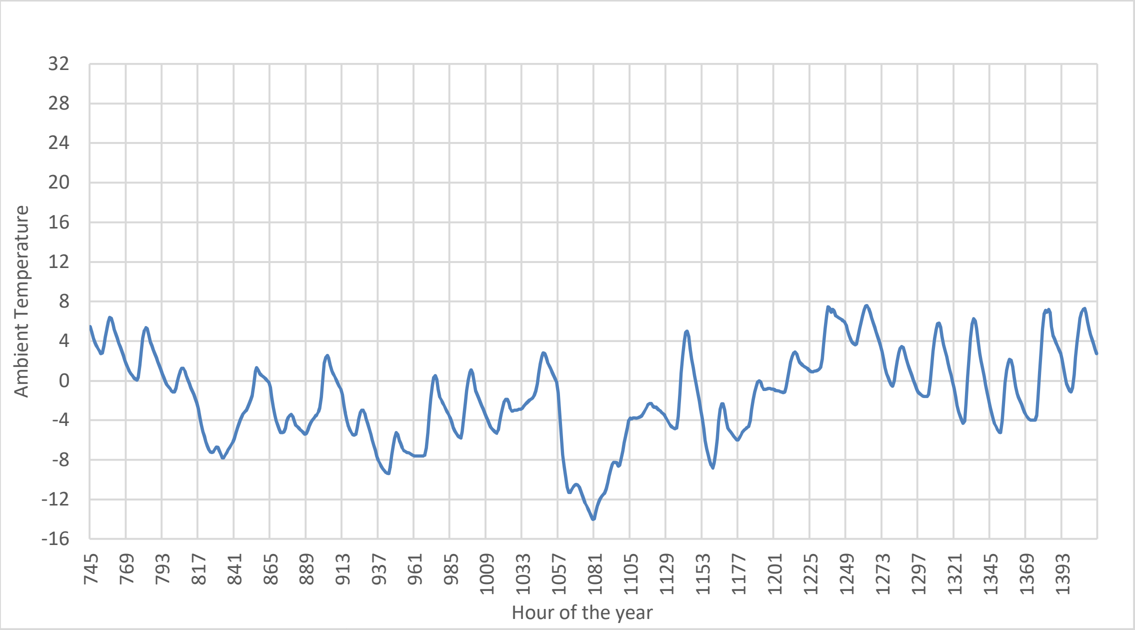


Figure 6 Ambient temperature hourly profile of January in Stuttgart (Meteonorm 7)

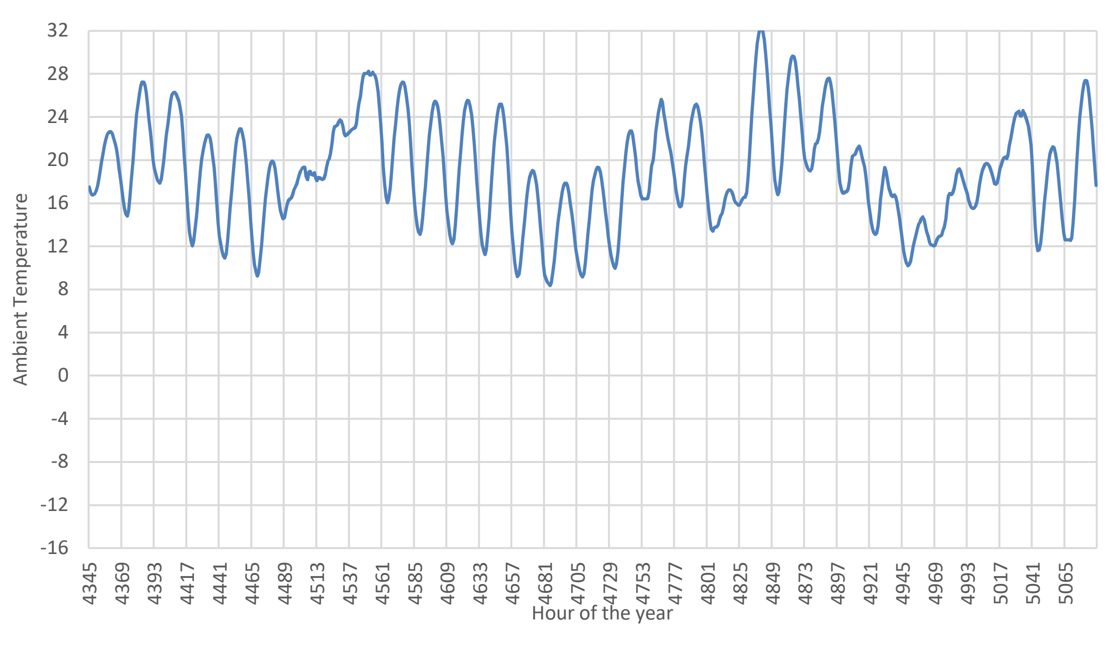


Figure 7 Ambient temperature hourly profile of July in Stuttgart (Meteonorm 7)

Table 7 shows the heating and cooling degree days of Stuttgart. The annual HDDs are equal to 2250, indicating a high request of heating energy. When it comes to the cooling demand, few CDDs are present during summer, with a cooling need that can be easily satisfied with passive cooling strategies.

Table 7 Stuttgart Heating and Cooling degree days

| | HDD15 | CDD21 |
|---|---|---|
| **Jan** | 441 | 0 |
| **Feb** | 356 | 0 |
| **Mar** | 295 | 0 |
| **Apr** | 161 | 0 |
| **May** | 54 | 1 |
| **Jun** | 16 | 13 |
| **Jul** | 5 | 17 |
| **Aug** | 4 | 14 |
| **Sep** | 56 | 0 |
| **Oct** | 151 | 0 |
| **Nov** | 296 | 0 |
| **Dec** | 442 | 0 |
| **Annual** | 2250 | 45 |

## 2.3 Southern Continental Climate: Lyon

Lyon is located on the south east of France, in Rhone valley. The climate is in the middle of Mediterranean and Continental climate. The annual average temperature is 13.1 °C and the difference between the annual max and annual min is about 40 °C. The winter is cold from November to March, while temperatures in spring and autumn are pleasant. The summer is hot with mean temperatures above 20 °C in June, July and August.

The average humidity is 69%, lower than in the colder climates. It varies from 56% in July to 81% in December.

Table 8 shows the monthly climatic data of Lyon.

Table 8 Lyon Climatic data (Meteonorm 7)

| | **$T_{amb}$ mean** | **$T_{amb}$ min** | **$T_{amb}$ max** | **RH** | **Gh** | **Dh** |
|---|---|---|---|---|---|---|
| | °C | °C | °C | % | kWh/m2 | kWh/m2 |
| **Jan** | 3.7 | -6.7 | 14.5 | 79 | 36 | 22 |
| **Feb** | 5.0 | -4.5 | 17.3 | 74 | 49 | 28 |
| **Mar** | 9.0 | -2.3 | 20.6 | 66 | 99 | 53 |
| **Apr** | 12.4 | 1.6 | 23.7 | 63 | 140 | 65 |
| **May** | 17.1 | 6.9 | 29.2 | 64 | 162 | 74 |
| **Jun** | 21.0 | 10.6 | 33.9 | 58 | 186 | 76 |
| **Jul** | 22.7 | 12.3 | 34.8 | 56 | 199 | 80 |
| **Aug** | 21.9 | 11.6 | 35.1 | 61 | 155 | 73 |
| **Sep** | 17.5 | 8.1 | 30.1 | 70 | 120 | 58 |
| **Oct** | 13.8 | 3.8 | 25.3 | 75 | 74 | 37 |
| **Nov** | 7.8 | -1.8 | 18.5 | 80 | 41 | 22 |
| **Dec** | 4.3 | -4.9 | 15.6 | 81 | 27 | 17 |
| **Annual** | 13.1 | -6.7 | 35.1 | 69 | 1289 | 603 |

The following figures show the trend of the monthly temperature (Figure 8) and the hourly profile of the colder and hotter months, represented by February (Figure 9) and July (Figure 10) in Lyon.

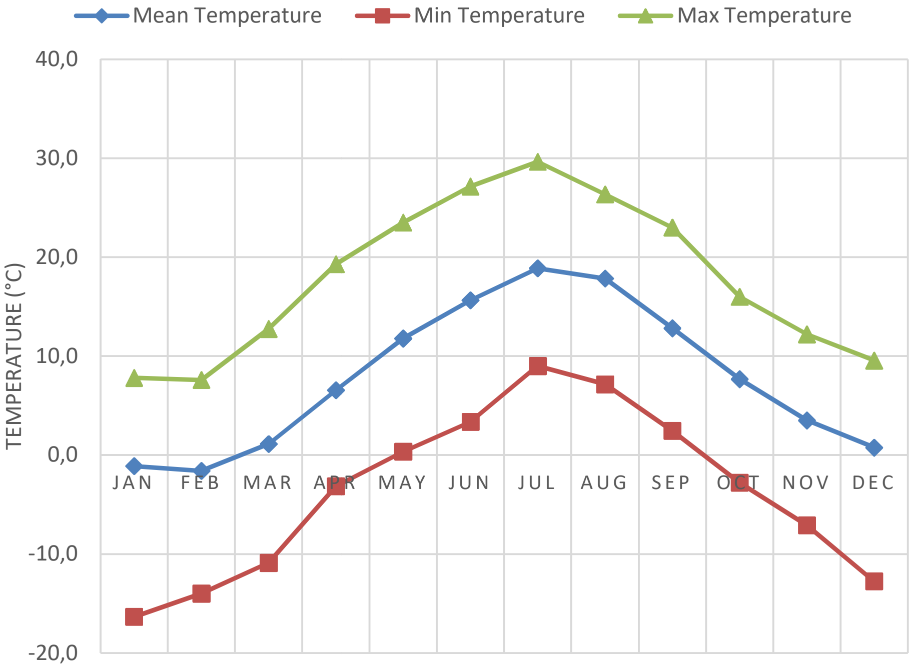


Figure 8 Monthly ambient temperatures in Lyon (Meteonorm 7)

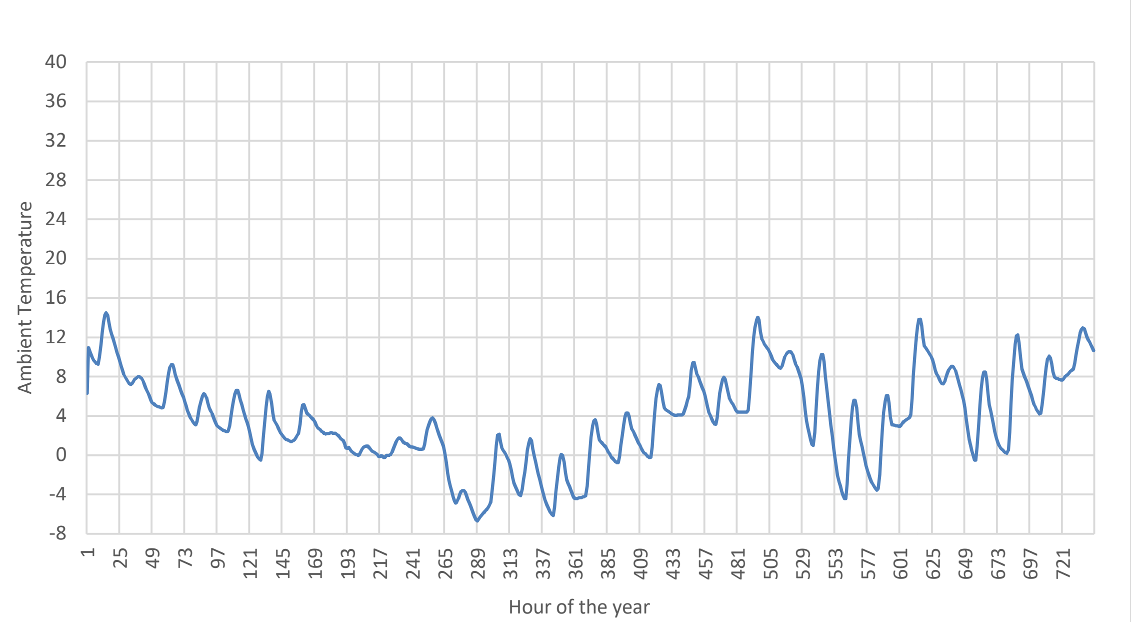


Figure 9 Ambient temperature hourly profile of january  in Lyon (Meteonorm 7)

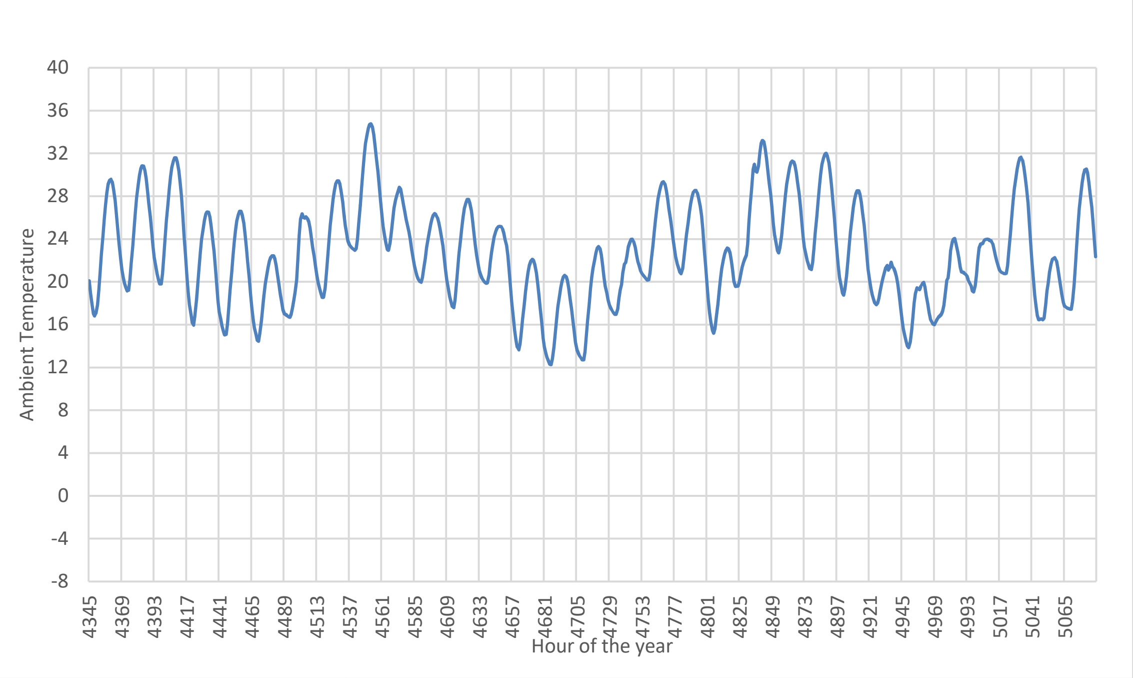


Figure 10 Ambient temperature hourly profile of July in Lyon (Meteonorm 7)

Heating and cooling degree days of Lyon are shown in Table 9. The total amount of HDDs is 1546, with the heating season lasting from November to April. Annual CDDs are equal to 185, with need for cooling from June to August, even if it is limited with respect to the Mediterranean and Southern Dry climates.

Table 9 Lyon Heating and Cooling degree days

| | **HDD15** | **CDD21** |
|---|---|---|
| **Jan** | 349 | 0 |
| **Feb** | 279 | 0 |
| **Mar** | 187 | 0 |
| **Apr** | 93 | 0 |
| **May** | 16 | 5 |
| **Jun** | 0 | 43 |
| **Jul** | 0 | 73 |
| **Aug** | 0 | 57 |
| **Sep** | 10 | 7 |
| **Oct** | 64 | 0 |
| **Nov** | 215 | 0 |
| **Dec** | 333 | 0 |
| **Annual** | 1546 | 185 |

## 2.4 Southern Continental Climate: Bordeaux (demo site)

Bordeaux is situated in the Nouvelle Aquitaine Region, North-west of France. It is the site for one of the demo buildings. As Lyon, it belongs to the Southern Continental climate, with an average annual temperature of 13.6 degrees. However, it presents higher mean temperature during winter, due to the proximity of the ocean.

Relative Humidity varies from 67 % to 83 %, with an average of 74%, higher than Lyon.

Table 10 Bordeaux Climatic data (Meteonorm 7)

| | **$T_{amb}$ mean** | **$T_{amb}$ min** | **$T_{amb}$ max** | **RH** | **Gh** | **Dh** |
|---|---|---|---|---|---|---|
| | °C | °C | °C | % | kWh/m2 | kWh/m2 |
| **Jan** | 6.6 | -3.7 | 16.9 | 83 | 42 | 27 |
| **Feb** | 7.4 | -3.9 | 18.4 | 78 | 58 | 33 |
| **Mar** | 10.3 | -0.4 | 23.2 | 71 | 104 | 49 |
| **Apr** | 12.5 | 3.3 | 24.7 | 72 | 128 | 63 |
| **May** | 16.5 | 7.0 | 29.2 | 70 | 170 | 82 |
| **Jun** | 20.0 | 10.2 | 30.7 | 68 | 183 | 83 |
| **Jul** | 21.2 | 11.7 | 35.9 | 67 | 183 | 89 |
| **Aug** | 21.2 | 11.3 | 34.5 | 67 | 163 | 74 |
| **Sep** | 18.0 | 8.8 | 29.7 | 72 | 120 | 58 |
| **Oct** | 15.0 | 5.4 | 25.8 | 79 | 79 | 43 |
| **Nov** | 9.4 | 0.8 | 20.2 | 83 | 46 | 26 |
| **Dec** | 6.5 | -4.6 | 17.1 | 85 | 32 | 20 |
| **Annual** | 13.6 | -4.6 | 35.9 | 74 | 1308 | 648 |

In the following figures monthly values for ambient temperature and hourly temperature profiles for the hotter and the colder month are presented (Figure 11; Figure 12; Figure 13).

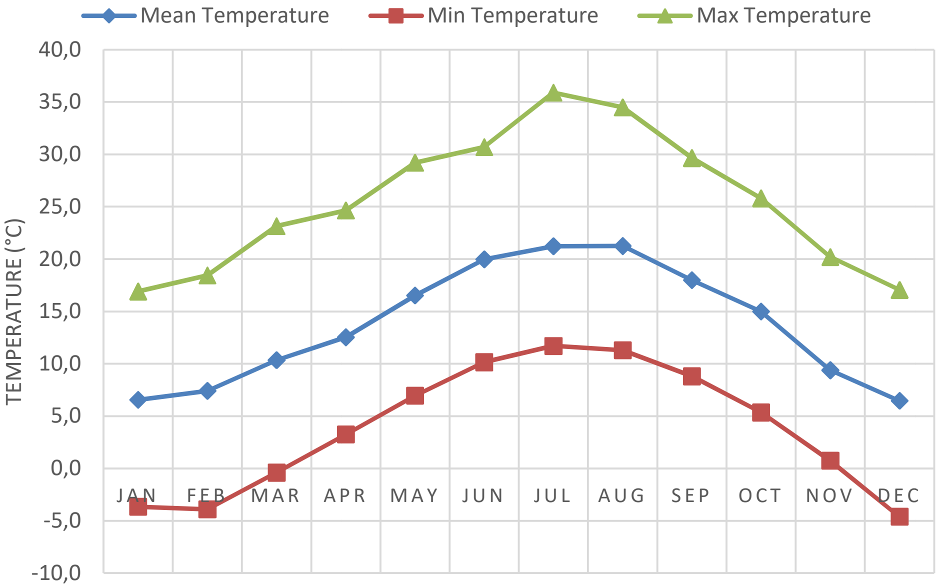


Figure 11 Monthly ambient temperature in Bordeaux (Meteonorm 7).

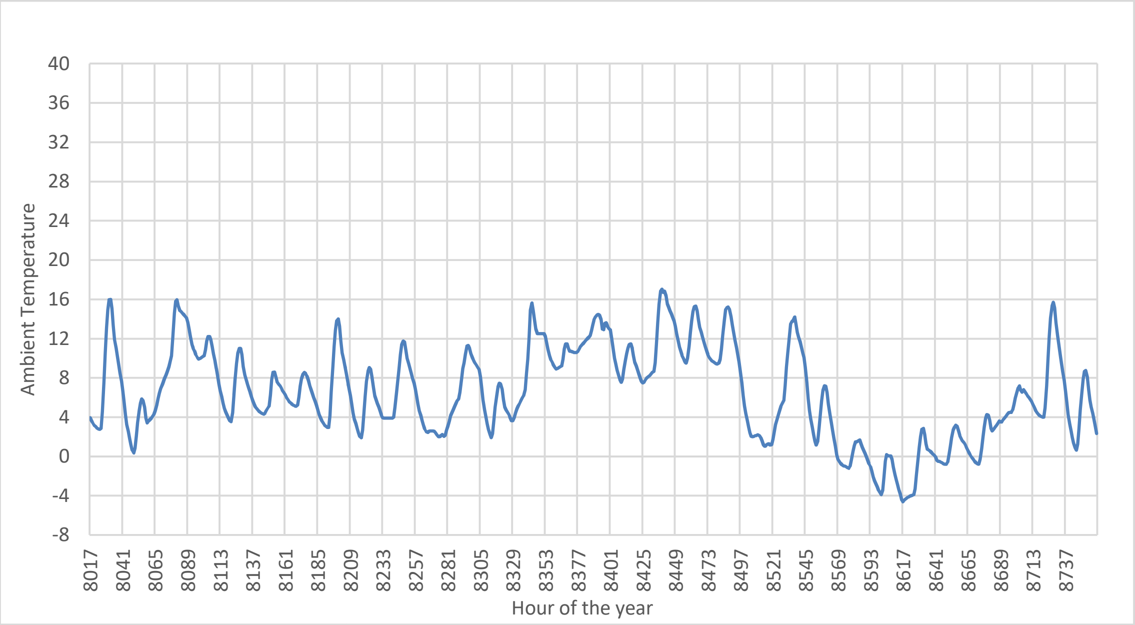


Figure 12 Ambient temperature hourly profile of December in Bordeaux (Meteonorm 7)

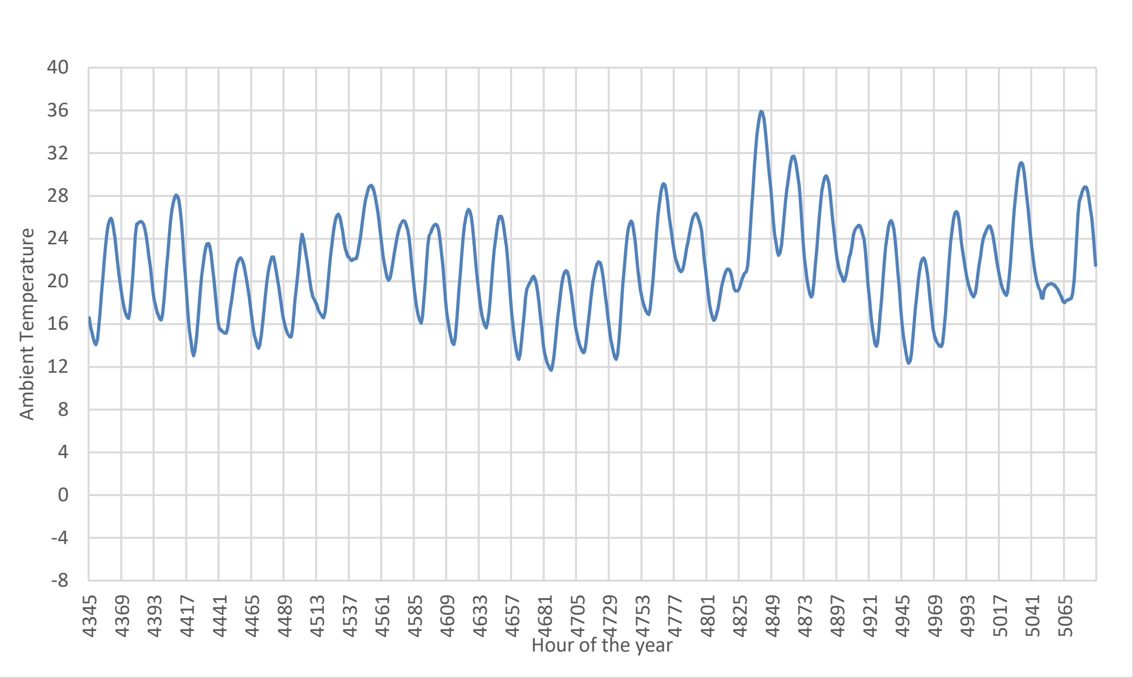


Figure 13 Ambient temperature hourly profile of July in Bordeaux (Meteonorm 7)

With respect to the case of Lyon described in chapter 2.3, the heating degree days in Bordeaux are lower, equal to 1197, as well as the cooling degree days (115) indicating lower energy need both in winter and summer. In particular the need for cooling in residential building is very low. In the case of HYBUILD project and the Bordeaux demo site, it has to be considered that it is an office building, where cooling demand is higher than in residential building. To give an assessment of the cooling need for office buildings, the calculation of CDDs with base temperature equal to 16 °C could be used (Kuhn T., 2014). In this case, CDDs vary between 115 (base 21) and 588 (base 16). In Table 11 HDDs and CDDs of Bordeaux are presented.

Table 11 Bordeaux Heating and Cooling degree Days

| | HDD15 | CDD21 | CDD16 |
|---|---|---|---|
| **Jan** | 262 | 0 | 0 |
| **Feb** | 213 | 0 | 0 |
| **Mar** | 145 | 0 | 0 |
| **Apr** | 86 | 0 | 6 |
| **May** | 16 | 4 | 45 |
| **Jun** | 0 | 25 | 121 |
| **Jul** | 0 | 40 | 162 |
| **Aug** | 0 | 38 | 163 |
| **Sep** | 3 | 8 | 68 |
| **Oct** | 39 | 0 | 24 |

| | | | |
|---|---|---|---|
| **Nov** | 169 | 0 | 0 |
| **Dec** | 265 | 0 | 0 |
| **Annual** | 1197 | 115 | 588 |

## 2.5 Southern Dry Climate: Madrid

Madrid, the Capital of Spain is located in the middle of the Iberian Peninsula. It presents a mean ambient temperature of 14.4°C on annual basis. The summer is very hot, with average temperatures in July and August of about 25 °C and a maximum up to 37°C. The cold season lasts from half of October until March, reaching a minimum temperature of -4.9 °C and average temperatures between 5 and 10 Celsius degrees.

The climate in Madrid is dry, with an annual average relative humidity of 57% and average values near 30% in July and August.

Monthly and annual data on temperature, relative humidity and solar irradiation are shown in Table 12.

Table 12 Madrid Climatic Data (Meteonorm 7)

| | $T_{amb}$ mean | $T_{amb}$ min | $T_{amb}$ max | RH | Gh | Dh |
|---|---|---|---|---|---|---|
| | °C | °C | °C | % | kWh/m$^2$ | kWh/m$^2$ |
| **Jan** | 5.2 | -4.2 | 16.3 | 75 | 63 | 24 |
| **Feb** | 6.7 | -3.3 | 17.6 | 69 | 82 | 32 |
| **Mar** | 10.3 | -1.2 | 22.9 | 60 | 134 | 47 |
| **Apr** | 12.2 | 1.6 | 24.4 | 59 | 164 | 63 |
| **May** | 17.0 | 5.2 | 32.0 | 53 | 197 | 73 |
| **Jun** | 22.9 | 10.6 | 36.7 | 41 | 230 | 68 |
| **Jul** | 25.7 | 13.0 | 37.2 | 31 | 234 | 63 |
| **Aug** | 24.9 | 12.4 | 37.1 | 33 | 204 | 60 |
| **Sep** | 20.0 | 8.8 | 32.4 | 45 | 151 | 53 |
| **Oct** | 14.8 | 5.1 | 25.8 | 65 | 99 | 45 |
| **Nov** | 8.5 | -1.2 | 21.0 | 72 | 67 | 28 |
| **Dec** | 5.5 | -4.9 | 16.9 | 76 | 50 | 25 |
| **Annual** | 14.5 | -4.9 | 37.2 | 57 | 1676 | 583 |

In the following figures monthly values for ambient temperature (Figure 14) and hourly temperature profiles for the hotter and the colder month in Madrid are presented (Figure 15; Figure 16).

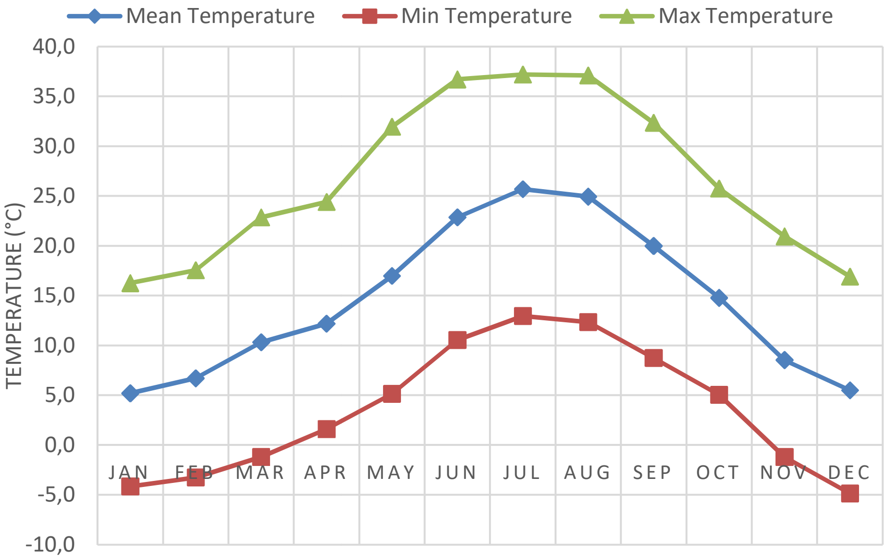


Figure 14 Monthly ambient temperature in Madrid (Meteonorm 7).

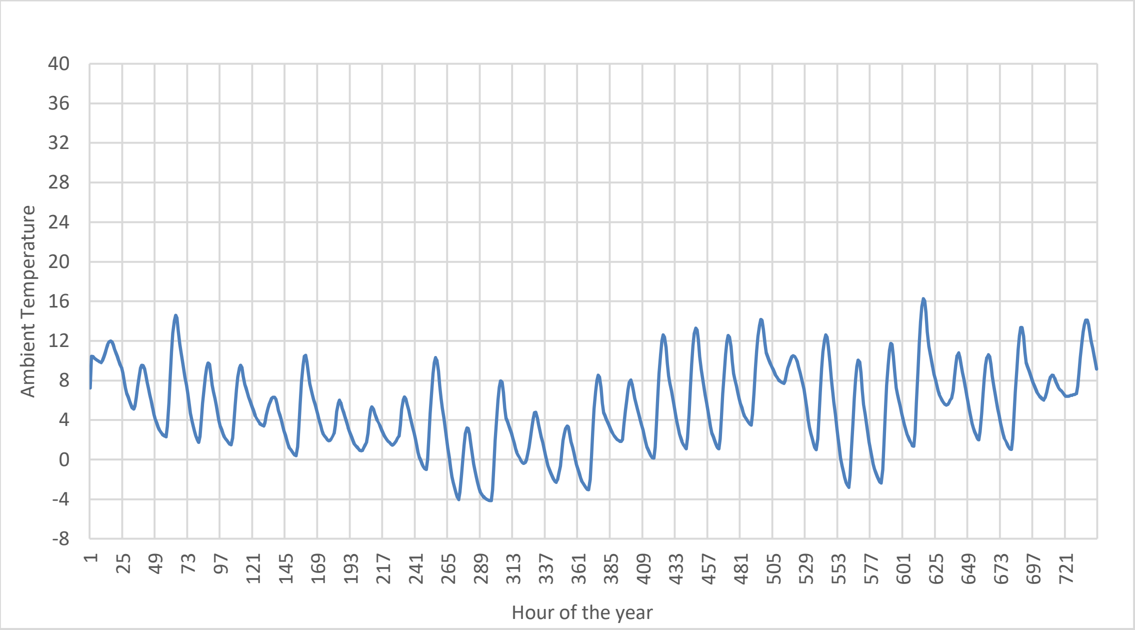


Figure 15 Ambient temperature hourly profile of January in Madrid (Meteonorm 7)

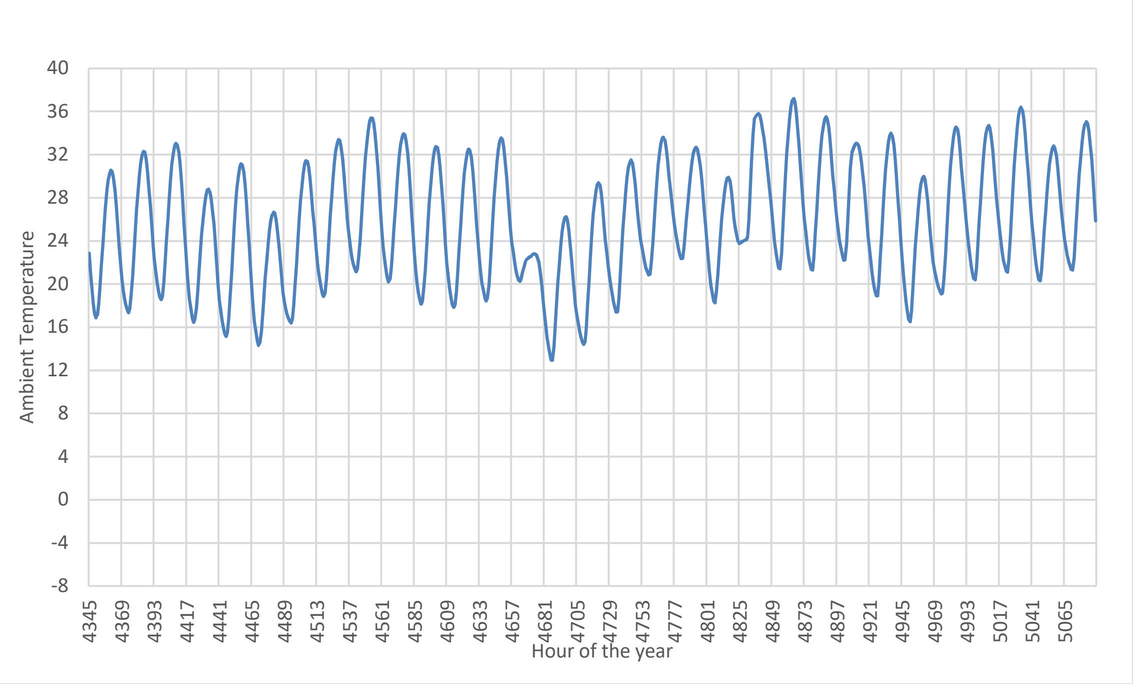


Figure 16 Ambient temperature hourly profile of July in Madrid (Meteonorm 7)

In Madrid the total amount of HDDs is 1324 and the heating season lasts from November to March. The annual cooling degree days are equal to 377, with high cooling demand for residential building from June to August. HDDs and CDDs are shown in Table 13.

Table 13 Madrid Heating and Cooling Degree Days

| | HDD15 | CDD21 |
|---|---|---|
| **Jan** | 304 | 0 |
| **Feb** | 232 | 0 |
| **Mar** | 145 | 0 |
| **Apr** | 94 | 0 |
| **May** | 23 | 8 |
| **Jun** | 0 | 75 |
| **Jul** | 0 | 147 |
| **Aug** | 0 | 124 |
| **Sep** | 1 | 23 |
| **Oct** | 35 | 0 |
| **Nov** | 194 | 0 |
| **Dec** | 295 | 0 |
| **Annual** | 1324 | 377 |

## 2.6 Southern Dry Climate: Almatret (demo site)

Almatret is a little village located in the region of Segrià (Lleida), in Catalonia, Spain. It is the location for one of the three demonstrators, consisting in a single family house. Since no specific information for Almatret is available in Meteonorm, the typical temperature profile has been created considering data available from nearest weather stations.

The average annual temperature is equal to 17 °C; the summer is slightly hotter than in Madrid, with average temperatures of 26 °C in July and August. The winter is warmer, with only two months having an average temperature below 10 °C.

Table 14 shows monthly and annual mean temperature for Almatret.

Table 14 Almatret Climatic Data

| | $T_{amb}$ mean | $T_{amb}$ min | $T_{amb}$ max |
|---|---|---|---|
| | °C | °C | °C |
| **Jan** | 8.7 | -3.2 | 21.1 |
| **Feb** | 10.2 | 0.5 | 21.0 |
| **Mar** | 13.3 | 2.8 | 25.6 |
| **Apr** | 15.4 | 6.2 | 25.6 |
| **May** | 19.5 | 10.3 | 30.5 |
| **Jun** | 24.0 | 14.3 | 34.6 |
| **Jul** | 26.1 | 16.7 | 35.8 |
| **Aug** | 26.0 | 16.2 | 35.2 |
| **Sep** | 22.0 | 13.2 | 31.5 |
| **Oct** | 18.3 | 8.6 | 28.0 |
| **Nov** | 12.5 | 3.2 | 22.0 |
| **Dec** | 9.1 | -1.4 | 20.1 |
| **Annual** | 17.1 | -3.2 | 35.8 |

In the following figures monthly values for ambient temperature (Figure 17) and hourly temperature profiles for the hotter and the colder month in Almatret are presented (Figure 18; Figure 19).

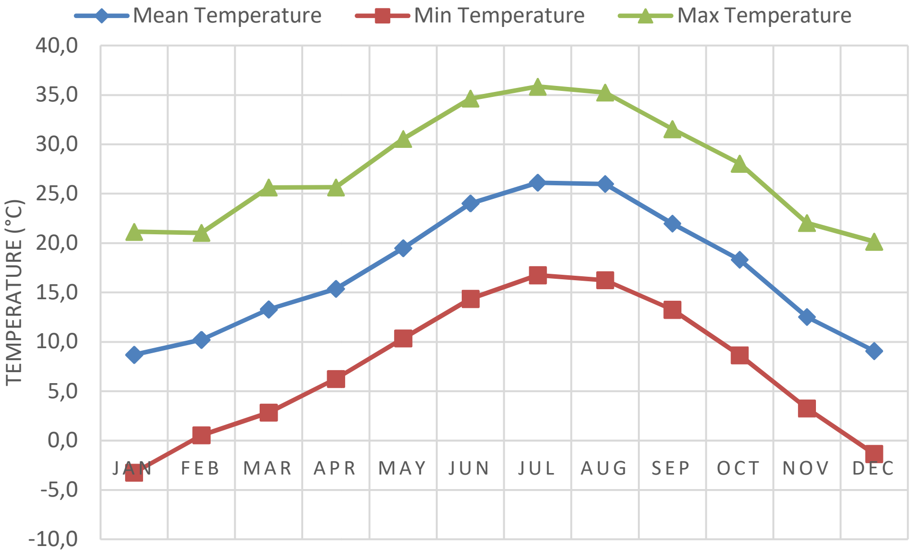


Figure 17 Monthly ambient temperature in Almatret (Meteonorm).

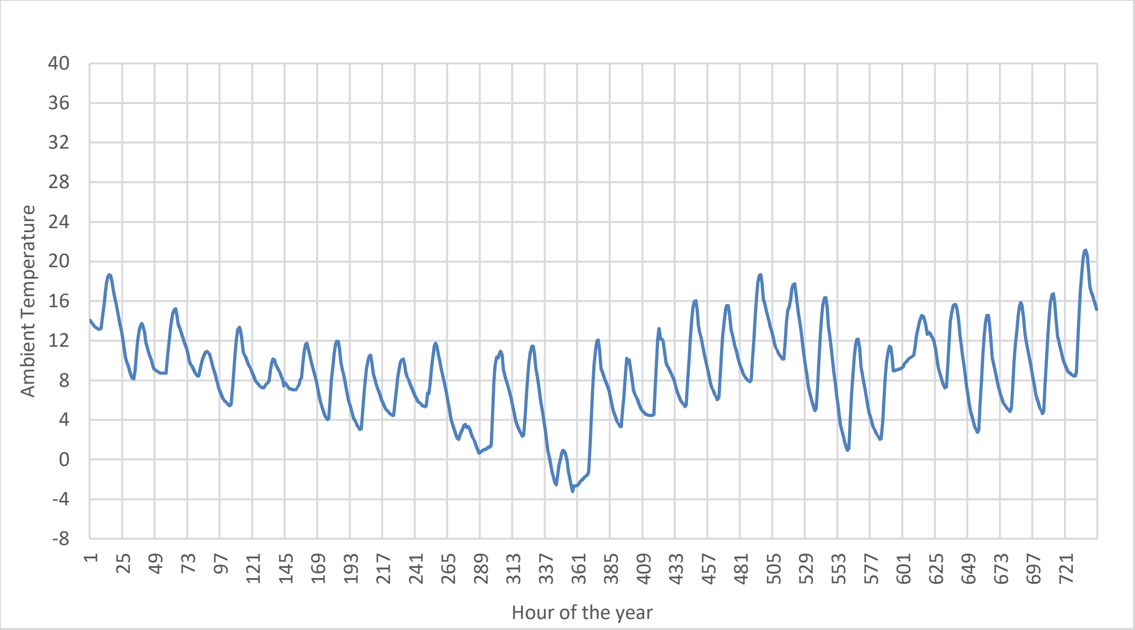


Figure 18 Ambient temperature hourly profile of January in Almatret

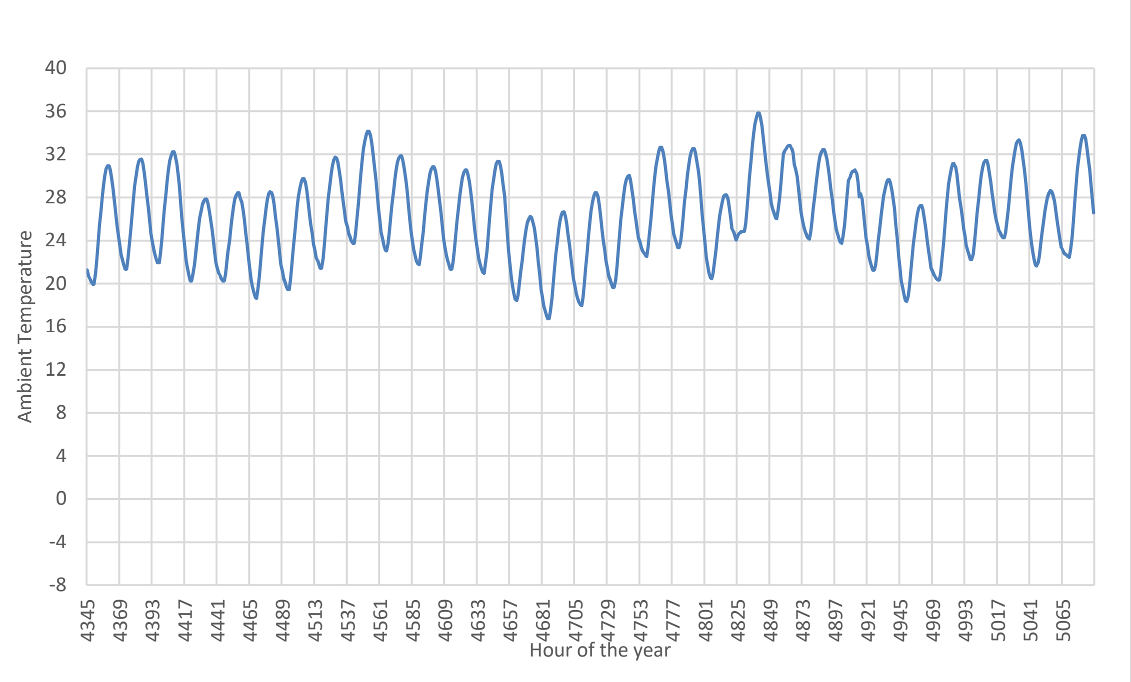


Figure 19 Ambient temperature hourly profile of July in Almatret

Total amount of heating degree days in Almatret is 696, presenting a climate a bit different from the one of Madrid, despite geographical proximity. The cooling degree days, equal to 468, indicate high cooling demand from June to August.

Table 15 Almatret heating and Cooling Degree Days

| | HDD15 | CDD21 |
|---|---|---|
| **Jan** | 196 | 0 |
| **Feb** | 135 | 0 |
| **Mar** | 68 | 0 |
| **Apr** | 24 | 0 |
| **May** | 3 | 15 |
| **Jun** | 0 | 94 |
| **Jul** | 0 | 159 |
| **Aug** | 0 | 155 |
| **Sep** | 0 | 42 |
| **Oct** | 4 | 4 |
| **Nov** | 81 | 0 |
| **Dec** | 184 | 0 |
| **Annual** | 696 | 468 |

When it comes to the other climatic parameters, in particular the Solar irradiation, in order to perform the energy simulation for the HYBUILD system evaluation, the weather data of Barcelona has been chosen: in fact, comparing the solar irradiation data obtained thanks to PVGIS (Joint Research Centre - European Commission, 2012) for Almatret, Madrid and Barcelona, the results show that the irradiation in Almatret is very close to the one in Barcelona, with little differences also on a monthly basis (Table 16):

Table 16 Comparison of solar irradiation in Almatret, Barcelona and Madrid

| Month | Almatret | Barcelona | Difference | Madrid | Difference |
|---|---|---|---|---|---|
| | Wh/m$^2$/day | Wh/m$^2$/day | % | Wh/m$^2$/day | % |
| **Jan** | 1990 | 2120 | 6.1 | 2080 | 4 |
| **Feb** | 3090 | 3070 | -0.7 | 3130 | 1 |
| **Mar** | 4690 | 4630 | -1.3 | 4690 | 0 |
| **Apr** | 5360 | 5440 | 1.5 | 5600 | 4 |
| **May** | 6510 | 6660 | 2.3 | 6640 | 2 |
| **Jun** | 7310 | 7380 | 0.9 | 7670 | 5 |
| **Jul** | 7450 | 7330 | -1.6 | 8030 | 7 |
| **Aug** | 6380 | 6300 | -1.3 | 7000 | 9 |
| **Sep** | 4970 | 4830 | -2.9 | 5370 | 7 |
| **Oct** | 3580 | 3530 | -1.4 | 3700 | 3 |
| **Nov** | 2300 | 2300 | 0.0 | 2390 | 4 |
| **Dec** | 1740 | 1870 | 7.0 | 1910 | 9 |
| **Year** | 4620 | 4630 | 0.2 | 4860 | 5 |

## 2.7 Mediterranean Climate: Athens

Athens is located in the Attica region, in South east of Greece. The annual mean temperature is equal to 16.5°C. The average winter temperature goes below 10 °C from December to February, with the annual minimum temperature reached in January equal to -8.1°C. The summer is hot and long, with average temperature above the 20 °C from May to September, and maximum temperatures up to 36 °C.

The annual relative humidity is equal to 68%. Humidity percentages are higher during summer, with value above 70%, than in winter, showing opposite trends with respect to the southern dry climate.

Table 17 shows monthly and annual values of ambient temperature, relative humidity and solar radiation in Athens.

Table 17 Athens Climatic Data (Meteonorm 7)

| | $T_{amb}$ mean | $T_{amb}$ min | $T_{amb}$ max | RH | Gh | Dh |
|---|---|---|---|---|---|---|
| | °C | °C | °C | % | $kWh/m^2$ | $kWh/m^2$ |
| **Jan** | 6.6 | -8.1 | 22.6 | 63 | 82 | 31 |
| **Feb** | 8.2 | -4.4 | 21.9 | 61 | 90 | 46 |
| **Mar** | 12.5 | -2.6 | 27.9 | 61 | 138 | 61 |
| **Apr** | 16.4 | 3.7 | 30.3 | 63 | 172 | 66 |
| **May** | 20.8 | 9.1 | 33.1 | 68 | 188 | 80 |
| **Jun** | 24.3 | 14.1 | 35.7 | 70 | 199 | 82 |
| **Jul** | 25.9 | 16.8 | 36.1 | 71 | 192 | 92 |
| **Aug** | 25.8 | 17.2 | 36.1 | 72 | 174 | 82 |
| **Sep** | 22.0 | 11.4 | 33.0 | 74 | 135 | 63 |
| **Oct** | 16.8 | 2.9 | 29.5 | 72 | 131 | 48 |
| **Nov** | 11.6 | -1.2 | 27.2 | 68 | 80 | 43 |
| **Dec** | 7.0 | -5.5 | 22.2 | 67 | 72 | 32 |
| **Annual** | 16.5 | -8.1 | 36.1 | 68 | 1655 | 727 |

In the following figures monthly values for ambient temperature (Figure 20) and hourly temperature profiles for the hotter and the colder month in Athens are presented (Figure 21; Figure 22).

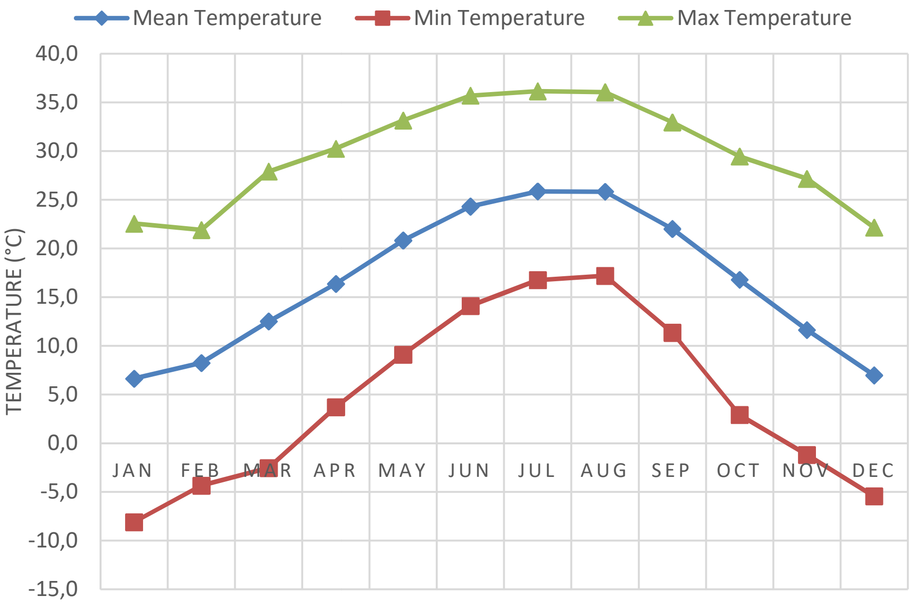


Figure 20 Monthly ambient temperature in Athens (Meteonorm 7)

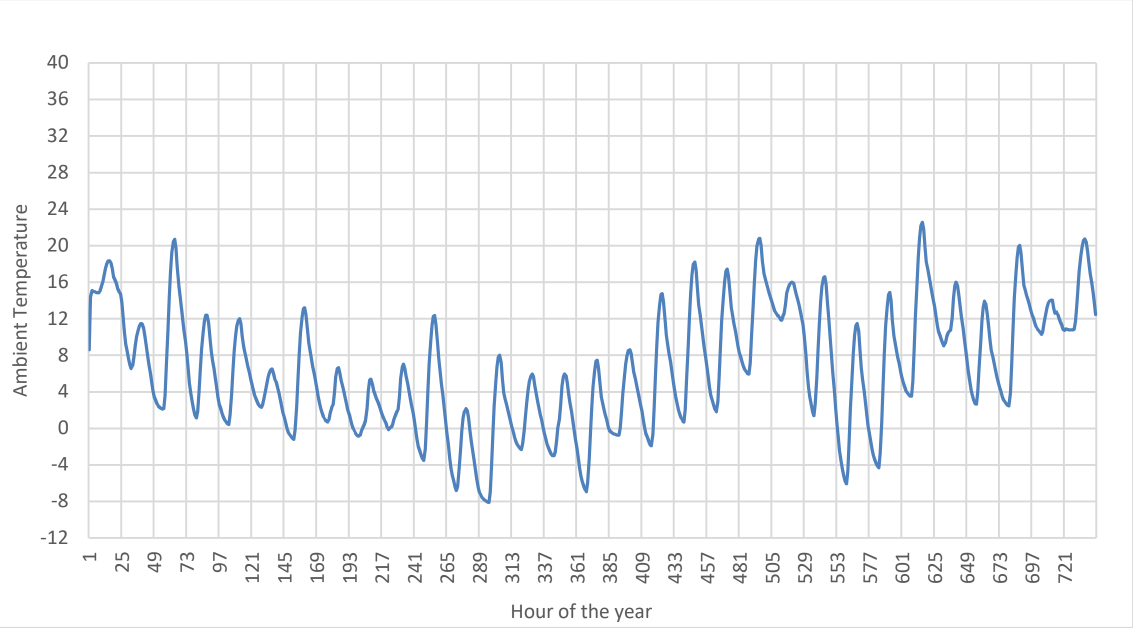


Figure 21 Ambient temperature hourly profile of January in Athens (Meteonorm 7)

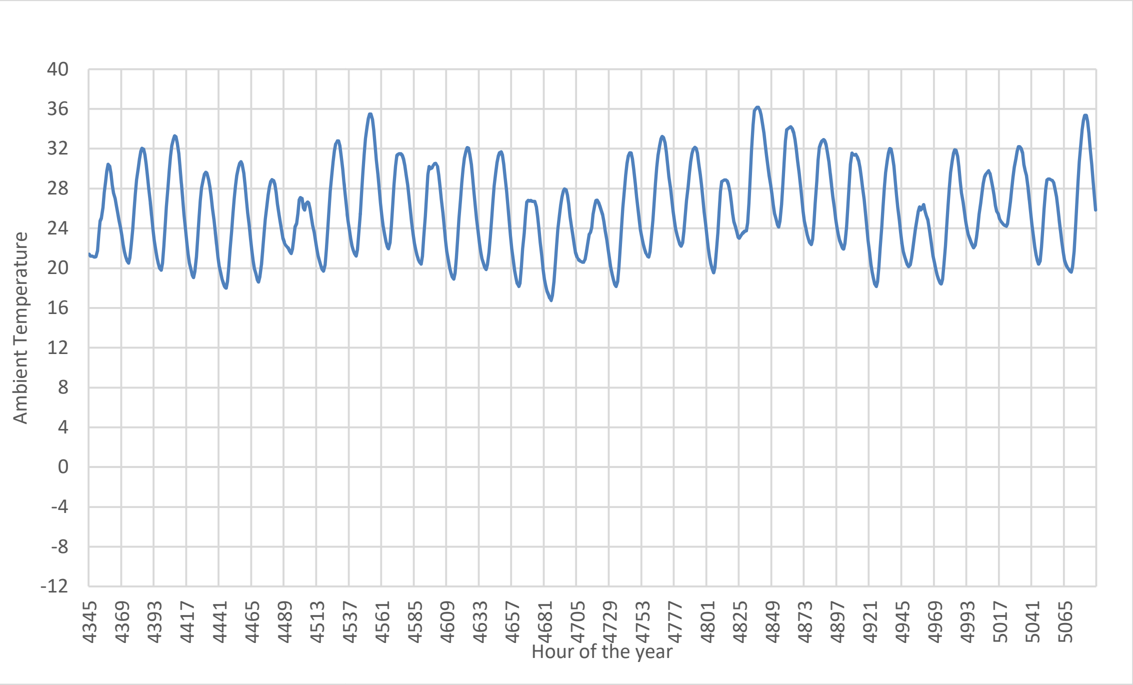


Figure 22 Ambient temperature hourly profile of July in Athens (Meteonorm 7)

Heating degree days in Athens are equal to 971, with the heating season lasting from November to March. The cooling degree days are equal to 490, with cooling demand in June, July and August.

Table 18 Athens heating and Cooling Degree Days

| | HDD15 | CDD21 |
|---|---|---|
| **Jan** | 260 | 0 |
| **Feb** | 190 | 0 |
| **Mar** | 98 | 0 |
| **Apr** | 25 | 4 |
| **May** | 1 | 34 |
| **Jun** | 0 | 100 |
| **Jul** | 0 | 151 |
| **Aug** | 0 | 150 |
| **Sep** | 0 | 47 |
| **Oct** | 29 | 4 |
| **Nov** | 117 | 0 |
| **Dec** | 251 | 0 |
| **Annual** | 971 | 490 |

## 2.8 Mediterranean Climate: Nicosia (Aglantzia demo site)

Nicosia is located in the middle of Cyprus Island, of which it is the Capital. The HYBUILD demo site is located in Aglantzia, a municipality within the Nicosia district.

The climate is very hot, with average annual temperature of 19.2 °C, and having monthly mean temperature above 10 °C all over the year. During summer, temperatures up to 37 °C are reached, with average temperature above 25 °C from June to September.

The annual relative humidity is equal to 66%, with a maximum of 73% during winter and a minimum of 61% during summer. Table 19 shows monthly and annual value of ambient temperature, relative humidity and solar radiation in Nicosia.

Table 19 Nicosia Climatic data (Meteonorm 7)

| | $T_{amb}$ mean | $T_{amb}$ min | $T_{amb}$ max | RH | Gh | Dh |
|---|---|---|---|---|---|---|
| | °C | °C | °C | % | kWh/m$^2$ | kWh/m$^2$ |
| **Jan** | 11.4 | 3.1 | 20.8 | 71 | 77 | 37 |
| **Feb** | 11.7 | 2.3 | 20.3 | 73 | 94 | 37 |
| **Mar** | 14.4 | 5.4 | 24.6 | 69 | 143 | 60 |
| **Apr** | 17.6 | 9.3 | 27.8 | 66 | 174 | 76 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **May** | 22.2 | 13.4 | 32.5 | 60 | 207 | 80 |
| **Jun** | 25.8 | 17.6 | 36.1 | 61 | 231 | 76 |
| **Jul** | 28.6 | 21.4 | 37.4 | 65 | 220 | 78 |
| **Aug** | 28.5 | 21.7 | 34.9 | 67 | 203 | 72 |
| **Sep** | 25.4 | 18.7 | 32.8 | 64 | 168 | 57 |
| **Oct** | 22.4 | 13.3 | 31.2 | 62 | 136 | 41 |
| **Nov** | 17.1 | 8.7 | 27.2 | 66 | 91 | 34 |
| **Dec** | 13.2 | 4.4 | 22.3 | 72 | 70 | 35 |
| **Annual** | 19.2 | 2.3 | 37.4 | 66 | 1813 | 682 |

In the following figures monthly values for ambient temperature (Figure 23) and hourly temperature profile for the hotter and the colder month in Athens are presented (Figure 24; Figure 25).

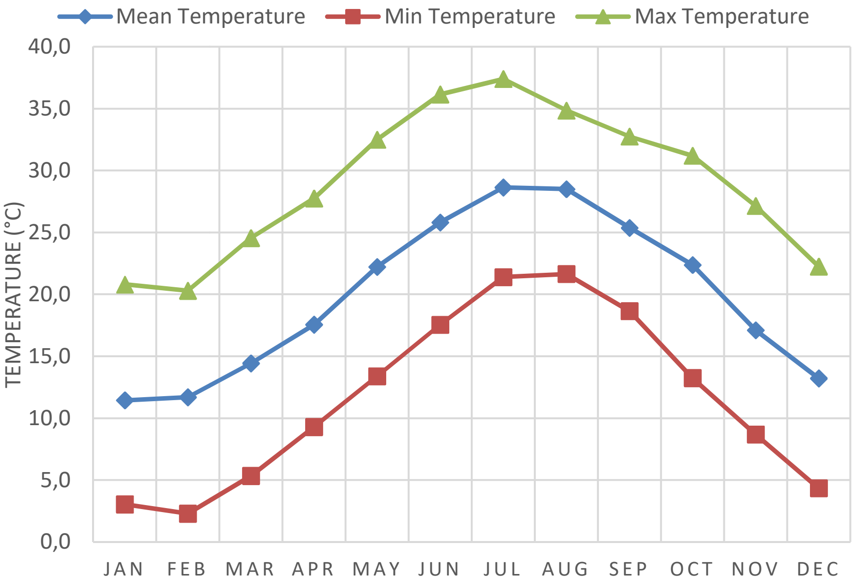


Figure 23 Monthly ambient temperature in Nicosia (Meteonorm 7)

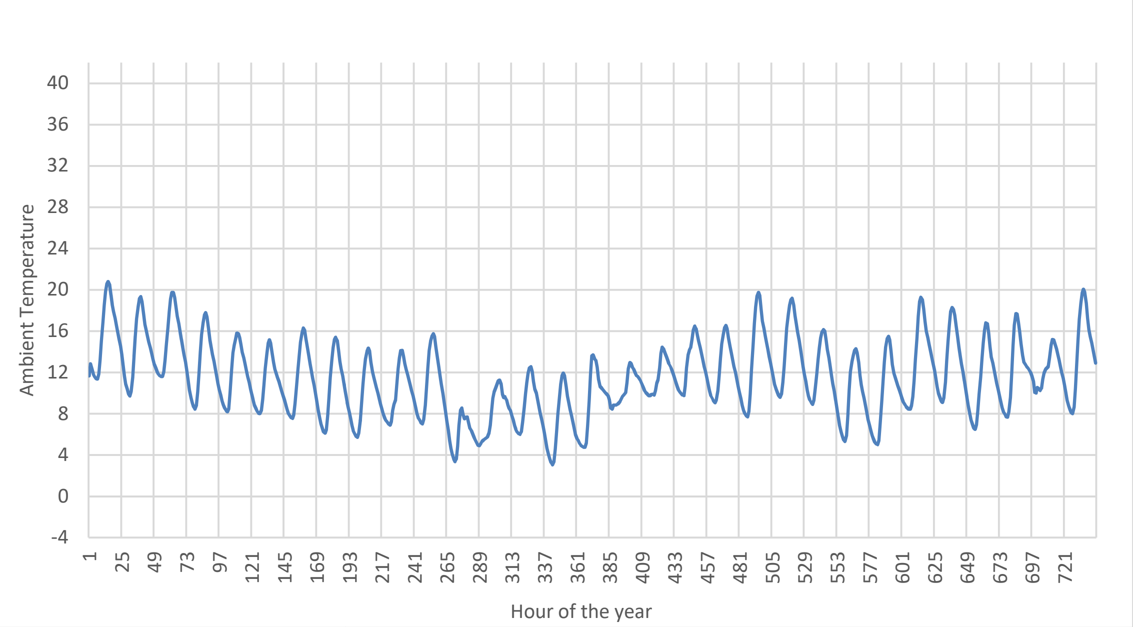


Figure 24 Ambient temperature hourly profile of January in Nicosia (Meteonorm 7)

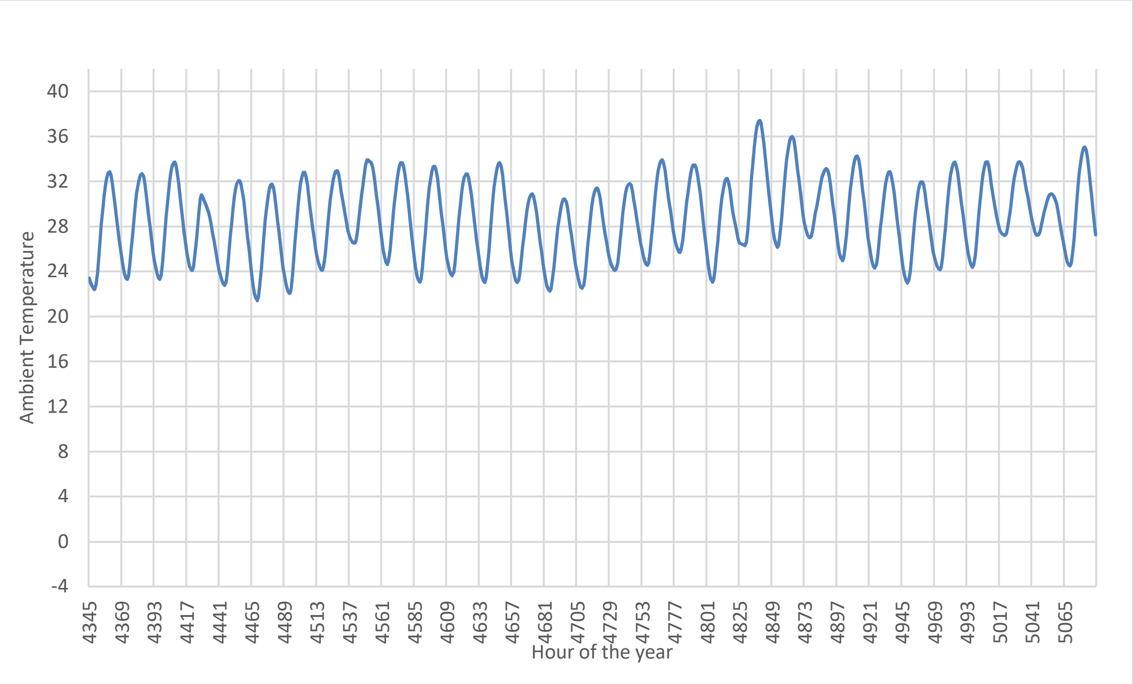


Figure 25 Ambient temperature hourly profile of July in Nicosia (Meteonorm 7)

The total amount of heating degree days in Nicosia is low, equal to 308. It presents a slight heating demand in December, January and February. The Cooling degrees are equal to 851, with high cooling demand from June until September.

Table 20 Nicosia Heating and Cooling Degree Days

| | HDD15 | CDD21 |
|---|---|---|
| **Jan** | 111 | 0 |
| **Feb** | 93 | 0 |
| **Mar** | 36 | 0 |
| **Apr** | 1 | 1 |
| **May** | 0 | 49 |
| **Jun** | 0 | 145 |
| **Jul** | 0 | 237 |
| **Aug** | 0 | 233 |
| **Sep** | 0 | 131 |
| **Oct** | 0 | 54 |
| **Nov** | 5 | 1 |
| **Dec** | 62 | 0 |
| **Annual** | 308 | 851 |

# 3 Focus on TABULA/EPISCOPE and INSPIRE available datasets about building characterization

Buildings typological characterization of the EU building stocks has been investigated in several FP7 European projects, which collected a large amount of information related to building envelope characteristics, building energy demand, as well as heating and cooling systems implemented.

In the following chapter a focus on **TABULA/EPISCOPE** and **INSPIRE** projects is done since they contain an exhaustive analysis of the EU building stocks, compliant with the information needed by HYBUILD Project i.e. to extract data regarding building characterization. The focus on these two datasets was intended to avoid a duplication of efforts, as recommended by the Project Officer in the Kick-off Meeting of WP 1.

Another important database available on European building stock is the **EU Building database** (European Commission, 2018) part of the EU Building Stock Observatory (European Commission, 2018)) developed by the European Commission. The database contains information on building stock characteristics, building shell performance, technical building systems, nearly zero-energy buildings, building renovation, energy consumption, certification, financing, Energy poverty and Energy Market.

INPIRE project contains itself an analysis of the BPIE database which have been used as basis to design the EU building stock Observatory (Buildings Performance Institute Europe (BPIE), 2018)

## 3.1 TABULA/EPISCOPE

TABULA developed several building typologies to represent the EU residential building stock. The typologies consist of the following elements (EPISCOPE FP7 EU funded Project, 2012-2016)

- A classification concept for existing residential buildings according to their age, size and energy system installed;
- A set of example buildings which represent specific building types of the national stocks;
- Typical energy consumption values for the example buildings;
- Showcase calculations of the possible energy savings based on different level of refurbishment;
- Statistical data about energy consumptions and energy performances of buildings

Four residential building categories have been identified and investigated in TABULA: Single-Family House (SFH); Terraced House (TH); Multi Family House (MFH); Apartment Block (AB).

Starting from TABULA concept, the EPISCOPE project extended the scope towards the elaboration of a building stock model to assess refurbishment processes. The implementation of various energy saving measures and their effect has been investigated in 16 EU different countries.

The web tool developed within the two projects is divided into two main sections, described below:

- Building typologies:
  The buildings systems and the thermal properties for different building elements are identified per several categories of residential buildings in different countries. The building energy performance is estimated with reference to both existing state and

two possible refurbishment scenarios (usual and advanced scenarios, defined according to national practices).

- Building stocks:
  Information about “average buildings”, with geometrical and thermo-physical characteristics equal to the average of the building stock of each country considered. Information regarding the annual energy balance for heating and DHW of average buildings is also available.

It is possible to download data in PDF or Excel format.

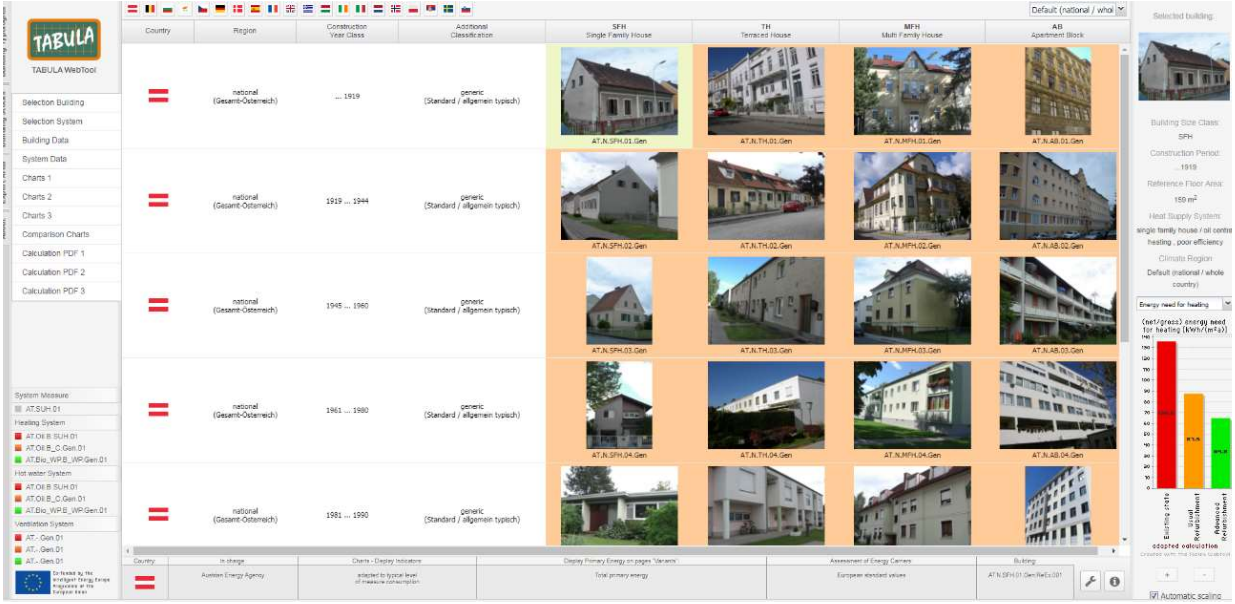


Figure 26 A view of TABULA webtool

Table 21 summarizes the main data available related to the building stock in TABULA web tool:

Table 21 TABULA Web Tool description

| **Name** | **TABULA (Typology Approach for Building Stock Energy Assessment)** |
|---|---|
| **Source** | European Commission, Intelligent Energy Europe Programme |
| **Database coverage** | Austria, Germany, Bulgaria, Cyprus, Czech Republic, Belgium, Denmark, Spain, France, UK, Greece, Ireland, Italy , Hungary, Netherlands, Norway, Poland, Serbia, Sweden, Slovenia |
| **Link** | http://webtool.building-typology.eu/#bm |
| **Data available** | U-Value for roof, façade and window [W/m$^2$k] |
| | Total primary energy demand for heating and domestic hot water [kWh/(m$^2$ yr)] per building category |
| | Carbon dioxide emissions for heating and domestic hot water [kg/(m$^2$ yr)] |
| | Kind of heating systems installed (% and capacity) |

| | |
|---|---|
| | Building stock characteristics (age – consumption etc.) |
| | Energy consumption per building type – Evaluation of Residential/Tertiary Demand |

Moreover, within the TABULA calculator excel file (available in the download section of the EPISCOPE website), the climatic parameters used for the building performance calculation are available for each country and region considered. The main climatic data available are:

- Length of heating period [day];
- Average external air temperature (seasonal and monthly based) during heating season [°C];
- Global solar radiation during heating season Horizontal and Vertical [kWh];
- Global solar radiation of a year Horizontal and Vertical[kWh];
- Average daily global solar radiation Horizontal and Vertical [kWh/($m^2$·day)].

## 3.2 INSPIRE

The INSPIRE EU co-funded project conducted two major activities:

- the first activity has been the analysis of the EU building stock across Europe to produce seven target examples that represent the majority of buildings;
- the second INSPIRE activity has been the development of multifunctional renovation kits that make use of innovative envelope technologies, energy generation systems (including RES integration) and energy distribution systems. (INSPIRE FP7 EU funded Project, 2016)

The analysis targeted both residential and office stock, highlighting the different building typologies present in each country, their energy use and their architectural features. When it comes to the residential stock, as shown in Figure 27, the analysis has been based on several European and national databases, considering two building typologies: Single Family House (SFH) and Multi Family House (MFH).

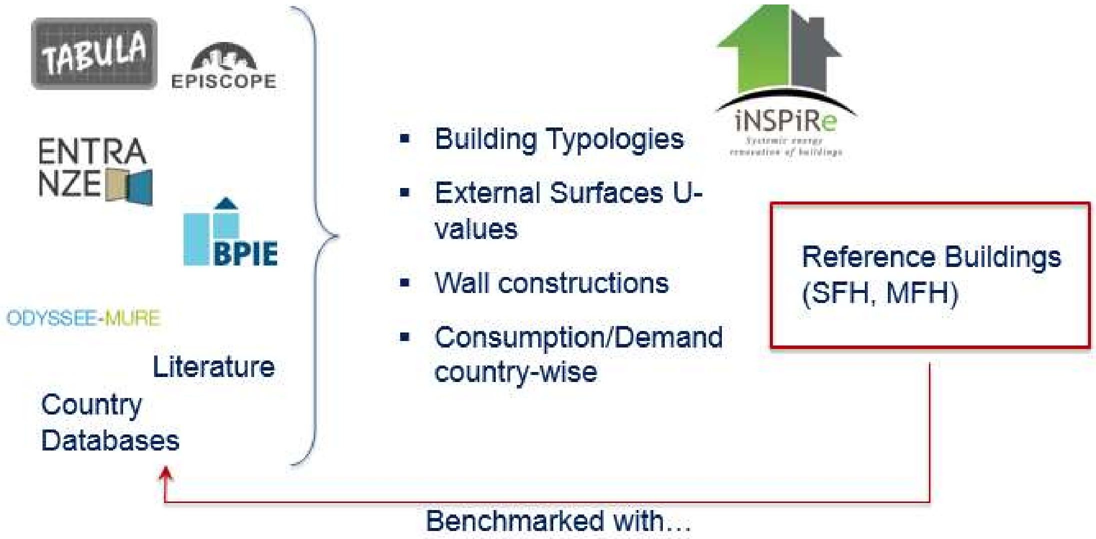


Figure 27 Scheme of INSPIRE Residential Building Analysis.

A database has been created, targeting professionals in the engineering and architectural sectors as well as local authorities and decision makers.

It divides Europe into seven climate regions, grouped together based on how many days of the year each requires heating (HDD), the latter parameter varying from about 500 to 2,500. Each climate region contains one of the seven most populated countries in Europe (Italy, Spain, France, Germany, UK, Poland and Sweden) and these countries are home to 80%of Europe's total population.

Table 22 INSPIRE Web Tool description

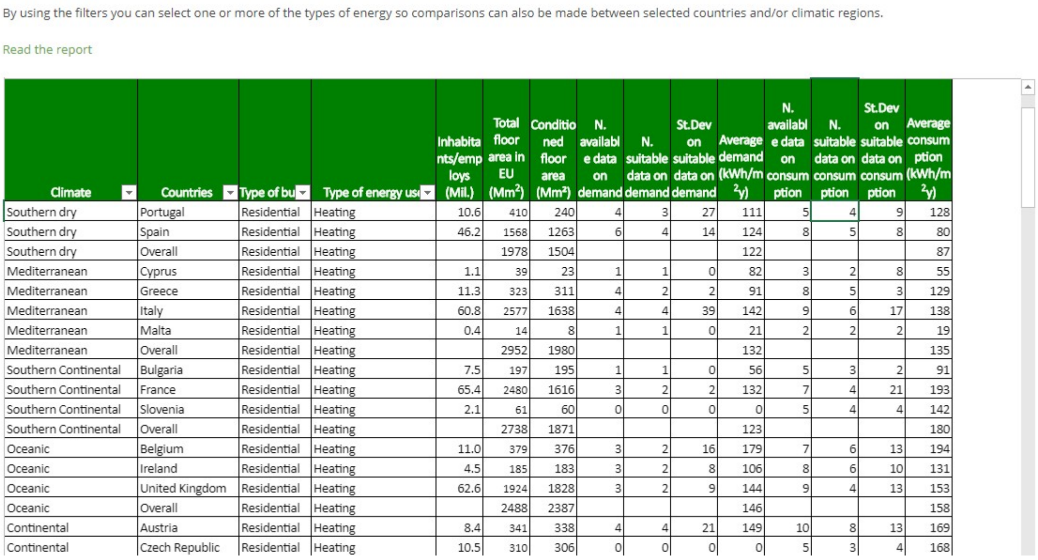
| **Name** | **INSPIRE** |
|---|---|
| **Source** | European Commission, 7th Framework Program |
| **Database coverage** | Austria, Belgium, Bulgaria, Cyprus; Czech Republic, Denmark, Estonia, Finland, France, German, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland Portugal Slovakia, Slovenia, Spain, Sweden, United Kingdom. |
| **Link** | http://inspirefp7.eu/retrofit-solutions-database/ |
| **Sections available** | Building Stock Statistics |
| | Reference Building Simulations |
| | Target Building Simulations |

As described in Table 22, the database is divided into 3 sections containing several data, described below:

- Building Stock Statistics:

The database shows information on EU country's energy use, collected in publicly available literature. It also shows each country's population, its total available floor space and floor space being heated and/or cooled.

- Climate;
- Countries;
- Type of building;
- Type of energy use;
- Inhabitants/employs (Mil.);
- Total floor area in EU ($Mm^2$);
- Conditioned floor area ($Mm^2$);
- Number of available data on demand;
- Number of suitable data on demand;
- Standard deviation on suitable data on demand;
- Average demand ($kWh/m^2y$);
- Number available data on consumption;
- Number suitable data on consumption;
- Standard deviation on suitable data on consumption;
- Average consumption ($kWh/m^2y$);



By using the filters you can select one or more of the types of energy so comparisons can also be made between selected countries and/or climatic regions.

Read the report

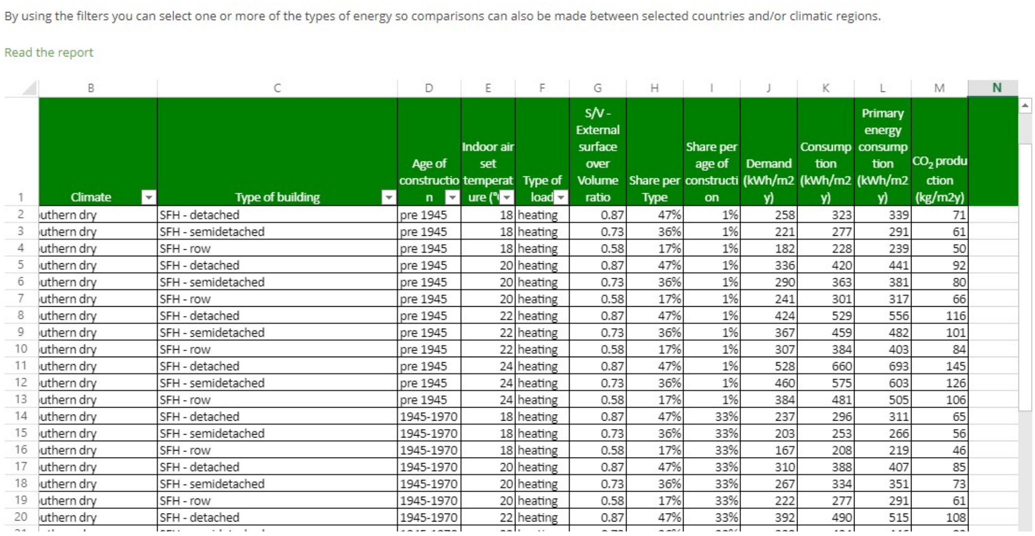
| Climate | Countries | Type of bu | Type of energy us | Inhabitants/employs (Mil.) | Total floor area in EU ($Mm^2$) | Conditioned floor area ($Mm^2$) | N. available data on demand | N. suitable data on demand | St.Dev on suitable data on demand | Average demand ($kWh/m^2y$) | N. available data on consumption | N. suitable data on consumption | St.Dev on suitable data on consumption | Average consumption ($kWh/m^2y$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Southern dry | Portugal | Residential | Heating | 10.6 | 410 | 240 | 4 | 3 | 27 | 111 | 5 | 4 | 9 | 128 |
| Southern dry | Spain | Residential | Heating | 46.2 | 1568 | 1263 | 6 | 4 | 14 | 124 | 8 | 5 | 8 | 80 |
| Southern dry | Overall | Residential | Heating |  | 1978 | 1504 |  |  |  | 122 |  |  |  | 87 |
| Mediterranean | Cyprus | Residential | Heating | 1.1 | 39 | 23 | 1 | 1 | 0 | 82 | 3 | 2 | 8 | 55 |
| Mediterranean | Greece | Residential | Heating | 11.3 | 323 | 311 | 4 | 2 | 2 | 91 | 8 | 5 | 3 | 129 |
| Mediterranean | Italy | Residential | Heating | 60.8 | 2577 | 1638 | 4 | 4 | 39 | 142 | 9 | 6 | 17 | 138 |
| Mediterranean | Malta | Residential | Heating | 0.4 | 14 | 8 | 1 | 1 | 0 | 21 | 2 | 2 | 2 | 19 |
| Mediterranean | Overall | Residential | Heating |  | 2952 | 1980 |  |  |  | 132 |  |  |  | 135 |
| Southern Continental | Bulgaria | Residential | Heating | 7.5 | 197 | 195 | 1 | 1 | 0 | 56 | 5 | 3 | 2 | 91 |
| Southern Continental | France | Residential | Heating | 65.4 | 2480 | 1616 | 3 | 2 | 2 | 132 | 7 | 4 | 21 | 193 |
| Southern Continental | Slovenia | Residential | Heating | 2.1 | 61 | 60 | 0 | 0 | 0 | 0 | 5 | 4 | 4 | 142 |
| Southern Continental | Overall | Residential | Heating |  | 2738 | 1871 |  |  |  | 123 |  |  |  | 180 |
| Oceanic | Belgium | Residential | Heating | 11.0 | 379 | 376 | 3 | 2 | 16 | 179 | 7 | 6 | 13 | 194 |
| Oceanic | Ireland | Residential | Heating | 4.5 | 185 | 183 | 3 | 2 | 8 | 106 | 8 | 6 | 10 | 131 |
| Oceanic | United Kingdom | Residential | Heating | 62.6 | 1924 | 1828 | 3 | 2 | 9 | 144 | 9 | 4 | 13 | 153 |
| Oceanic | Overall | Residential | Heating |  | 2488 | 2387 |  |  |  | 146 |  |  |  | 158 |
| Continental | Austria | Residential | Heating | 8.4 | 341 | 338 | 4 | 4 | 21 | 149 | 10 | 8 | 13 | 169 |
| Continental | Czech Republic | Residential | Heating | 10.5 | 310 | 306 | 0 | 0 | 0 | 0 | 5 | 3 | 4 | 168 |

Figure 28 View of INSPIRE Building Stock Statistic Database

- Reference Building Simulations:
  This database shows information regarding the energy behaviour of the reference buildings defined in INSPIRE project. The reference building models are based on a representative building models in terms of building construction type and geometry, defined for three type of residential buildings (Single Family House; small Multi Family House, Multi Family House) and one office building. For each climate, different average U-values (thermal transmittance of the building envelope) have been considered in the simulation.
  In the following the main data available are shown:

  - Climate;
  - Type of building;

- ○ Age of construction;
- ○ Indoor air set point temperature (°C);
- ○ Type of load;
- ○ S/V - External surface over Volume ratio;
- ○ Share per Type;
- ○ Share per age of construction;
- ○ Demand (kWh/m$^2$y);
- ○ Consumption (kWh/m$^2$y);
- ○ Primary energy consumption (kWh/m$^2$y);
- ○ CO$_2$ production (kg/m$^2$y).



By using the filters you can select one or more of the types of energy so comparisons can also be made between selected countries and/or climatic regions.

Read the report

|  | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Climate | Type of building | Age of construction | Indoor air set temperature (° | Type of load | S/V - External surface over Volume ratio | Share per Type | Share per age of construction | Demand (kWh/m2 y) | Consumption (kWh/m2 y) | Primary energy consumption (kWh/m2 y) | CO$_2$ production (kg/m2y) |  |
| 2 | uthern dry | SFH - detached | pre 1945 | 18 | heating | 0.87 | 47% | 1% | 258 | 323 | 339 | 71 |  |
| 3 | uthern dry | SFH - semidetached | pre 1945 | 18 | heating | 0.73 | 36% | 1% | 221 | 277 | 291 | 61 |  |
| 4 | uthern dry | SFH - row | pre 1945 | 18 | heating | 0.58 | 17% | 1% | 182 | 228 | 239 | 50 |  |
| 5 | uthern dry | SFH - detached | pre 1945 | 20 | heating | 0.87 | 47% | 1% | 336 | 420 | 441 | 92 |  |
| 6 | uthern dry | SFH - semidetached | pre 1945 | 20 | heating | 0.73 | 36% | 1% | 290 | 363 | 381 | 80 |  |
| 7 | uthern dry | SFH - row | pre 1945 | 20 | heating | 0.58 | 17% | 1% | 241 | 301 | 317 | 66 |  |
| 8 | uthern dry | SFH - detached | pre 1945 | 22 | heating | 0.87 | 47% | 1% | 424 | 529 | 556 | 116 |  |
| 9 | uthern dry | SFH - semidetached | pre 1945 | 22 | heating | 0.73 | 36% | 1% | 367 | 459 | 482 | 101 |  |
| 10 | uthern dry | SFH - row | pre 1945 | 22 | heating | 0.58 | 17% | 1% | 307 | 384 | 403 | 84 |  |
| 11 | uthern dry | SFH - detached | pre 1945 | 24 | heating | 0.87 | 47% | 1% | 528 | 660 | 693 | 145 |  |
| 12 | uthern dry | SFH - semidetached | pre 1945 | 24 | heating | 0.73 | 36% | 1% | 460 | 575 | 603 | 126 |  |
| 13 | uthern dry | SFH - row | pre 1945 | 24 | heating | 0.58 | 17% | 1% | 384 | 481 | 505 | 106 |  |
| 14 | uthern dry | SFH - detached | 1945-1970 | 18 | heating | 0.87 | 47% | 33% | 237 | 296 | 311 | 65 |  |
| 15 | uthern dry | SFH - semidetached | 1945-1970 | 18 | heating | 0.73 | 36% | 33% | 203 | 253 | 266 | 56 |  |
| 16 | uthern dry | SFH - row | 1945-1970 | 18 | heating | 0.58 | 17% | 33% | 167 | 208 | 219 | 46 |  |
| 17 | uthern dry | SFH - detached | 1945-1970 | 20 | heating | 0.87 | 47% | 33% | 310 | 388 | 407 | 85 |  |
| 18 | uthern dry | SFH - semidetached | 1945-1970 | 20 | heating | 0.73 | 36% | 33% | 267 | 334 | 351 | 73 |  |
| 19 | uthern dry | SFH - row | 1945-1970 | 20 | heating | 0.58 | 17% | 33% | 222 | 277 | 291 | 61 |  |
| 20 | uthern dry | SFH - detached | 1945-1970 | 22 | heating | 0.87 | 47% | 33% | 392 | 490 | 515 | 108 |  |

Figure 29 View of INSPIRE Reference Building Simulations database

- Target Building Simulations:
  The database includes information on how given retrofit packages impact on the specific reference building, highlighting the needs and effects of decisions taken during retrofit design. The seven climatic regions are represented by the climates of Rome, Madrid, Lyon, Stuttgart, London, Gdansk and Stockholm.
  In order to evaluate the retrofit packages impact, different parameters can be selected, such as:
  - ○ Wished heating demand after retrofit, which determines the insulation and new windows quality;
  - ○ Type of heating & cooling generation system;
  - ○ Temperature set points imposed to the indoor air;
  - ○ Type and temperatures of the heating & cooling distribution systems;
  - ○ Size and position of the solar thermal collectors and PV panels.

In addition to the information stored in the database presented, additional information related to the European building stock is contained in the public deliverables available on the Inspire project website, in the downloadable results section (INSPIRE FP7 EU funded project, 2016). The most relevant report is the D2.1a ‘Survey on the energy needs and architectural features of the EU building stock’,: which focus on both residential and office stock, containing information on: size and age of the building stock, type of tenure, building type, thermal performance and U values, energy consumption/demand by end use, fuel and system types (Birchall S., 2014). When it comes to the building envelope characteristics, the before mentioned document presents, for each country investigated and for different construction periods, typical U values which have been considered equal for SFH and MFH. In addition, in the document D6.3a ‘Performance of the Studied Systemic Renovation Packages – Method’ a focus of the wall construction for all the residential buildings and offices for the two periods 1945-1970 and 1980-1990 is presented, including information on envelope layers and U values (Fedrizzi R., 2015).

# 4 Building typologies characterization

Starting from the analysis of the two databases presented in the previous chapter, the aim of this activity is to identify the most representative building typologies in Europe to be considered as potential candidates for the systems developed in HYBUILD project, and use them to propose user scenarios and to carry out energy simulation in the next phases of the project.

Two building typologies have been chosen as representative for European building stock: **Single-family house (SFH)** and **Multi-family house (MFH)**.

According to the EU Buildings Database (European Commission, 2018), the residential buildings cover approximately 22.7 billion $m^2$of floor area in 2014. The residential mix between SFH and MFH, varies among the different countries, but the age of construction for the two typologies is distributed homogeneously (Birchall S., 2014). This allows for choosing a common reference period for all the climates considered. The aim is, for each climate, to characterize the two typologies (SFH and MFH) with standard building characteristics referring to one chosen reference period.

In particular, the period **1980-1989** has been chosen. According to the EU Building database (European Commission, 2018) it represent 12.54% of the EU28 building stock varying from 10.16% in Sweden to 19.44% in Cyprus, as shown in Table 23.

The choice has been done considering that in the climates selected the energy performance of buildings starts to increase in the 1979s and 1980s, while in the previous years the energy performance was generally low. The analysis carried out in INSPIRE (Birchall S., 2014) showed that in France more stringent insulation standards were introduced following the energy crises in the 1970s. In Germany, the first standard related to the building energy performance came in effect after the 1960s but in the 70s and 80s there has been a significant improvement both in the regulations and the technologies related to heat protection. In Greece the first significant improvement of the performance of the building envelope occurred in the 1980s, as happened in Spain, with the introduction of the first thermal regulation. In Cyprus and Sweden no significant variation has occurred in the building insulation during the last 60 years: in Cyprus the majority of the buildings have been built among 1975 and 1985, but with low insulation performance, due also to the hot climate; In Sweden, on the contrary, the very cold climate encourages the construction of highly insulated buildings and it has been effective for a long time already.

Table 23 Percentage of residential building stock per age of construction (European Commission, 2018)

| Country | Source | before 1945 | 1945-1969 | 1970-1979 | 1980-1989 | 1990-1999 | 2000-2010 | after 2010 |
|---|---|---|---|---|---|---|---|---|
| **Cyprus** | Cystat | 3.00 | 10.09 | 13.32 | 19.44 | 16.77 | 28.96 | 8.43 |
| **France** | INSEE | 26.72 | 18.04 | 15.66 | 12.45 | 9.81 | 13.00 | 4.33 |
| **Germany** | DESTATIS | 25.24 | 34.12 | 14.90 | 10.97 | 7.68 | 5.17 | 1.92 |
| **Greece** | Odyssee | 7.28 | 24.00 | 20.96 | 16.79 | 12.82 | 14.50 | 3.65 |
| **Spain** | Odyssee | 12.84 | 18.62 | 17.41 | 13.07 | 14.27 | 17.28 | 6.51 |
| **Sweden** | SCB | 26.19 | 34.32 | 16.18 | 10.16 | 5.92 | 5.55 | 1.68 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **EU28** | Odyssee | 22.69 | 26.19 | 15.98 | 12.54 | 9.34 | 9.56 | 3.69 |

In order to carry out a benchmarking of the energy performance of the HYBUILD solutions, two reference buildings have been defined from a geometrical point of view, one SFH and one MFH. On the other hand, the envelope energy performances in terms of U values (W/m$^2$K) are defined for each climate identified. This allows for defining different comparable models to be used in energy simulations with the aim to investigate the HYBUILD systems behaviour in different climates considering the two building typologies defined.

## 4.1 Typical U values definition by Country

Analysing the data coming from TABULA/EPISCOPE and INSPIRE project, it is possible to define typical U values for each climate and for each country selected. As described in chapter 3, the two databases can provide information related to Walls, floors, ceilings and windows U values and to the construction typologies, divided per construction period.

In the definition of the reference buildings to be used in energy simulations within HYBUILD Project, INSPIRE database has been taken as reference, as it includes an analysis of the TABULA database and it contains data organized by the same construction periods for all the countries considered, which makes comparisons across different climates easier. On the contrary, in the TABULA database, specific construction periods for each country have been considered in the building stock analysis. In the following tables, the U values considered in the HYBUILD energy simulations, coming from deliverable D6.3a of INSPIRE project (Fedrizzi R., 2015) are shown.

Table 24 SFH U values [W/m2K] in Sweden (Nordic Climate) – INSPIRE

| | *SFH_STOCKHOLM_1980-1990* | | |
|---|---|---|---|
| | ***Material*** | ***λ*** | ***l*** |
| | | *[W/m]* | *[m]* |
| **EXTERNAL WALL** | *Resistance int surface [m²K/W]* | 0.13 | |
| | *Gypsum plaster* | 0.35 | 0.012 |
| | *Mineral wool 035* | 0.04 | 0.100 |
| | *Perpendicular Air layer 10-20* | 1.00 | 0.000 |
| | *Spruce/Pine* | 0.13 | 0.025 |
| | *Resistance ext surface [m²K/W]* | 0.04 | |
| | ***Total U-value [W/m²K]*** | | ***0.30*** |
| **FLOORS** | *Resistance int surface [m²K/W]* | 0.17 | |
| | *Common concrete* | 2.10 | 0.025 |
| | *Mineral wool 035* | 0.04 | 0.100 |
| | *Concrete slab* | 1.13 | 0.150 |
| | *Resistance ext surface [m²K/W]* | 0 | |
| | ***Total U-value [W/m²K]*** | | ***0.32*** |
| **ROOFS** | *Resistance int surface [m²K/W]* | 0.1 | |
| | *Spruce/Pine* | 0.13 | 0.025 |
| | *Mineral wool 035* | 0.04 | 0.110 |
| | *Horizontal Air layer 10-500* | 1.00 | 0.100 |
| | *Spruce/Pine* | 0.13 | 0.025 |
| | *Resistance ext surface [m²K/W]* | 0.04 | |
| | ***Total U-value [W/m²K]*** | | ***0.27*** |
| | | | |
| **WINDOW** | *Double glazed* | ***g** value* | ***U** value* |
| | | | *[W/m²K]* |
| | | 0.7 | ***2.43*** |

Table 25 MFH U values [W/m2K] in Sweden (Nordic Climate) – INSPIRE

| | MFH_STOCKHOLM_1980-1990 | | |
|---|---|---|---|
| | **Material** | **λ** | **l** |
| | | [W/m] | [m] |
| **EXTERNAL WALL** | *Resistance int surface [m$^2$K/W]* | 0.13 | |
| | *Lw concrete w natural pumice 1* | 0.15 | 0.250 |
| | *Mineral wool 035* | 0.04 | 0.035 |
| | *Block m pumice 1* | 0.20 | 0.120 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***0.29*** |
| **FLOORS** | *Resistance int surface [m$^2$K/W]* | 0.17 | |
| | *Linoleum* | 0.17 | 0.003 |
| | *Common concrete* | 2.10 | 0.016 |
| | *Mineral wool 035* | 0.04 | 0.110 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***0.31*** |
| **ROOFS** | *Resistance int surface [m$^2$K/W]* | 0.1 | |
| | *Common concrete* | 2.10 | 0.014 |
| | *Mineral wool 035* | 0.04 | 0.110 |
| | *Roofdeck* | 0.14 | 0.040 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***0.29*** |
| | | | |
| **WINDOW** | *Double glazed* | $g_{value}$ | $U_{value}$ |
| | | | [W/m$^2$K |
| | | 0.7 | ***2.43*** |

Table 26 SFH U values [W/m2K] in Germany (Continental Climate) – INSPIRE

| | ***SFH_STUTTGART_1980-1990*** | | |
|---|---|---|---|
| | ***Material*** | ***λ*** | ***l*** |
| | | *[W/m]* | *[m]* |
| **EXTERNAL WALL** | *Resistance int surface [m$^2$K/W]* | 0.13 | |
| | *Lime cement mortar* | 0.87 | 0.015 |
| | *Hollow block 3K 5* | 0.55 | 0.230 |
| | *Polystyrene 040* | 0.04 | 0.040 |
| | *Lime cement mortar* | 0.87 | 0.010 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***0.61*** |
| **FLOORS** | *Resistance int surface [m$^2$K/W]* | 0.17 | |
| | *Timberfloor* | 0.14 | 0.015 |
| | *Lw concrete 11* | 1.60 | 0.070 |
| | *Polystyrene 040* | 0.04 | 0.035 |
| | *Sand gravel* | 0.70 | 0.050 |
| | *Concrete slab* | 1.13 | 0.180 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***0.67*** |
| **ROOFS** | *Resistance int surface [m$^2$K/W]* | 0.1 | |
| | *Spruce/Pine* | 0.13 | 0.020 |
| | *Mineral wool 040* | 0.04 | 0.080 |
| | *Spruce/Pine* | 0.13 | 0.020 |
| | *Roofdeck* | 0.14 | 0.010 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***0.39*** |
| | | | |
| **WINDOW** | *Double glazed* | ***gvalue*** | ***Uvalue*** |
| | | | *[W/m$^2$K]* |
| | | 0.755 | ***2.83*** |

Table 27 MFH U values [W/m2K] in Germany (Continental Climate) – INSPIRE

| | MFH_STUTTGART_1980-1990 | | |
|---|---|---|---|
| | **Material** | **λ** | **l** |
| | | [W/m] | [m] |
| **EXTERNAL WALL** | Resistance int surface [$m^2K/W$] | 0.13 | |
| | Lime cement mortar | 0.87 | 0.015 |
| | Hollow block 3K 5 | 0.55 | 0.230 |
| | Polystyrene 040 | 0.04 | 0.040 |
| | Lime cement mortar | 0.87 | 0.010 |
| | Resistance ext surface [$m^2K/W$] | 0.04 | |
| | **Total U-value [$W/m^2K$]** | | **0.61** |
| **FLOORS** | Resistance int surface [$m^2K/W$] | 0.17 | |
| | Timberfloor | 0.14 | 0.015 |
| | Lw concrete 11 | 1.60 | 0.070 |
| | Polystyrene 040 | 0.04 | 0.035 |
| | Sand gravel | 0.70 | 0.050 |
| | Concrete slab | 1.13 | 0.180 |
| | Resistance ext surface [$m^2K/W$] | 0.04 | |
| | **Total U-value [$W/m^2K$]** | | **0.67** |
| **ROOFS** | Resistance int surface [$m^2K/W$] | 0.1 | |
| | Spruce/Pine | 0.13 | 0.020 |
| | Mineral wool 040 | 0.04 | 0.080 |
| | Spruce/Pine | 0.13 | 0.020 |
| | Roofdeck | 0.14 | 0.010 |
| | Resistance ext surface [$m^2K/W$] | 0.04 | |
| | **Total U-value [$W/m^2K$]** | | **0.39** |
| | | | |
| **WINDOW** | Double glazed | **gvalue** | **Uvalue** |
| | | | [$W/m^2K$ |
| | | 0.755 | **2.83** |

Table 28 SFH U values [W/m2K] in France (Southern Continental Climate) - INSPIRE

| | ***SFH_LYON_1980-1990*** | | |
|---|---|---|---|
| | ***Material*** | ***λ*** | ***l*** |
| | | *[W/m]* | *[m]* |
| **EXTERNAL WALL** | *Resistance int surface [m$^2$K/W]* | 0.13 | |
| | *Lime cement mortar* | 0.87 | 0.015 |
| | *Hollow block 3K 8* | 0.90 | 0.240 |
| | *Polystyrene 040* | 0.04 | 0.030 |
| | *Lime cement mortar* | 0.87 | 0.010 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***0.81*** |
| **FLOORS** | *Resistance int surface [m$^2$K/W]* | 0.17 | |
| | *Timberfloor* | 0.14 | 0.015 |
| | *Lw concrete 11* | 1.60 | 0.050 |
| | *Polystyrene 040* | 0.04 | 0.030 |
| | *Sand gravel* | 0.70 | 0.050 |
| | *Concrete slab* | 1.13 | 0.200 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***0.73*** |
| **ROOFS** | *Resistance int surface [m$^2$K/W]* | 0.1 | |
| | *Spruce/Pine* | 0.13 | 0.020 |
| | *Mineral wool 040* | 0.04 | 0.030 |
| | *Spruce/Pine* | 0.13 | 0.020 |
| | *Roofdeck* | 0.14 | 0.010 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***0.78*** |
| | | | |
| **WINDOW** | *Double glazed* | $g_{value}$ | $U_{value}$ |
| | | | *[W/m$^2$K* |
| | | 0.755 | ***2.83*** |

Table 29 MFH U values [W/m2K] in France (Southern Continental Climate) - INSPIRE

| | **MFH_LYON_1980-1990** | | |
|---|---|---|---|
| | **Material** | **λ** | **l** |
| | | [W/m] | [m] |
| **EXTERNAL WALL** | Resistance int surface [m$^2$K/W] | 0.13 | |
| | Lime cement mortar | 0.87 | 0.015 |
| | Hollow block 3K 8 | 0.90 | 0.240 |
| | Polystyrene 040 | 0.04 | 0.030 |
| | Lime cement mortar | 0.87 | 0.010 |
| | Resistance ext surface [m$^2$K/W] | 0.04 | |
| | **Total U-value [W/m$^2$K]** | | **0.81** |
| **FLOORS** | Resistance int surface [m$^2$K/W] | 0.17 | |
| | Timberfloor | 0.14 | 0.015 |
| | Lw concrete 11 | 1.60 | 0.050 |
| | Polystyrene 040 | 0.04 | 0.030 |
| | Sand gravel | 0.70 | 0.050 |
| | Concrete slab | 1.13 | 0.200 |
| | Resistance ext surface [m$^2$K/W] | 0.04 | |
| | **Total U-value [W/m$^2$K]** | | **0.73** |
| **ROOFS** | Resistance int surface [m$^2$K/W] | 0.1 | |
| | Spruce/Pine | 0.13 | 0.020 |
| | Mineral wool 040 | 0.04 | 0.030 |
| | Spruce/Pine | 0.13 | 0.020 |
| | Roofdeck | 0.14 | 0.010 |
| | Resistance ext surface [m$^2$K/W] | 0.04 | |
| | **Total U-value [W/m$^2$K]** | | **0.78** |
| | | | |
| **WINDOW** | 2-insulating glazing | **gvalue** | **Uvalue** |
| | | | [W/m$^2$K |
| | | 0.755 | **2.83** |

Table 30 SFH U values [W/m2K] in Spain (Southern Dry Climate) – INSPIRE

| | **SFH_MADRID_1980-1990** | | |
|---|---|---|---|
| | **Material** | **λ** | **l** |
| | | [W/m] | [m] |
| **EXTERNAL WALL** | Resistance int surface [m²K/W] | 0.13 | |
| | Gypsum plaster | 0.35 | 0.020 |
| | Block massive 8 | 0.63 | 0.230 |
| | Gypsum plaster | 0.35 | 0.020 |
| | Resistance ext surface [m²K/W] | 0.04 | |
| | **Total U-value [W/m²K]** | | **1.54** |
| **FLOORS** | Resistance int surface [m²K/W] | 0.17 | |
| | Ceramics | 1.20 | 0.030 |
| | Lw concrete 6 | 0.70 | 0.040 |
| | Hollow block 2K 1 | 0.29 | 0.160 |
| | Gypsum plaster | 0.35 | 0.020 |
| | Resistance ext surface [m²K/W] | 0.04 | |
| | **Total U-value [W/m²K]** | | **1.11** |
| **ROOFS** | Resistance int surface [m²K/W] | 0.1 | |
| | Gypsum plaster | 0.35 | 0.020 |
| | Wood siding | 0.14 | 0.035 |
| | Roofdeck | 0.14 | 0.040 |
| | Bitumen | 0.17 | 0.005 |
| | Resistance ext surface [m²K/W] | 0.04 | |
| | **Total U-value [W/m²K]** | | **1.31** |
| | | | |
| **WINDOW** | Double pain | **gvalue** | **Uvalue** |
| | | | [W/m |
| | | 0.773 | **4.14** |

Table 31 MFH U values [W/m2K] in Spain (Southern Dry Climate) – INSPIRE

| | MFH_MADRID_1980-1990 | | |
|---|---|---|---|
| | ***Material*** | ***λ*** | ***l*** |
| | | *[W/m]* | *[m]* |
| **EXTERNAL WALL** | *Resistance int surface [$m^2K/W$]* | 0.13 | |
| | *Gypsum plaster* | 0.35 | 0.020 |
| | *Hollow block 2K 7* | 0.76 | 0.260 |
| | *Gypsum plaster* | 0.35 | 0.020 |
| | *Resistance ext surface [$m^2K/W$]* | 0.04 | |
| | ***Total U-value [$W/m^2K$]*** | | ***1.60*** |
| **FLOORS** | *Resistance int surface [$m^2K/W$]* | 0.17 | |
| | *Ceramics* | 1.20 | 0.030 |
| | *Lw concrete 1* | 0.39 | 0.030 |
| | *Hollow block 2K 1* | 0.29 | 0.160 |
| | *Gypsum plaster* | 0.35 | 0.020 |
| | *Resistance ext surface [$m^2K/W$]* | 0.04 | |
| | ***Total U-value [$W/m^2K$]*** | | ***1.08*** |
| **ROOFS** | *Resistance int surface [$m^2K/W$]* | 0.1 | |
| | *Gypsum plaster* | 0.35 | 0.020 |
| | *Lw concrete 3* | 0.49 | 0.120 |
| | *Roofdeck* | 0.14 | 0.040 |
| | *Bitumen* | 0.17 | 0.005 |
| | *Resistance ext surface [$m^2K/W$]* | 0.04 | |
| | ***Total U-value [$W/m^2K$]*** | | ***1.32*** |
| | | | |
| **WINDOW** | *WIN_4_1* | ***gvalue*** | ***Uvalue*** |
| | | | *[W/m* |
| | | 0.773 | ***4.14*** |

Table 32 SFH U values [W/m2K] in Greece (Mediterranean Climate)- INSPIRE

| | ***SFH_ATHENS_1980-1990*** | | |
|---|---|---|---|
| | ***Material*** | ***λ*** | ***l*** |
| | | *[W/m]* | *[m]* |
| **EXTERNAL WALL** | *Resistance int surface [m$^2$K/W]* | 0.13 | |
| | *Lime mortar* | 0.87 | 0.020 |
| | *Block massive 7* | 0.54 | 0.090 |
| | *Polystyrene 035* | 0.04 | 0.030 |
| | *Block massive 7* | 0.54 | 0.090 |
| | *Lime mortar* | 0.87 | 0.020 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***0.72*** |
| **FLOORS** | *Resistance int surface [m$^2$K/W]* | 0.17 | |
| | *Floor tiles* | 1.84 | 0.010 |
| | *Cement* | 1.40 | 0.020 |
| | *Leveling layer* | 1.10 | 0.080 |
| | *Slab* | 2.50 | 0.150 |
| | *Cement* | 1.40 | 0.010 |
| | *Gravel* | 1.00 | 0.200 |
| | *Soil* | 1.80 | 0.250 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***1.41*** |
| **ROOFS** | *Resistance int surface [m$^2$K/W]* | 0.1 | |
| | *Lime mortar* | 0.87 | 0.015 |
| | *Slab* | 2.50 | 0.150 |
| | *Cement* | 1.40 | 0.010 |
| | *Polystyrene 035* | 0.04 | 0.060 |
| | *Air gap* | 0.09 | 0.100 |
| | *Roof tiles* | 0.44 | 0.030 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***0.33*** |
| | | | |
| **WINDOW** | *double pain 3.9/12/3.9* | ***gvalue*** | ***Uvalue*** |
| | | | *[W/m$^2$K* |
| | | 0.51 | ***4.10*** |

Table 33 MFH U values [W/m2K] in Greece (Mediterranean Climate)- INSPIRE

| | ***MFH_ATHENS_1980-1990*** | | |
|---|---|---|---|
| | ***Material*** | ***λ*** | ***l*** |
| | | *[W/m]* | *[m]* |
| EXTERNAL WALL | *Resistance int surface [m$^2$K/W]* | 0.13 | |
| | *Lime mortar* | 0.87 | 0.020 |
| | *Block massive 7* | 0.54 | 0.090 |
| | *Polystyrene 035* | 0.04 | 0.030 |
| | *Block massive 7* | 0.54 | 0.090 |
| | *Lime mortar* | 0.87 | 0.020 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***0.72*** |
| FLOORS | *Resistance int surface [m$^2$K/W]* | 0.17 | |
| | *Floor tiles* | 1.84 | 0.010 |
| | *Cement* | 1.40 | 0.020 |
| | *Leveling layer* | 1.10 | 0.080 |
| | *Slab* | 2.50 | 0.150 |
| | *Cement* | 1.40 | 0.010 |
| | *Gravel* | 1.00 | 0.200 |
| | *Soil* | 1.80 | 0.250 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***1.41*** |
| ROOFS | *Resistance int surface [m$^2$K/W]* | 0.1 | |
| | *Lime mortar* | 0.87 | 0.015 |
| | *Slab* | 2.50 | 0.150 |
| | *Cement* | 1.40 | 0.010 |
| | *Polystyrene 035* | 0.04 | 0.060 |
| | *Air gap* | 0.09 | 0.100 |
| | *Roof tiles* | 0.44 | 0.030 |
| | *Resistance ext surface [m$^2$K/W]* | 0.04 | |
| | ***Total U-value [W/m$^2$K]*** | | ***0.24*** |
| | | | |
| WINDOW | *double pain 3.9/12/3.9* | ***gvalue*** | ***Uvalue*** |
| | | | *[W/m* |
| | | 0.51 | ***4.10*** |

## 4.2 Reference Buildings Geometrical definition

In this section the geometrical definition of the two reference buildings (SFH and MFH) is presented.

According to INSPIRE database, a single family house built between 1945 and 2000 has an average floor area of 102 m$^2$. The MFHs have dwellings with an average area of 50 m$^2$ with the number of floor and of dwelling varies significantly.

According to the TABULA database, the MFHs average floor area varies in the countries selected, from 112 m$^2$ in Cyprus to the 1207 m$^2$ in Sweden, with an average of 800 m$^2$.

The geometrical definition of the two reference-buildings is presented in detail in Table 34 and Table 35. For the SFH, a heated area of 100 m$^2$ and a roof with a tilt angle of 30 °C has been considered. The MFH is composed by 2 dwellings per floor and five floors, with a total heated area of 500 m$^2$. In this case the roof is considered flat.

Table 34 SFH Geometrical definition

| **Residential building - SFH** | |
|---|---|
| **m$^2$ of living area** | 100 |
| **External surface over Volume ratio (S/V)** | 0.9 |
| **Zones** | 2 |
| **Roof** | Tilted roof (3 0°) |
| **Ceiling/Floor height** | 2,5/3,5 |
| **Building width /depth** | 6,5/8 |
| **glazing ratio** | |
| **North** | 20% |
| **South** | 10% |
| **West** | 12% |
| **East** | 12% |

Table 35 MFH Geometrical definition

| **Residential building - MFH** | |
|---|---|
| **m$^2$ of living area** | 500 |
| **S/V - External surface over Volume ratio** | 0.52 |
| **Dwelling area [m$^2$]** | 50 |
| **Zone per floor** | 2 |
| **Number of dwelling per floor** | 2 |
| **Number of floors** | 5 |
| **Staircase zone** | 1 |
| **Roof** | flat roof |
| **Ceiling/Floor height** | 2,5/3,5 |
| **Building width / depth** | 7.6/16.3 |
| **glazing ratio** | |
| **North** | 20% |
| **South** | 20% |
| **West** | none |
| **East** | none |

# 5 Methodology development

In this chapter, the procedure to assess the applicability of HYBUILD solutions is described, defining the size of the HYBUILD technologies and their performance in the different conditions considered, i.e. for different type of buildings and in different climates defined.

The building typologies considered are the **Single Family House** and the **Multi Family house**, as described in chapter 4. When it comes to the climate, as described in the previous chapters, five reference climates and countries have been characterized and are considered in the HYBUILD solution performance evaluation: Nordic climate (Sweden - Stockholm), Continental climate (Germany - Stuttgart), South Continental climate (France - Lyon); Southern dry climate (Spain – Madrid); Mediterranean climate ( Greece - Athens).

In HYBUILD, two technological solutions are proposed to optimize the energy consumption of residential houses. The two solutions are supposed to be particularly suitable for two general climates: one for hot climates (‘Mediterranean’ solution), where the main need is summer conditioning, and the other for cold climates (‘Continental’ solution), where the energy is mainly needed for heating purpose.

In order to comprehend the main features of the HYBUILD solutions (Figure 30), here below a brief description is reported:

- **‘Mediterranean’ solution:** it is based on the coupling of a Direct Current (DC)-driven heat pump (HP) with an advanced sorption storage (sorption heat pump) and a low-temperature latent thermal storage. During cooling season, when cooling energy is requested, the renewable electricity is employed to feed the compression HP, through a properly designed DC bus. The condenser of the compression HP is directly connected to the evaporator of the sorption storage which is driven either by solar thermal or district heating (or gas burner if DH is not available), thus increasing the electrical COP of the system. The produced cooling is stored in a high-density low temperature latent storage. In case of a surplus of renewable electricity, energy can be stored in an electrical storage (i.e. properly identified and sized battery), efficiently converted into thermal energy or stored in the sorption storage. Domestic hot water and space heating, when needed, can be either produced directly by the thermal source or efficiently produced and stored by the hybrid compression/sorption storage.

- **‘Continental’ solution**: it is able to increase the system efficiency and renewable sources exploitation through the integration of a high-density high temperature latent storage, employed to store the sensible energy of the hot gas exiting the compressor which is powered by a DC driven inverter and fed by renewable electricity. Indeed the amount of sensible energy delivered by the gas is able to cover a large share of the DHW demand in northern countries. In such a way, the renewable electricity is efficiently converted, through the modulating compression HP, in thermal energy for heating and DHW which is then stored in the building and in the high temperature latent storage. The system will also implement an electrical storage, which will allow to further increase the share of renewable energy both for buildings connected and non-connected to district heating networks. The operation mode can be reversed, to provide cooling energy and DHW during summer season. Therefore, the latent storage for DHW is used all over the year.

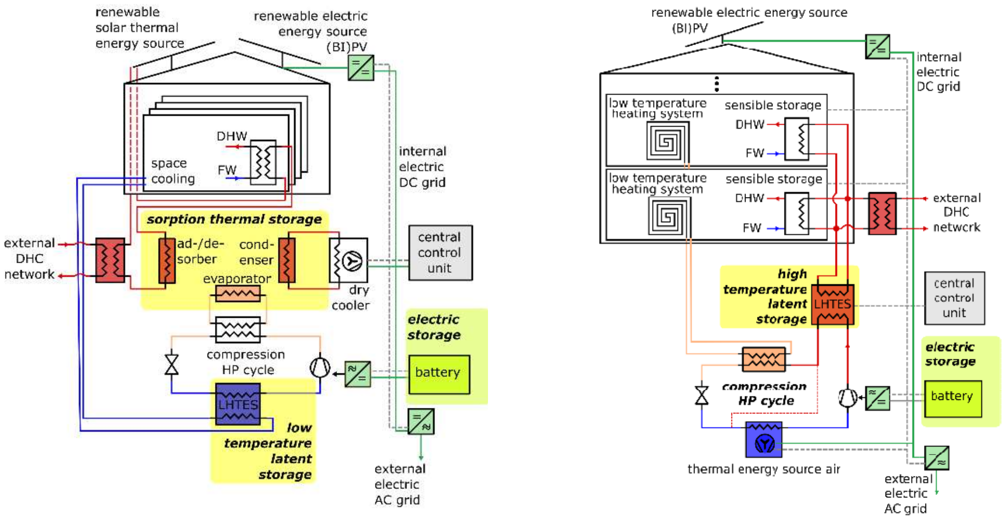


Figure 30 On the left the 'Mediterranean' solution during summer operation;
On the right the 'Continental' solution during winter operation

In general terms, to better define the applicability of a system to different boundary conditions a rigorous method has to be followed in order to produce results that can be quantified and compared. In this sense, the first way to quantify the performance of the two HYBUILD systems is to calculate their consumptions in terms of electrical energy taken from the external grid; then, economical consideration can be taken into account for country specific evaluations.

Since the core of the systems is represented by heat pumps, the electricity consumption of the system is dependent on both the external and internal ambient temperature and on the temperature of the hot and cold sources in general. To assess system performance, it is mandatory to use, as an input, the variation of the source temperatures along a period of investigation. Moreover, since the most relevant variations occur daily, the hourly frequency is the best option to obtain the desired result.

To work with annual/monthly aggregated values for demand and technology performance characterization can provide rough estimations about the applicability of the two HYBUILD systems. A more detailed analysis at hourly level can determine with better accuracy in which climate and in which type of building each system performs better.

## 5.1 Method for HYBUILD Solution analysis

The scope of this section is to define the necessary steps to perform time dependent simulations in order to determine which type of building can use the systems to be developed and under which climatic conditions and to describe how the tools presented in Section 3 (e.g. TABULA and INSPIRE) could be used as an input to perform the analysis. One of the scopes of task 4.1 is to apply the methodology here described, using appropriate simulation tools, in order to verify the systems performance according to the definition of the boundary conditions of WP1.

Hence, in order to assess the technology applicability, and determine which type of building can use the system developed, the steps to be followed are:

- Definition of the climatic conditions (**climatic characterization**);

- Definition of the characteristics related to geometrical and thermal features for each building typologies investigated (**building characterization**);
- Definition of the **boundary conditions** in terms of internal temperature set point, internal gains, shading elements, air infiltrations;
- User scenario definition (described in detail in chapter 6.2);
- Definition of heating and cooling **peak load and energy demand profile**;
- **Sizing of the systems** according to the condition defined;
- **Calculation of KPIs** for the evaluation of the technology as a function of the context of application.

The **climatic characterization** is necessary to define the building energy demand for heating and cooling and to define the external conditions at which the HYBUILD systems have to work. In particular the main parameters to be defined for each climate are listed in Table 36. The table presents a high level analysis of the impact of each parameter on the design and performance on the HYBUILD solutions. Moreover, the availability of the climatic data in TABULA and INSPIRE is reported in the table, in other to define if the data available in the database analysed are sufficient for the climate characterization and to perform the technology evaluation.

Table 36 Climatic parameters

| **Parameter** | | **Availability in TABULA/INSPIRE** |
|---|---|---|
| **$T_{amb}$** | • Monthly max/min/average. [°C]<br>• Hourly Temperature profile [°C] | **TABULA**<br>• Within TABULA calculator .xls file (downloadable), the mean monthly temperatures are available.<br>• No availability in the web-tool.<br>**INSPIRE**<br>• $T_{amb}$ is available as Annual max/min/average in INSPIRE report D2.3.<br>• No availability in the database |
| **Solar Energy** | • Annual and Monthly solar irradiation [kWh/m$^2$]<br>• Hourly profile of solar radiation [kWh/m$^2$] | **TABULA**<br>• Monthly values for different orientation available in TABULA calculator .xls file (downloadable).<br>• No availability in online database<br>**INSPIRE**<br>• Monthly values for different orientation available in INSPIRE reports D2.3 (downloadable).<br>• No availability in online database. |

| | | |
|---|---|---|
| **Degree days** | • Heating degree days (HDD)<br>• Cooling degree days (CDD) | • HDD and CCD are available in the INSPIRE report D2.3 as annual values. |

The data listed in Table 36 have been defined for each of the selected climates, countries and cities detailed in Chapter 2.

When it comes to the **building characterization**, both geometrical and thermal properties have to be considered. In particular the main parameters to be defined are:

- Net heated area [m$^2$];
- Surface/Volume rate;
- Roof: surface [m$^2$] and tilt angle;
- Wall; doors: surface [m$^2$] and thermal properties (U values [W/m$^2$K]);
- Windows: surface [m$^2$] in for each façade and thermal properties (U values [W/m$^2$K]); in alternative to the surface, the Glazing Ratio for each orientation (Nord, South, East , West) could be defined;
- Ceiling/Floor height and Building width /depth;

By assigning to each element the appropriate thermal properties for the building stock of each climate, a **reference building** per climate can be defined, in order analyse energy demand and systems behaviour under different conditions. To do so, the data available in **INSPIRE** and **TABULA/EPISCOPE** database has been analysed in chapter 3. A large number of information is available regarding the building typologies. In particular in INSPIRE the average U values (W/m$^2$) for reference countries of each building elements (Walls, roof, windows, floors) are available. In TABULA/EPISCOPE the information is available for different building typologies of different construction period, indicating not only on the U values but also on the layers composing each element.

As described in the chapter 3, in the case of HYBUILD project, the average value provided by INSPIRE database have been used and considered representative for the reference climates.

Having defined the building characteristics, it is necessary to define the **boundary conditions** to perform the calculations. The parameters to be defined are:

- Internal temperature set points for heating and cooling season;
- Internal gains due to occupancy, appliances and lighting;
- Ventilation parameter due to windows opening and infiltration: Airflow (V/h); Air Temperature; Relative humidity;
- Shading factor on transparent elements, depending on external condition;
- User scenarios: definition of the scheduling related to temperature set points, ventilation parameters, internal gains and their variations due to the building usage.

Now, **simulations** at hourly/daily level are done to define the energy demand (kWh/y) and the peak load (kWh) needed for the system designing.

Thanks to the models of each component developed in WP2 and WP3, simplified model of the whole systems will be developed and its behaviour will be investigated again throughout dynamic simulations in WP4.

Thanks to the analysis of these results, it will be possible define for each climate considered and for each type of building modelled, the **size of the systems** (Power), the storage capacities considered the seasonal energy efficiency of the systems regarding heating and cooling and the DHW production covered.

Finally, with the calculation of specific **KPIs** (defined in Task 1.5) the performance of the system can be evaluated in detail.

In the case of the **'Mediterranean' solution**, the presence of the sorption module allows for lowering the temperature at the condenser side of the DC-Driven heat pump, increasing the COP of the system. The HP is connected to an electric storage that draws energy from a PV plant, in order to cover the majority of the electrical energy demand. Moreover, to activate with 'free' energy the desorption cycle of the sorption module, a solar thermal (ST) plant providing heat at temperatures above 70 °C is needed. For these reasons the solar irradiation available in the building location, the orientation, the availability of sufficient space for installing both PV and ST plants are crucial factor to maximize the effectiveness of the HYBUILD system. In particular for the ST plant, the Fresnel system is the one recommended.

The ST plant contributes not only to the increasing of the COP of the system, activating the desorption process, but it also can be used for DHW supply, with the help of apposite water storage in the building.

At the other side of the system, the presence of the low temperature latent storage optimizes the cooling production, both mitigating the variation in the cooling demand and reducing the variation of the temperature at the evaporator side. This beneficial effect can be only evaluated by dynamic simulation at hourly level, which gives back an accurate estimation of the electricity consumption for satisfying cooling demand.

Another advantage to be considered in the assessment of the 'Mediterranean' solution is the possibility to cover heating demand during winter. This allows for having a unique high efficiency system for both cooling and heating, increasing the share of renewable.

When it comes to the **'Continental' solution**, the presence of the high temperature latent thermal storage allows for producing DHW while producing heating for a low temperature heating system. A PV plant and an electrical storage provide the renewable energy to cover the electrical energy need of the system. With this system, the DHW can be provided by slowly charging the latent storage, using the sensible heat of the hot gas after the compressor. This allows for having an intermediate temperature at the condenser, maintaining a high COP even if energy for DHW is provided.

To evaluate the performance of the system, it has to be considered that the COP and the amount of DHW that can be provided by the latent storage depend on the operating temperatures. To charge the latent storage, the temperature reached after the compressor should be higher enough to be practicable for DHW (≈60 °C). So, the performance of the system highly depends on supply temperature for heating on one side and from the ambient temperature form the other. The climates, the emission system (e.g. radiant floor panel) and the energy performance of the building envelope have therefore high influence both on the COP of the system and on the amount of the DHW produced.

# 6 Dynamic user integration

Once the reference climates and building typologies are defined, load profiles for heating, cooling and DHW demand are calculated. The next paragraphs describe the inputs used for setting the energy models and the simulation results. For the sake of clarity, in the report only yearly and monthly demands are reported. The analysed cases are the two building typologies presented in section 4, located in the 5 climates described in section 2.

## 6.1 Boundary conditions

This section reports the inputs for building occupancy, infiltration and ventilation rate, shading elements and temperature set points for assessing the reference building load profiles. Boundary conditions are kept equal for all the climates and typology in order to allow a comparison between different cases whose influence is due to the building shape or weather conditions.

### 6.1.1 Internal gains

In the two building typologies, schedule and load profile for the occupancy are slightly different: in SFH a daily profile is defined and maintained equal for the whole year while in MFH stochastic profiles are outlined in order to take into account the irregularities in the presence and behaviour in different apartments (Widén, 2010).

Appliances and lighting consumption are accounted together: the same contribution of internal gains is used as electric consumption. The schedule used for SFHs refers to a 140 m² building (Haller, 2014); for the reference case this profile is scaled up by W/m² and applied to the two reference floors.

Table 37. Occupancy, appliances and lighting internal gains

| INTERNAL GAINS | | Unit |
|---|---|---|
| **Occupancy** | | |
| **Schedule** | see Figure 31 (SFH) and Figure 33 (MFH) | [-] |
| **Activity level (ISO 7730)** | Seated, very light writing | [-] |
| **Sensible heat** | 65 | [W] |
| **Latent heat** | 55 | [W] |
| **Number of people** | 4 (SFH) – 3 (MFH) | [-] |
| **Appliances & lighting** | | |
| **Schedule** | see Figure 32 (SFH) and Figure 34 (MFH) | [-] |
| **Peak sensible heat** | 10 | [W/m²] |
| **Stand-by sensible heat (min values)** | 2 | [W/m²] |

## SFH

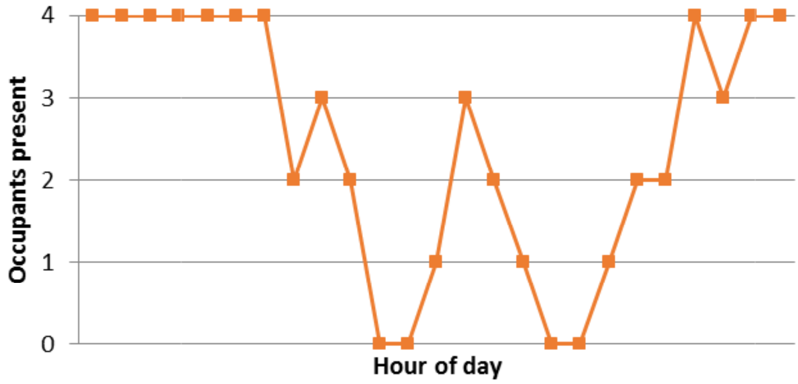


Figure 31 – Task 44 presence profile for Single Family House (SFH) with four occupants

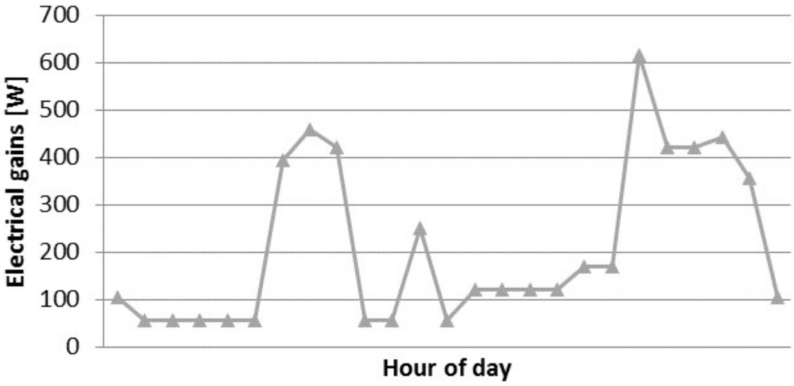


Figure 32 – Task 44 profile for internal electrical gains in a Single Family House (SFH) of 140 m² with four occupants

## MFH

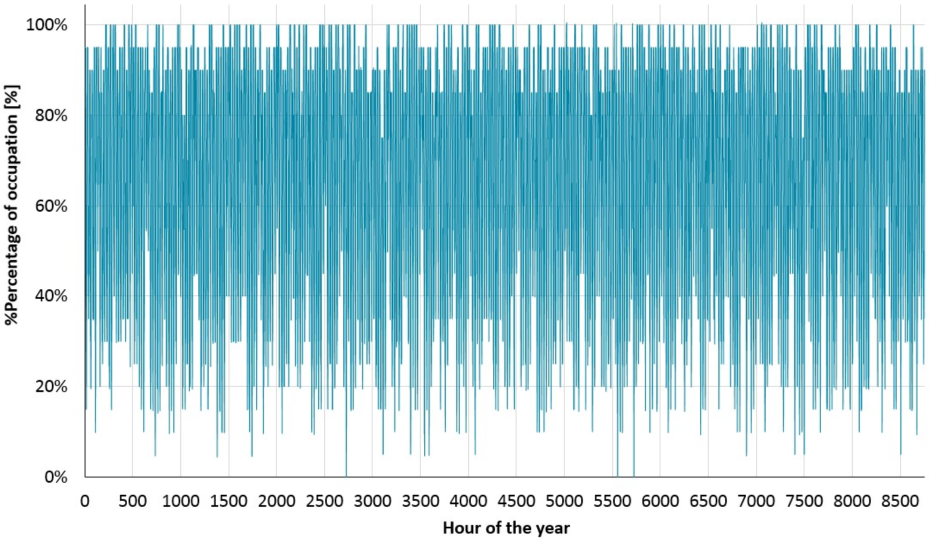


Figure 33 – Stochastically generated occupancy profile for a multi-family house with 20 occupants

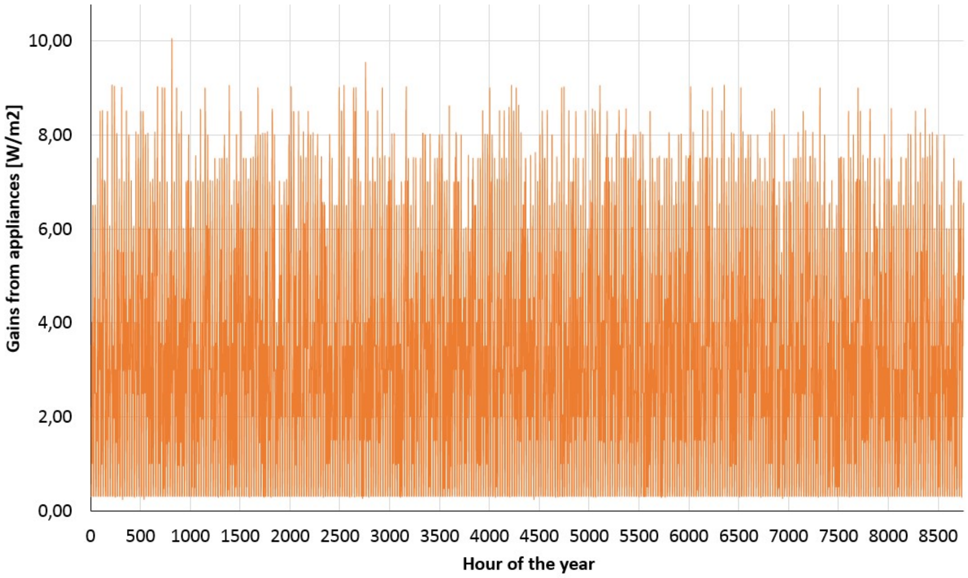


Figure 34 – Stochastically generated internal gains profile for appliances for a multi-family house with 20 occupants

### 6.1.2 Infiltration and mechanical ventilation

A total air change rate (with external air) equal to 0.45 vol/h has been considered as constant for the whole year. This value accounts for infiltration, 0.15 vol/h, and windows opening, 0.30 vol/h.

Table 38. Summary of ventilation and infiltration for residential buildings

| **VENTILATION / WINDOWS OPENING** | | **Unit** |
|---|---|---|
| **Airflow** | 0.30 | [vol/h] |
| **Temperature** | outside | [°C] |
| **Relative humidity** | outside | [%] |
| **Profile** | 0-24 | Day hour |
| **INFILTRATION** | | |
| **Airflow** | 0.15 | [vol/h] |
| **Temperature** | outside | [°C] |
| **Relative humidity** | outside | [%] |
| **Profile** | 0-24 | Day hour |

### 6.1.3 Shading elements

Shading on windows has been assumed to be activated considering a shading factor of 70% if three conditions are met:

- Global vertical irradiation on the façade element is greater than 150 W/m²
- Room temperature is greater than 24 °C (shades removed if < 23 °C)
- 24 hour moving average ambient temperature greater than 12 °C

This strategy takes into account the user behaviour that is supposed to partially cover the windows when there is direct radiation entering through the window, temperature in the room rises and it is not wintertime.

### 6.1.4 Temperature set points and schedules

Heating and cooling demands are assessed assuming ideal capacity of the conditioning system in a way that the internal temperature is maintained between two set temperatures. The fixed temperature during winter time is 20°C while during summertime is 25°C (see Table 39).

Table 39. Space heating and space cooling set point, schedule and air properties

| **SPACE HEATING** | | **Unit** |
|---|---|---|
| **Set temperature** | 20 | [°C] |
| **Schedule** | 0-24 | Day hour |
| **Humidification** | OFF | |
| **SPACE COOLING** | | |
| **Set temperature** | 25 | [°C] |
| **Schedule** | 0-24 | Day hour |
| **Dehumidification** | 50% Relative humidity | |

## 6.2 User scenarios definition

### 6.2.1 Set temperatures and schedule variation

In order to provide a wider overview of the building demand, and consequently building consumption, under different conditions, three other heating set points and two other cooling set points are investigated. Table 40 reports the space heating and space cooling simulation temperature set points.

Table 40. Space heating and space cooling simulations temperature set point

| CASE | SET TEMPERATURE HEATING [°C] | SET TEMPERATURE COOLING [°C] |
|---|---|---|
| **Case 1** | 19 | 25 |
| **Case 2** | 20 | 25 |
| **Case 3** | 21 | 25 |

| | | |
|---|---|---|
| **Case 4** | 22 | 25 |
| **Case 5** | 20 | 24 |
| **Case 6** | 20 | 26 |

## 6.3 Energy demand analysis

Demand Profiles are calculated on an hourly-basis thanks to the energy simulations. In this report, data regarding heating and cooling energy demands and specific heating and cooling peak values are reported on yearly basis, considering each analysed climate, building typology and temperature set points. Monthly values are also presented for one set point temperature combination, i.e. 20°C and 25°C.

### 6.3.1 Monthly heating and cooling demand

Figure 35 reports on the monthly heating demand for SFH in the five reference climates, while Figure 37 shows the monthly heating demand for the MFH.

As can be seen from the Figure 35 the maximum heating demand is reached in the southern dry climate (Madrid). This fact is due to the poor performance of the envelope in this climatic zone. On the contrary, the coldest climates result with higher envelope quality and, therefore, a lower heating demand. To be noted that the set point temperature is the same for all the cases and the reported heating demands refer to buildings belonging to the construction period 1980-1990.

As expected, the climate that presents the highest cooling demand is the Mediterranean one referred in this case to the city of Athens. Despite that, also the coldest climates account for cooling demand (see Figure 36, Figure 38). However, thanks to the low temperatures during the night, the cooling load in these climates can be reduced by night-cooling strategies.

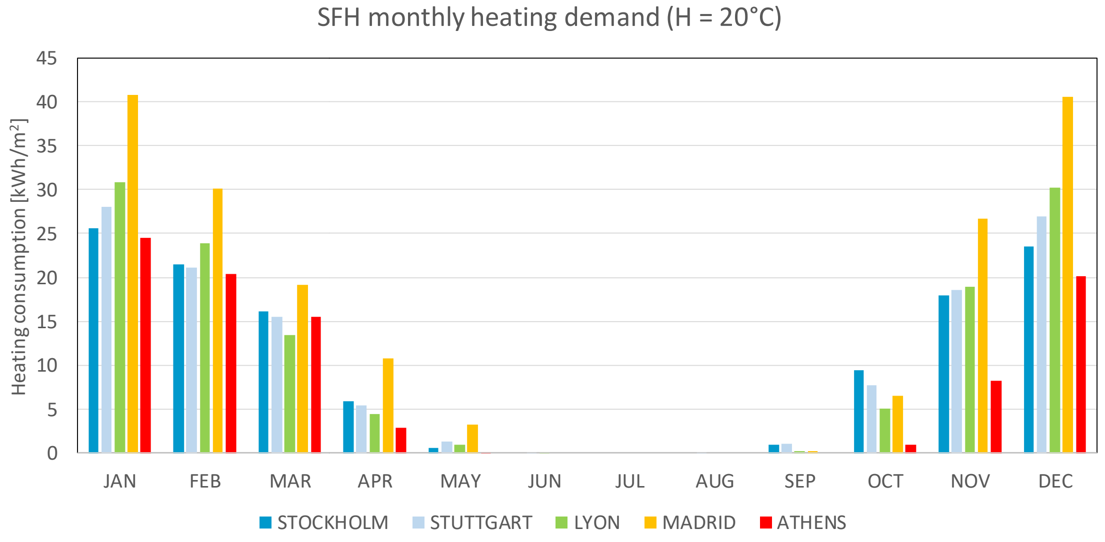


Figure 35 - SFH monthly heating demand

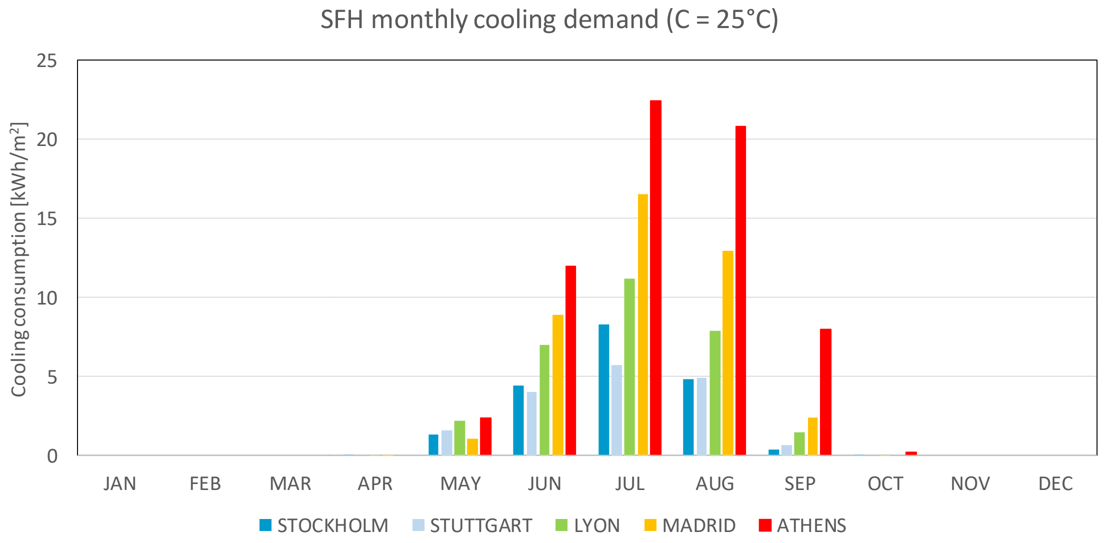


Figure 36 - SFH monthly cooling demand

For MFH, the behaviour is similar as for the SFH: the highest heating demand is observed for the Mediterranean climate due to the external temperatures during the winter and the low quality of the envelope (see Figure 37). In comparison to the SFH, the MFH heating demand for buildings with the same construction period is almost half due to the lower surface over volume (S/V) ratio (see Table 34 and Table 35).

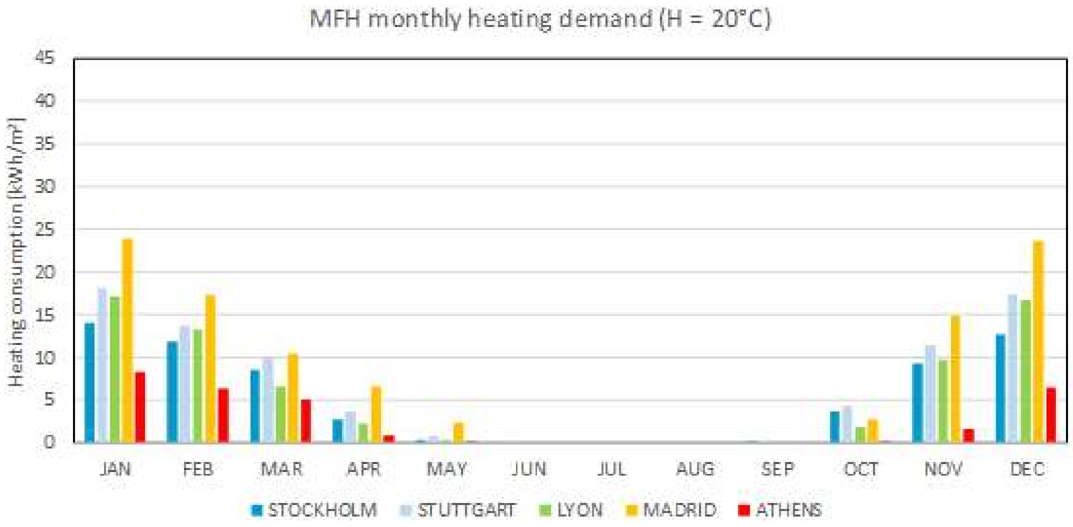


Figure 37 - MFH monthly heating demand

Due to the high external temperature during summertime in the Mediterranean climate, the cooling demand in this case results almost double than in the Southern Dry and around triple than in the northern climates (see Figure 38).

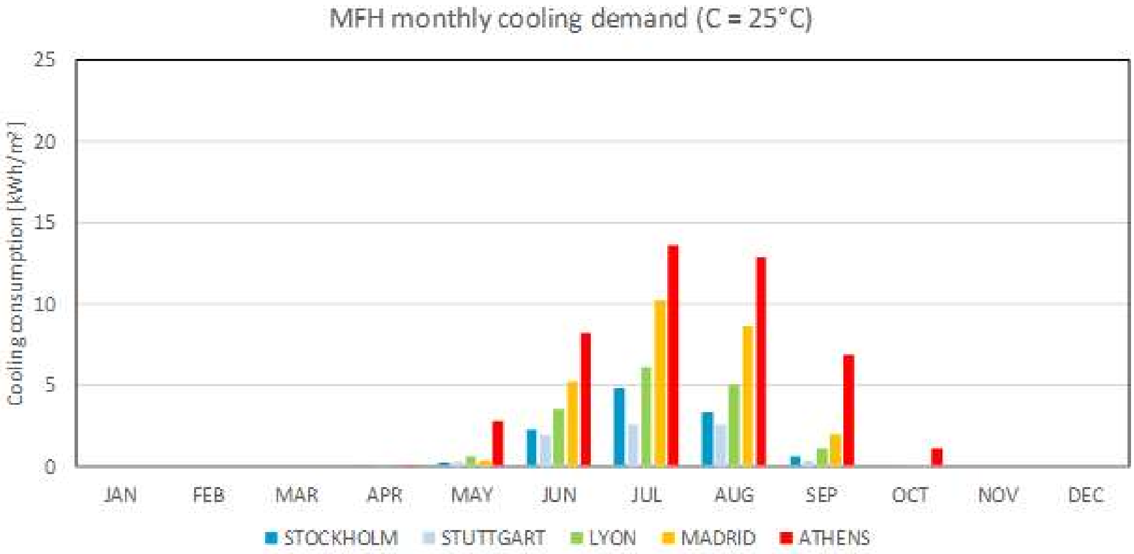


Figure 38. MFH monthly cooling demand

### 6.3.2 Yearly heating and cooling demand

In order to understand the building behaviour when changing the heating and cooling set points and, consequently the energy consumption, simulations at different set values have been carried out. Yearly building heating demands at different working conditions for SFH are reported in Table 41 and Figure 39, while for MFH in Table 45 and Figure 41.

**SFH:**

Looking at Figure 39, it can be observed that heating demand of buildings with a lower quality envelope is primarily influenced by the internal set point. Changing the internal temperature, results in heating demand of 10%-15% higher for each added degree. In the Mediterranean climate, the increase is around 20%-25% per degree.

Heating peak loads are reported in Table 42 as reference for design purposes.

Table 41. Heating energy demand for SFH in five climates for different set temperatures

| SFH | | | | |
|---|---|---|---|---|
| ***Heating demand [kWh/(m²y)]*** | | | | |
| **CLIMATE** | **19°C** | **20°C** | **21°C** | **22°C** |
| **Stockholm** | 111 | 122 | 133 | 144 |
| **Stuttgart** | 112 | 126 | 140 | 156 |
| **Lyon** | 113 | 128 | 144 | 162 |
| **Madrid** | 155 | 178 | 202 | 228 |
| **Athens** | 75 | 93 | 111 | 131 |

Table 42. Peak loads for heating for SFH in five climates for different set temperatures

| SFH | | | | |
|---|---|---|---|---|
| ***Peak load for heating [W/m²]*** | | | | |
| **CLIMATE** | **19°C** | **20°C** | **21°C** | **22°C** |
| **Stockholm** | 62 | 64 | 66 | 68 |
| **Stuttgart** | 67 | 70 | 73 | 75 |
| **Lyon** | 73 | 77 | 80 | 83 |
| **Madrid** | 94 | 98 | 103 | 108 |
| **Athens** | 62 | 67 | 71 | 76 |

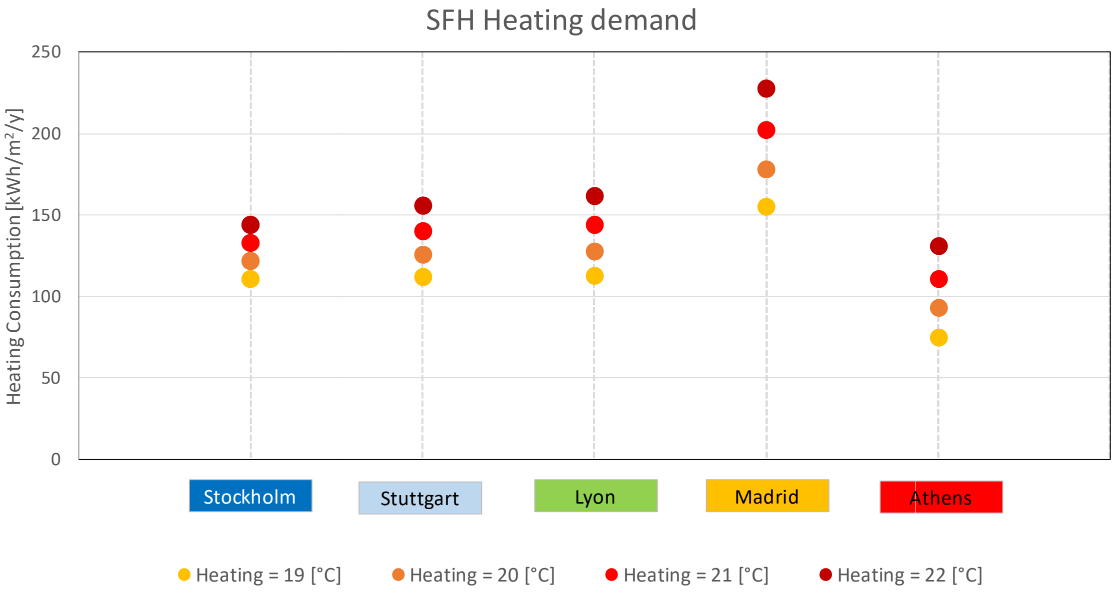


Figure 39. SFH heating yearly energy demand summary

Yearly cooling demands are reported in Table 43 and Figure 40. The decrease of 1°C on the set point temperature for space cooling has a higher effect on the used energy than for the heating demand: cooling demand in fact increases from 25% to 70% depending on the climate.

Cooling peak loads for SFH are reported in Table 44.

Table 43 Cooling energy demand for SFH in five climates for different temperature set points

| SFH | | | |
|---|---|---|---|
| ***Cooling demand [kWh/(m²y)]*** | | | |
| CLIMATE | **26 [°C]** | **25 [°C]** | **24 [°C]** |
| **Stockholm** | 15 | 19 | 27 |
| **Stuttgart** | 12 | 17 | 25 |
| **Lyon** | 23 | 30 | 50 |
| **Madrid** | 32 | 42 | 67 |

| | | | |
|---|---|---|---|
| **Athens** | 52 | 66 | 112 |

Table 44 Peak loads for cooling for SFH in five climates for different temperature set points

| SFH | | | |
|---|---|---|---|
| ***Peak load for cooling [W/m$^2$]*** | | | |
| CLIMATE | **26 [°C]** | **25 [°C]** | **24 [°C]** |
| **Stockholm** | 50 | 53 | 54 |
| **Stuttgart** | 41 | 44 | 49 |
| **Lyon** | 58 | 62 | 70 |
| **Madrid** | 61 | 65 | 76 |
| **Athens** | 59 | 63 | 91 |

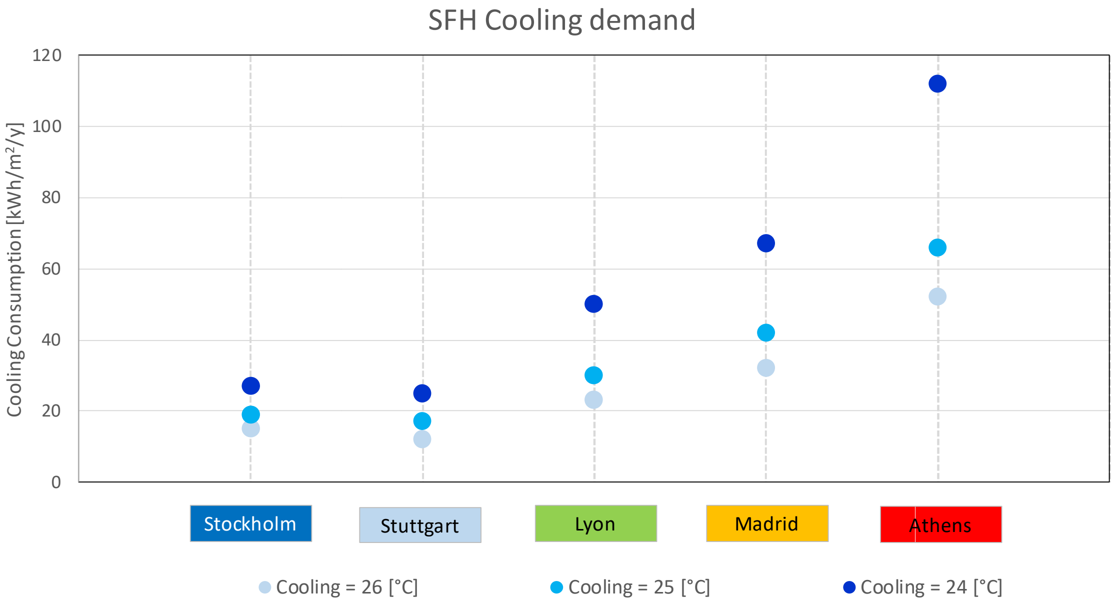


Figure 40. SFH cooling yearly energy demand summary

**MFH:**

Similar behaviour is observed for the MFH: the increase of 1 °C results in a 10-15% higher heating demand, and up to a 35-50% increase when moving from 19°C to 22°C.

Peak loads values are reported in Table 46 and can be used as reference for designing new systems.

Table 45 Heating energy demand for MFH in five climates for different temperature set points

| **MFH** |
|---|

| *Heading demand [kWh/(m²y)]* | | | | |
|---|---|---|---|---|
| **CLIMATE** | **19°C** | **20°C** | **21°C** | **22°C** |
| **Stockholm** | 57 | 63 | 70 | 77 |
| **Stuttgart** | 71 | 80 | 90 | 101 |
| **Lyon** | 59 | 68 | 78 | 89 |
| **Madrid** | 88 | 102 | 117 | 134 |
| **Athens** | 22 | 29 | 37 | 46 |

Table 46 Peak loads for heating for MFH in five climates for different temperature set points

| **MFH** | | | | |
|---|---|---|---|---|
| *Peak load for heating [W/m²]* | | | | |
| **CLIMATE** | **19°C** | **20°C** | **21°C** | **22°C** |
| **Stockholm** | 33 | 35 | 36 | 37 |
| **Stuttgart** | 45 | 47 | 49 | 51 |
| **Lyon** | 43 | 45 | 48 | 50 |
| **Madrid** | 58 | 62 | 65 | 68 |
| **Athens** | 28 | 30 | 33 | 35 |

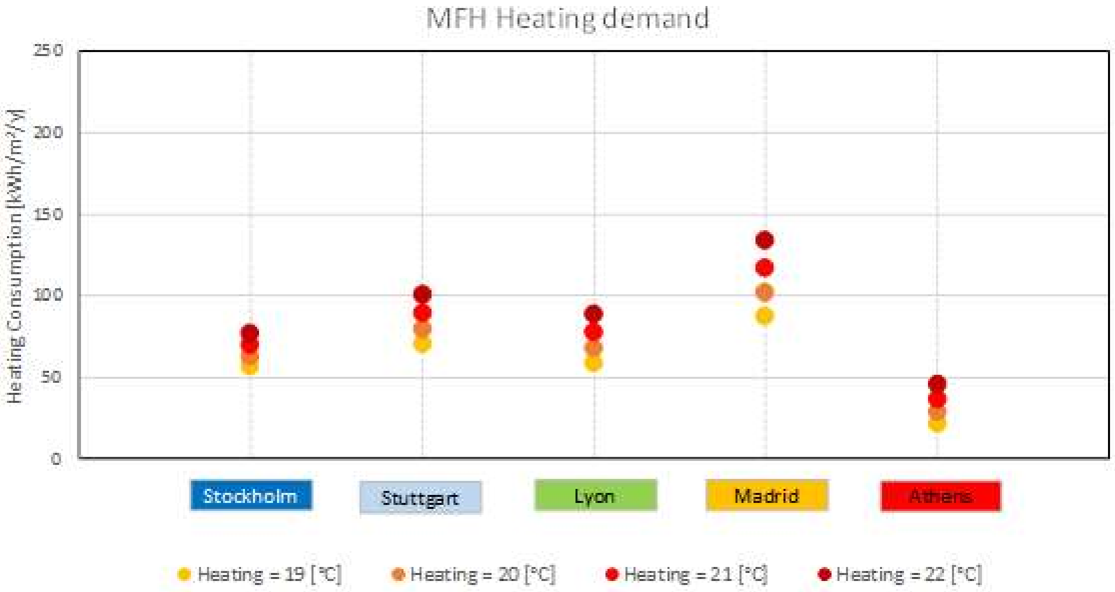


Figure 41 MFH heating yearly energy demand summary

The impact of 1°C reduction on the cooling set point is higher with respect to the heating demand: depending on the climate, cooling demand can increase from 20% to 65% for each degree. Moving from 26°C to 24°C can double the peak load.

As for the heating demand, cooling peak loads are reported in Table 48.

Table 47 Cooling energy demand for MFH in five climates for different temperature set points

| MFH | | | |
|---|---|---|---|
| *Cooling demand [kWh/(m²y)]* | | | |
| CLIMATE | **26 [°C]** | **25 [°C]** | **24 [°C]** |
| **Stockholm** | 9 | 11 | 16 |
| **Stuttgart** | 5 | 8 | 13 |
| **Lyon** | 12 | 17 | 28 |
| **Madrid** | 20 | 27 | 40 |
| **Athens** | 38 | 46 | 69 |

Table 48 Peak loads for cooling for MFH in five climates for different temperature set points

| MFH | | | |
|---|---|---|---|
| *Peak load for cooling [W/m²]* | | | |
| CLIMATE | **26 [°C]** | **25 [°C]** | **24 [°C]** |
| **Stockholm** | 25 | 27 | 29 |
| **Stuttgart** | 22 | 24 | 26 |
| **Lyon** | 28 | 30 | 41 |
| **Madrid** | 36 | 39 | 54 |
| **Athens** | 40 | 42 | 48 |

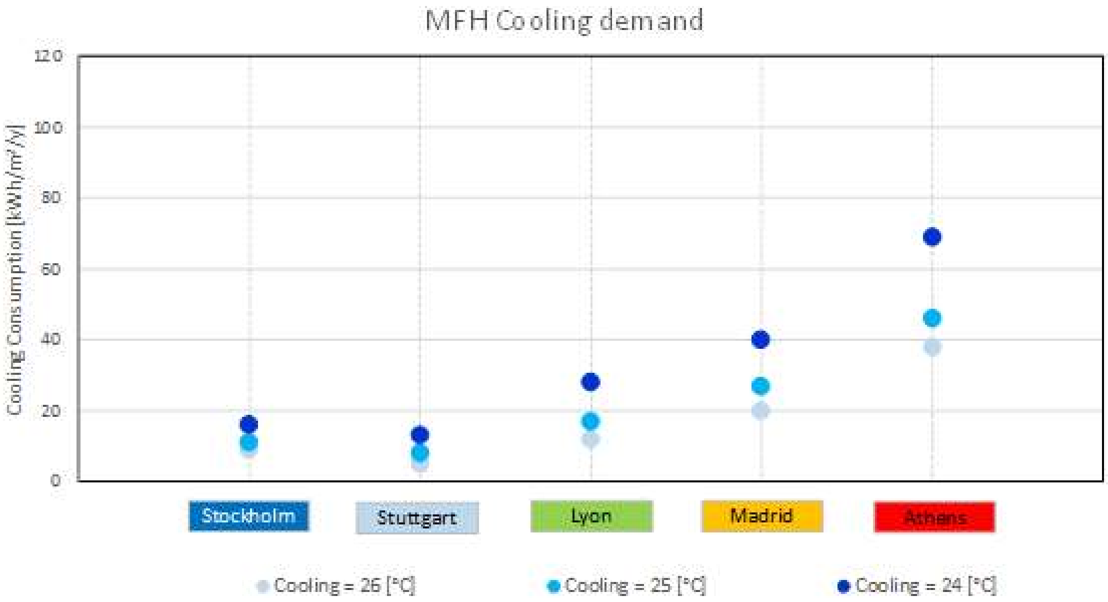


Figure 42 MFH cooling yearly energy demand summary

# 7 Conclusions

The aim of this report has been first to characterize a limited number of concerned climates to be taken as reference in the analysis of the HYBUILD solution, considering the different climatic conditions, habits and constraints in energy consumption. The residential building typologies representative of the Building stock in Europe have been identified, to be considered for the HYBUILD performance assessment and as potential candidates for the HYBUILD technologies application. Another objective has been to define user scenarios and boundary conditions consistent with the building typologies, serving as input in the energy simulations used to define loads profiles for heating, cooling and DHW. Load profiles and peak loads for each building and climate have been defined to be used in further energy simulation that will be carried out in the rest of the project to evaluate the HYBUILD system performance.

Five reference climates have been selected among the seven European climates defined in the INSPIRE project (taken as reference) and characterized considering different parameters such as ambient temperature, humidity, solar irradiation, HDD and CDD. The aim has been to represent cold, warm and hot climates in Europe, allowing for testing the two HYBUILD solutions under different conditions by means of the energy analysis which will be carried out during the project. To represent the five climates, five reference countries and cities (Table 49) have been selected collecting the climatic parameters from Meteonorm database.

Table **49 HYBUILD reference climates, country and cities.**

| **Climate** | **Country** | **City** |
|---|---|---|
| **Nordic** | Sweden | Stockholm |
| **Continental** | Germany | Stuttgart |
| **South continental** | France | Lyon |
| **Southern dry** | Spain | Madrid |
| **Mediterranean** | Greece | Athens |

In HYBUILD, the assessment of the two hybrid solutions will be carried not only thanks to energy simulation, but also deploying and testing them in three different demo sites: Bordeaux (France, South Continental climate), Almatret (Spain, Southern Dry climate) and Aglantzia (Nicosia district, Cyprus, Mediterranean climate). The specific climatic data of the three demo sites have been collected, in order to be used in the energy simulation activities.

The definition of the building typologies representative of the European building stock to be considered in the project started with an analysis of the data available in TABULA/EPISCOPE and INSPIRE European projects. The analysis highlighted the large number of data available related to the building stock: age of construction, envelope characteristics, heating system, energy demand and consumption are some of the data available. This information is both useful for the evaluation of the HYBUILD solutions performance, giving inputs for the energy analysis (e.g. typical building area, envelope characteristics, U values) and providing a snapshot of the state of art from which to compare the two HYBUILD solutions.

There are two building typologies in common for the two databases: the Single-Family House (SFH) and the Multi-Family House (MFH). In the HYBUILD project these two typologies have been chosen as representative of the EU Building stock, for different reasons: they are largely widespread in Europe, a large amount of data is available, and the age of construction for the two typologies is distributed homogeneously, allowing for choosing a common reference period.

Another objective of the work done has been to define a method describing the main steps to perform time dependent simulations in order to assess the applicability of the HYBUILD technologies and the performance of the HYBUILD solutions. This has been presented in chapter 5, with a description on how the databases analysed could be used to provide important data to perform energy analysis in chapter 3. The steps identified are:

- **climatic characterization**;
- **building characterization**;
- definition of the **boundary conditions** and user scenarios;
- definition of heating and cooling **peak load and energy demand profile**;
- **Sizing of the systems** according to the condition defined;
- **Calculation of KPIs** for the evaluation of the technology as a function of the context of application.

The boundary conditions and the user scenarios to be considered in the energy simulations that will define the load profiles have been defined in this report. This includes the definition of: internal gains, infiltration and mechanical ventilation, shading elements, temperature set points and scheduling of the appliances.

Slightly different internal gains have been considered for the two building typologies: in a SFH, a daily profile is defined and maintained the same for the whole year; in MFH stochastic profiles are outlined in order to take into account the irregularity in the presence and behaviour in different apartments (Widén, 2010). The user behaviour is also taken into account for both the typologies in the window shading definition. In fact, the user is supposed to partially cover the windows when there is direct radiation entering through the window or when the temperature in the room rises and it is not wintertime.

Two reference temperature set points have been fixed: 20°C during winter; 25°C during summertime. Then, different user scenarios have been considered by defining six combinations of set temperatures for the heating and cooling season: the winter temperature set points varying from 19 °C to 22 °C and the summer ones varying from 24 °C to 26 °C. This allowed for a wider overview of the building demand under different condition when calculating the load profile.

Having defined climates, building typologies, boundary conditions and user scenarios, an analysis of the energy demands for heating and cooling and the related peak loads has been carried out. The profiles have been calculated on hourly-basis considering the hourly profiles of temperature, the humidity and the solar irradiation, defined during the characterization of the reference climates. In particular in this report, data regarding heating and cooling energy demands and specific heating and cooling peak values are reported on yearly basis, considering each analysed climate, building typology and temperature set points. Monthly values are also presented for one set point temperatures combination, i.e. 20°C and 25°C.

Despite the fact that the definition of the load profiles and peak loads are propaedeutic to the energy simulations, some interesting consideration can be done at this stage. When it comes to the heating demand, the higher load profile has been found in Madrid. This is because, despite warmer external conditions with respect to the Nordic, Continental and South continental climates, the lower building insulation with respect to those climates results in a higher heating demand. Regarding the Cooling demand, as expected the higher values have been found in Mediterranean climate, in particular in Athens with the coldest climates accounting for a low cooling demand. However, thanks to the low temperatures during the night, the cooling load in these climates can be further reduced by night-cooling strategies.

The work reported in this deliverable is preparatory for the others tasks and work packages which will be carried out later in the project. In particular the climates, the building typologies and the load profiles and peak load defined will be used in the analysis of the system performance carried out in WP4 and also in the assessment of the component and sub-systems performance during the designing phase in WP2 and WP3. The methodology developed will help the definition of the proper sizing of the solution to be applied in the demo site within WP6.

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