Deliverable Report

Project Title:

Solar-Biomass Reversible energy system for covering a large share of energy needs in buildings

Project Acronym:

SolBio-Rev

Work Package 2

Deliverable 2.1

"Definition of climate and

building typologies "

Responsible for Deliverable:

Universitat de Lleida (UDL)

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Contents

Executive Summary

The SolBio-Rev project will develop an innovative renewable energy system based on a novel and creative heat pump-based configuration, for the production of heating (space heating and domestic hot water – DHW), space cooling, and electricity according to the daily and seasonal energy demand of buildings. This configuration hosts a reversible heat pump/organic Rankine cycle (ORC) coupled with a cascade chiller with a heat pump. The targeted benefit of the SolBio-Rev that combines different renewable energy systems is to reach an energy share of up to 100% in a variety of EU buildings, with a modular, flexible, and compact energy system.

This deliverable selects and characterizes the boundary conditions that can serve as an input for the numerical assessment of the proposed SolBio-Rev system to evaluate the technical performance. The boundary conditions presented in this deliverable are defined in terms of climate and building typologies. A literature review is carried out to define a limited number of concerned climates that can represent the Northern, Central and Southern Europe. For this purpose, five European locations are selected and the main parameters, such as temperature, humidity, and solar radiation are collected and analysed. Four main building typologies for residential and commercial buildings are identified and characterized for the potential application of the SolBio-Rev system. The characterization, based on a survey of the data available from European project database and scientific literature review is done in terms of construction age, renovation categories, specific energy consumption, architectural configuration, building size and key geometry indicators and type of management. The implementation of the EU directive in different national plans is also considered to define the minimum requirements and the energy performance of new and renovated buildings.

The results will serve as an input for the next step of the project that involves the dynamic simulation of the SolBio-Rev system together with the results from other activities contained in this WP.

Acronyms and abbreviations

Acronym	
CDD	*Cooling degree day*
DHR	*Diffuse horizontal radiation*
DHW	*Domestic hot water*
GHR	*Global horizontal radiation*
HDD	*Heating degree day*
MFH	*Multi-family house*
nZEB	*nearly Zero Energy Building*
RH	*Relative humidity*
WP	*Work package*

1 Introduction

1.1 *Aims and objectives*

The aim of this report is to define the boundary conditions that can be taken as a reference during the development of the SolBio-Rev system.

The first objective is to select and characterize a limited number of climate zones that can represent Southern, Central and Northern Europe. The second objective is to define and characterize different building typologies of residential and non-residential/commercial buildings. Renovated and nearly Zero Energy Buildings (nZEBs) are also considered.The classification is carried out in terms of construction age, renovation categories, specific energy consumption, architectural configuration, building size and key geometry indicators and type of management system.

To define the boundary conditions a survey of all the data available is done consulting other European Projects (TABULA, EPISCOPE, ENTRANZE, BUILD-UP, INSPIRE), current European standards, and a scientific literature review.

The results will serve as input for the dynamic simulations and the performance assessment of the SolBio-Rev system in different climates.

1.2 *Relation with other activities in the project*

This results and the data presented in this report will be integrated with the results of the activity carried out in WP3 that define the user behaviouralmodels (Task 3.1). The results serve as the input for the dynamic simulations of the system defined in Task 3.4 starting on M4.

1.3 *Report structure*

In Section 2 the climate zones are selected and characterized to represent different climate conditions where the system can operate. The different building typologies selected and their characterization are then presented in Section 3. The characterization of residential, non-residential buildings and new/renovated buildings is presented in the sub-sections. Section 4 reports the main conclusion of this report.

1.4 *Contribution of partners*

The main contributing authors of this report are Emiliano Borri (UDL) and Luisa F. Cabeza (UDL).

2 Climate identification and characterization

In this section different climate zones are selected and characterized to define the potential use of the SolBio-Rev system and define the boundary conditions that can be used to assess the performance of the system.

Europe is characterized by many different climate typologies that are influenced by a lot of factors. In order to characterize the Northern, Central and Southern European climate, five different cities have been selected to represent the typologies and are listed as follows:

- **Northern Europe**: Helsinki
- **Continental Europe**: Nuremberg, London
- **Southern Europe:** Athens, Madrid

The climate data for each location were collected from TRNSYS, Meteonorm database [1]. This software allows exporting, from the Meteonorm library, different meteorological properties in different time resolution from any location in the world. Indeed, Meteonorm provides a catalogue of meteorological data collected experimentally from different meteorological stations and the ones that are not available are calculated by interpolation. The parameters collected for climate characterization are:

- Mean Ambient Temperature.
- Minimum ambient temperature.
- Maximum ambient temperature.
- Relative Humidity.
- Diffuse horizontal radiation.
- Global horizontal radiation.

To describe the need for heating and cooling, Heating Degree days (HDDs) and Cooling Degree days (CDDs) are defined for each location. With the mean daily temperature method, those values are calculated, considering for each day the difference between the mean ambient temperature (T_{mean}) and the base temperature. The base temperature is a fixed value that usually depends on factors associated with the building and the surrounding environment. In the next section, the values of HDDs and CDDs are taken from the literature and are calculated with a base temperature of 15ºC and 18.3ºC for the HDD and CDD, respectively.

2.1 Northern Europe: Helsinki

Helsinki is the capital of Finland located on the Gulf of Finland on the BalticSea. This city was chosen as a reference for the Nordic climate. According to the Köppen-Geiger climate classification [1,2] shown in Figure 1, Finland is mainly characterized with a Tundra climate. However, the city of Helsinki is located in the southern part of the country that is characterized by a subarctic climate.

The HDDs and the CDDs of Helsinki are [3]:

- HDDs (base temperature 15ºC):4898.
- CDDs (base temperature 18.3ºC): 16.

Figure 1: Köppen-Geiger climate classification in Finland [1,2].

Table 1 shows the weather characteristics of Helsinki for each month of the year. The average of the minimum, maximum and mean temperature for each month are shown in Figure 2. The winter in Helsinki is very cold with an average sub-zero temperature from December to March with a minimum temperature of -25.60 ºC. A minimum sub-zero temperature can occur until the month of June. However, from the month of May the maximum temperature rises reaching 26.4ºC in July, the warmest month of the year. The relative humidity varies during the year from 72% to over 90%. The total solar radiation during the year is 486.41 kWh/m^2 and 953.12 kWh/m^2 for the diffuse horizontal radiation and the global horizontal radiation, respectively.

Table 1: Helsinki climate datafrom TRNSYS, Meteonorm

Month	T_{mean} [ºC]	T_{min} [ºC]	T_{max} [ºC]	RH [%]	DHR [kWh/m^2]	GHR [kWh/m^2]
Jan	-6.90	-23.60	1.30	76.00	6.214	8.193
Feb	-7.22	-25.60	4.70	84.00	15.130	24.163
March	-2.94	-16.10	8.00	74.50	34.744	64.723
April	2.87	-8.30	17.60	96.50	54.958	107.463
May	9.87	-2.00	23.00	73.00	75.028	163.669
June	14.71	2.70	26.20	76.50	80.560	180.402
July	16.61	6.20	26.40	60.00	86.460	165.710
Aug	15.04	3.80	24.30	71.00	60.0122	123.741
Sept	9.95	-1.30	21.70	83.00	40.885	68.890
Oct	5.51	-7.10	14.70	72.00	20.980	32.316
Nov	0.22	-11.30	9.80	96.00	7.957	9.457
Dec	-6.90	-23.60	1.30	71.50	3.482	4.392
Total	-	-	-	-	486.414	953.123

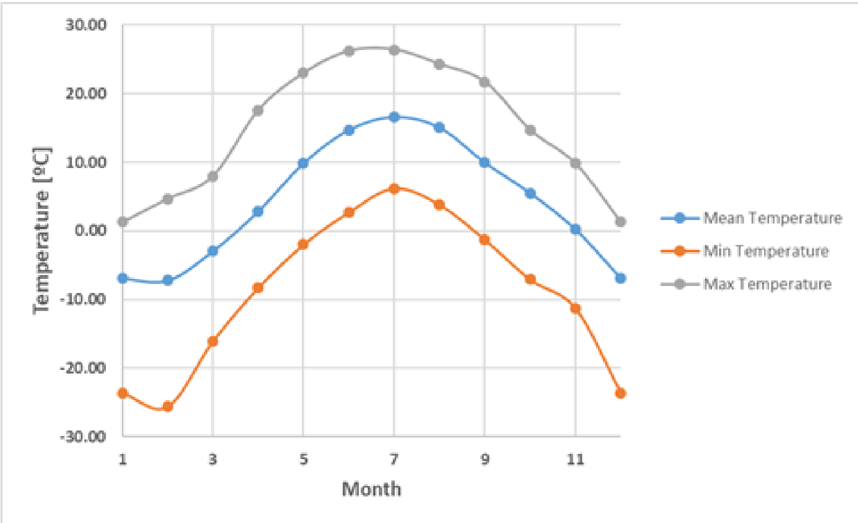

Figure 2: Annual mean, minimum and maximum temperature in Helsinki

2.2 Continental Europe: Nuremberg

Nuremberg is the second-largest city of the Bavaria region in Germany after Munich. The city is located on the Pegniz river with a population of 0.5 million people. According to the Köppen-Geiger climate classification[1,2]for Germany, Nuremberg is located on the area characterized by the oceanic climate, that dominates in most of the country (Figure 3).

The HDDs and the CDDs of Nuremberg can be considered the same as Munich as[3]:

- HDDs (base temperature 15ºC):3730.
- CDDs (base temperature 18.3ºC): 47.

Figure 3: Köppen-Geiger climate classification in Germany [1,2].

Table 2 shows the weather characteristics of Nuremberg for each month of the year. The average of the minimum, maximum and mean temperature for each month are shown in Figure 4. The coldest months of the year are January and December with an average temperature of -0.9ºC and a minimum temperature of 15ºC. The summer in Nuremberg can reach a maximum temperature of 33.90ºC where June and August represent the warmest months. However, the average summer temperature remains below 20ºC. The relative humidity is ranging from 57% in and 96%. The total solar radiation during the year is 624.78 kWh/m^2 and 1051.11 kWh/m^2 for the diffuse horizontal radiation and the global horizontal radiation, respectively.

Table 2: Nuremberg climate datafrom TRNSYS, Meteonorm

Month	*T_{mean} [ºC]*	*T_{min} [ºC]*	*T_{max} [ºC]*	*RH [%]*	*DHR [kWh/m^2]*	*GHR [kWh/m^2]*
Jan	*-0.90*	*-15.00*	*12.00*	*90.00*	*15.950*	*23.859*
Feb	*0.34*	*-13.90*	*15.30*	*68.50*	*27.072*	*45.098*
March	*3.96*	*-7.90*	*18.80*	*57.00*	*46.312*	*72.389*
April	*8.17*	*-5.30*	*24.30*	*93.50*	*68.521*	*113.567*
May	*13.31*	*-1.30*	*26.90*	*63.00*	*83.398*	*146.621*
June	*16.44*	*2.40*	*31.30*	*82.50*	*82.790*	*147.823*
July	*18.38*	*6.10*	*33.90*	*74.00*	*91.829*	*163.307*
Aug	*17.69*	*4.10*	*31.70*	*70.00*	*81.957*	*136.541*
Sept	*13.83*	*1.30*	*26.80*	*73.50*	*53.205*	*95.787*
Oct	*8.96*	*-2.70*	*22.40*	*77.00*	*39.789*	*58.469*
Nov	*3.84*	*-7.40*	*16.40*	*96.00*	*21.624*	*30.405*
Dec	*-0.90*	*-15.00*	*12.00*	*84.00*	*12.327*	*17.241*
Total	*-*	*-*	*-*	*-*	*624.781*	*1051.114*

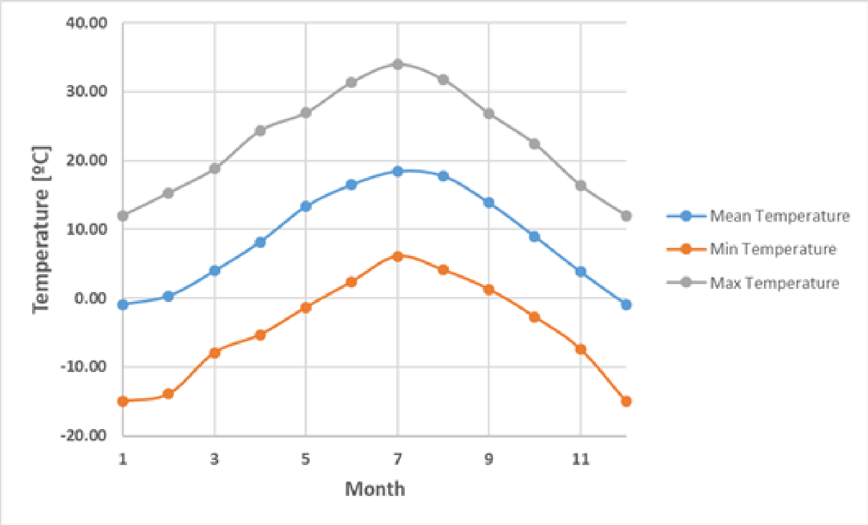

Figure 4: Annual mean, minimum and maximum temperature in Nurnberg

2.3 Continental Europe: London

London is the capital and the largest city of the United Kingdom. London stands on the river Thames located in the south east of England and represents one of the most important cities and commercial spots in Europe with a population of 8.5 million people. According to the Köppen-Geiger climate classification[1,2], London is located in the area characterized by the Oceanic climate that represents most of the United Kingdom (Figure 5).The HDDs and the CDDs of London are[3]:

- HDDs (base temperature 15ºC):2800.
  CDDs (base temperature 18.3ºC): 58.

Figure 5: Köppen-Geiger climate classification in United Kingdom[1,2].

Table 3 shows the weather characteristics of London for each month of the year. The average of the minimum, maximum and mean temperature for each month are shown in Figure 6. The coldest months of the year are January, February, and December with an average temperature of 4.93 ºC and a minimum temperature of -3.30ºC. The maximum temperature of the summer does not reach the 30ºC with an average temperature below the 18ºC. The relative humidity goes to 58.5% to 91.5% during the winter months. The total solar radiation during the year is 593.61 kWh/m^2 and 929.92 kWh/m^2 for the diffuse horizontal radiation and the global horizontal radiation, respectively.

Table 3: London climate datafrom TRNSYS, Meteonorm

Month	*T_{mean} [ºC]*	*T_{min} [ºC]*	*T_{max} [ºC]*	*RH [%]*	*DHR [kWh/m^2]*	*GHR [kWh/m^2]*
Jan	*4.93*	*-3.30*	*12.60*	*82.00*	*13.48*	*19.41*
Feb	*4.93*	*-2.90*	*12.80*	*73.50*	*22.57*	*31.66*
March	*7.17*	*0.20*	*15.90*	*58.50*	*43.07*	*66.42*
April	*8.76*	*0.20*	*18.60*	*89.00*	*68.73*	*99.15*
May	*12.20*	*3.20*	*23.80*	*76.00*	*83.04*	*133.92*
June	*15.34*	*7.60*	*26.00*	*70.50*	*87.48*	*143.52*
July	*17.89*	*9.40*	*28.50*	*76.00*	*85.46*	*139.35*
Aug	*17.93*	*9.70*	*28.90*	*71.50*	*74.17*	*120.65*
Sept	*14.81*	*7.50*	*23.70*	*72.50*	*56.59*	*84.96*
Oct	*11.14*	*4.00*	*19.20*	*70.00*	*29.76*	*50.92*
Nov	*7.64*	*0.50*	*15.70*	*91.50*	*17.33*	*25.39*
Dec	*4.93*	*-3.30*	*12.60*	*91.50*	*11.93*	*14.55*
Total	*-*	*-*	*-*	*-*	*593.614*	*929.918*

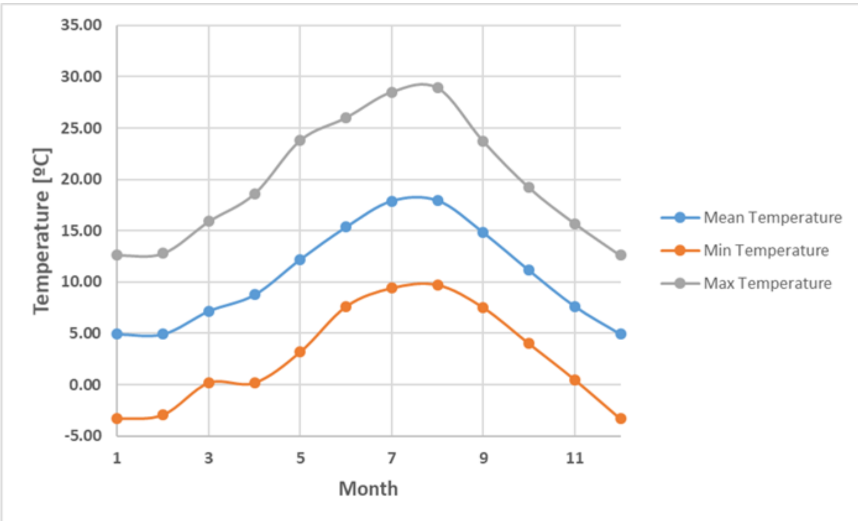

Figure 6: Annual mean, minimum and maximum temperature in London.

2.4 Southern Europe: Athens

Athens is the capital of Greece and represents one of the oldest cities in Europe. Although Greece is characterized by many microclimate typologies (Figure 7), Athens is located in the area with a typical Mediterranean climate characterized by a hot summer and a mild winter.

The HDDs and the CDDs of Athens as [3]:

- HDDs (base temperature 15ºC):876.
- CDDs (base temperature 18.3ºC): 1020.

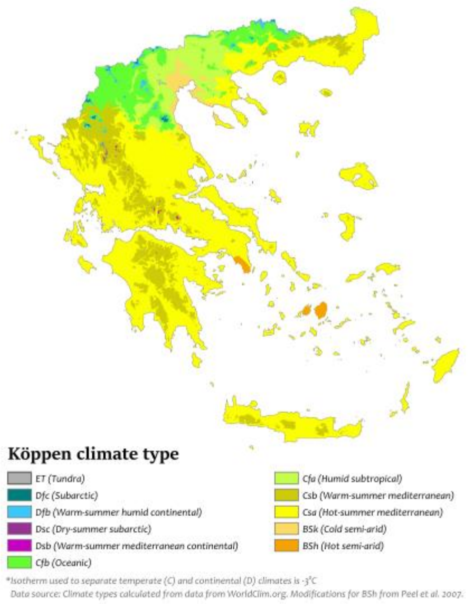

Figure 7: Köppen-Geiger climate classification in Greece [1,2].

Table 4 shows the weather characteristics of Athens for each month of the year. The average of the minimum, maximum and mean temperature for each month are shown in Figure 8. The coldest months of the year are January, February, and December. The average temperature in winter is warmer thancontinental Europe with an average temperature of slightly lower than 10ºC. Indeed, in the coldest month, the maximum temperature can reach 18ºC with a minimum temperature of 0ºC. June and August are the warmest months of the year with a maximum temperature of 37.9ºC and an average temperature of 27ºC in July. Summer months are characterized by a dry climate with a relative humidity of around 50% that increases in the winter to 85%. The total solar radiation during the year is 760.75 kWh/m^2 and 1571.38 kWh/m^2 for the diffuse horizontal radiation and the global horizontal radiation respectively.

Table 4: Athens climate data from TRNSYS, Meteonorm

Month	T_{mean} [ºC]	T_{min} [ºC]	T_{max} [ºC]	RH [%]	DHR [kWh/m^2]	GHR [kWh/m^2]
Jan	9.15	0.00	17.50	66.00	35.463	66.3059
Feb	9.69	0.80	19.20	70.00	44.467	74.8128
March	11.77	2.30	23.00	56.00	62.177	104.347
April	15.30	5.30	26.20	74.50	76.533	146.836
May	20.24	9.10	32.40	58.00	96.566	182.329
June	24.27	14.50	34.40	54.00	93.346	201.251
July	27.04	17.60	37.90	44.50	90.139	213.866
Aug	26.67	17.60	36.30	45.00	78.326	200.790
Sept	22.97	14.40	33.20	55.00	62.291	155.780
Oct	18.26	8.70	28.30	62.50	51.966	106.95
Nov	14.18	5.10	24.60	75.50	39.669	66.677
Dec	9.15	0.00	17.50	85.00	29.806	51.430
Total	-	-	-	-	760.755	1571.381

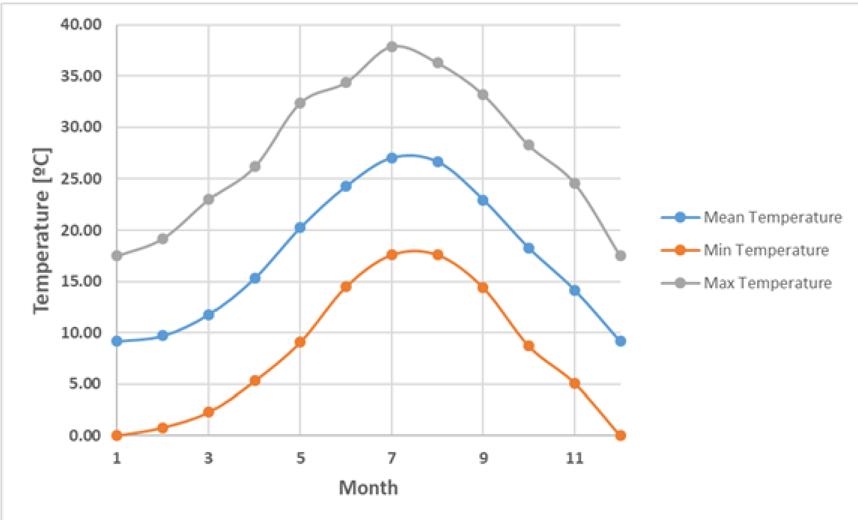

Figure 8: Annual mean, minimum and maximum temperature in Athens

2.5 Southern Europe: Madrid

Madrid is one of the largest cities in Spain and the capital of the country. Madrid is located over 600 meters above sea level and is one of the sunniest cities in Europe. According to the Köppen-Geiger climate classification[1,2] for Spain, Madrid is located in the part of Spain characterized by a Mediterranean climate (Figure 9) with a hot and dry summer and a mild winter.

The HDDs and the CDDs of Madrid as [3]:

- HDDs (base temperature 15ºC):1860.
- CDDs (base temperature 18.3ºC): 596.

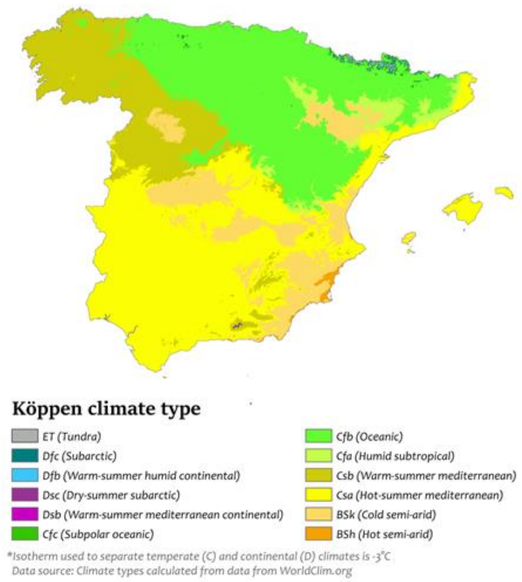

Figure 9: Köppen - Geiger climate classification in Spain[1,2].

Table 5 shows the weather characteristics of Madrid for each month of the year. The average of the minimum, maximum and mean temperature for each month are shown in Figure10. The coldest months of the year are January and December. The average temperature in winter is lower than the one in Athens reaching a minimum of -4.60 ºC with an average temperature of 5.44 ºC. During the summer the maximum temperature can reach 36.8 ºC in July with an average temperature of 24.3 ºC. Madrid is characterized by a dry summer with relative humidity around 50% that rises in the winter to 85%. The total solar radiation during the year is 658.36 kWh/m^2 and 1671.05 kWh/m^2 for the diffuse horizontal radiation and the global horizontal radiation, respectively.

Table 5: Madrid climate data from TRNSYS, Meteonorm

Month	*T_{mean} [ºC]*	*T_{min} [ºC]*	*T_{max} [ºC]*	*RH [%]*	*DHR [kWh/m^2]*	*GHR [kWh/m^2]*
Jan	*5.44*	*-4.60*	*15.30*	*68.00*	*28.882*	*66.238*
Feb	*6.99*	*-3.80*	*19.40*	*62.00*	*41.444*	*77.549*
March	*9.31*	*-2.80*	*21.90*	*51.50*	*51.770*	*141.73*
April	*11.44*	*-2.10*	*23.90*	*87.00*	*67.287*	*153.184*
May	*15.56*	*3.10*	*29.20*	*75.00*	*82.548*	*204.939*
June	*20.15*	*5.80*	*33.50*	*56.50*	*76.272*	*224.519*
July	*24.34*	*9.00*	*36.80*	*53.00*	*76.627*	*231.358*
Aug	*23.87*	*9.40*	*35.60*	*47.00*	*65.225*	*202.283*
Sept	*20.03*	*7.20*	*33.40*	*48.00*	*57.649*	*151.567*
Oct	*14.50*	*2.70*	*26.80*	*57.00*	*46.018*	*105.485*
Nov	*8.81*	*-3.30*	*21.10*	*85.00*	*34.428*	*64.546*
Dec	*5.44*	*-4.60*	*15.30*	*85.50*	*30.203*	*47.642*
Total	*-*	*-*	*-*	*-*	*658.358*	*1671.050*

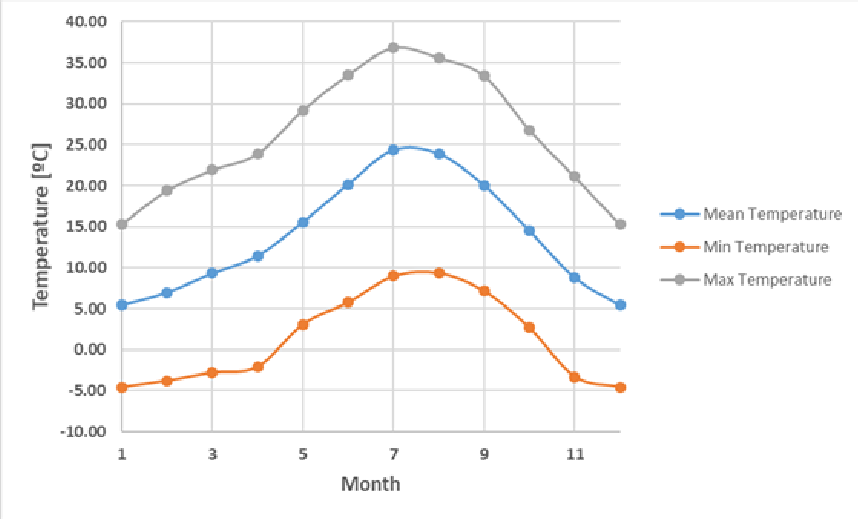

Figure10: Annual mean, minimum and maximum temperature in Madrid

3 Building typology characterization

The SolBio-Rev system is mostly suitable in buildings with a high ratio of heating and cooling needs compared to electricity. Buildings perfectly matching these requirements are multi-family houses (MFH) in all EU climatic zones, as well as hotels and restaurants, which show even higher heating and cooling demand. Other targeted building types are commercial buildings. Their energy consumption is similar to the wholesale and retail trade buildings. Therefore, in this deliverable, twomain categories have been identified and characterized:

- Residential buildings.
- Commercial buildings.

Please note that for these typologies, both new and renovated buildings are taken into consideration.

In the category of residential buildings, multi-family housesare considered in the following section. MFHs have been characterized for each of the location chosen as a boundary condition for the SolBio-Rev system. In particular, a review of the data available from the literature and various European projectswas conducted to classify the construction typologies in terms of age, main building characteristics and specific energy consumption for heating and cooling.The main databases used for the characterization of MFHs were TABULA/EPISCOPE[4,5], INSPIRE[6], and ENTRANZE[7]. TABULA[4] mainly represents the EU building stock developing several building typologies for different EU counties, according to their age, size, and energy equipment. From this project,EPISCOPE[5] elaborated a building stock to assess the refurbishment process. INSPIRE is an EU co-funded project that, in one of the main activities, it analysed the EU building stock to an identified target that represents the majority of buildings. ENTRANZE[7] project focuses on supporting policy-making by providing data, analysis, and guidelines within the existing national building stocks to support policy-making and achieve a fast penetration of nZEBs.

For the commercial buildings, three main typologies were selected and characterized:

- Offices.
- Hotels.
- Hospitals.

To characterize the structure and the different typologies of commercial/non-residential buildings is complex, due to the large varieties of structure. Indeed, there is not a methodical way to collect data, especially for old buildings. Therefore, there is poor availability of data regarding the non-residential sector. However, the characterization of the commercial building typologies selected, reported in thenext sections,is based on the data available from different resources.The construction characteristics were collected from the project ENTRANZE[7] for three cities that represent the different climate zones selected (Nordic, Continental, and Southern). Furthermore, the building characterization and the estimation of the heating and cooling demands are based on offices and schools as reference building. However, the hot water demand for non-residential buildings is strictly related to the use of the structure. Indeed, hotels and hospital make extensive use of domestic hot water, therefore it has to be specifically defined for those types of buildings. In this case, a literature review was conducted to collect the data available for the categories selected. The last building typology considered in the next sections is the new/renovated buildings. Therefore, in the next sections, the most recent residential buildings are characterized and the integration of the Energy Performance of Buildings Directive(EPBD) in the national plans with the energy performance requirements for both the residential and non-residential section are discussed.

3.1 Residential buildings: multi-familyhouses

Multi-family houses account for 40% of the European residential sector. They can be defined as a multi-occupancy building made of multiple dwellings. Table 6 shows the residential stock for multi-family houses for the selected countries by age.

Table 6: Residential stock of MFH construction by age countries, INSPIRE

Country	Before 1970 $x10^{12} [m^2]$	1971-1980 $x10^{12} [m^2]$	1981-1990 $x10^{12} [m^2]$	1991-2000 $x10^{12} [m^2]$	After 2000 $x10^{12} [m^2]$
Finland	26	17	9	8	7
Germany	119	35	19	14	14
UK	0.75	0.45	0.4	0.35	0.32
Greece	59	38	27	18	9
Spain	295	179	110	135	127

The monthly value of theenergy demand for multi-family refers to the one estimated from the project ENTRANZE. According to the data available, one country for each climate zone was selected to represent the energy demand for Northern, Central and Southern Europe. The building selected as a reference for the MFH is a south/north-oriented four-floor building that includes 12-16 dwellings with a conditioned area around 1000 m^2 and a surface to volume (S/V) ratio of 0.33. The heating demand, the cooling demand and the domestic hot water demand for the multi-family house was estimated through simulation with the Energy Plus software considering an indoor set point temperature of 20°C in winter, and 26°C in summer. Ventilation rate was considered to be 0.5 air changes/hour. The DHW demand is calculated by applying the Standard EN 15316-3-1. The results of the simulations available from the ENTRANZE database are reported in the next section for Finland, Germany, and Spain.

3.1.1 Finland

Dwellings in multi-family houses in Finland have an average size of 56 m^2. Table 7 reports the average U-values of Finnish residential buildings from different construction periods from 1940 to 2009. The following data for Finland refers to the data published from the projects ENTRANZE [7], BUILDUP [8] and INSPIRE [6].

Table 7: Average U-values for multi-family houses in Finland from 1940 to 2009, source: ENTRANZE

Component	*1940-1959*	*1960-1969*	*1970-1979*	*1980-1989*	*1990-1999*	*2000-2009*
	U-value [W/m^2·K]	*U-value [W/m^2·K]*	*U-value [W/m^2·K]*	*U-value [W/m^2·K]*	*U-value [W/m^2·K]*	*U-value [W/m^2·K]*
Roof	*0.4*	*0.35*	*0.35*	*0.25*	*0.24*	*0.23*
Wall	*0.75*	*0.6*	*0.45*	*0.3*	*0.27*	*0.25*
Floor	*0.75*	*0.45*	*0.4*	*0.35*	*0.32*	*0.3*
Windows	*2.1*	*2.1*	*2.1*	*1.75*	*1.75*	*1.6*

In Finland, multi-family houses are typically furbished with district heating system (88%), the rest is collective central heating using oil as the main fuel. Typically, in the residential sector, 68% of the total energy consumption can be assumed to be used for space heating and 11% to produce DHW. Figure 11 reports the value of the monthly energy demand estimated for an MFH building considering Helsinki as a reference case. The energy demand values were calculated in the project ENTRANZE [7] considering the following U-values:

- Wall: 0.60 W/m^2·K
- Roof: 0.39 W/m^2·K
- Basement: 0.47 W/m^2·K
- Glass: 2.79 W/m^2·K

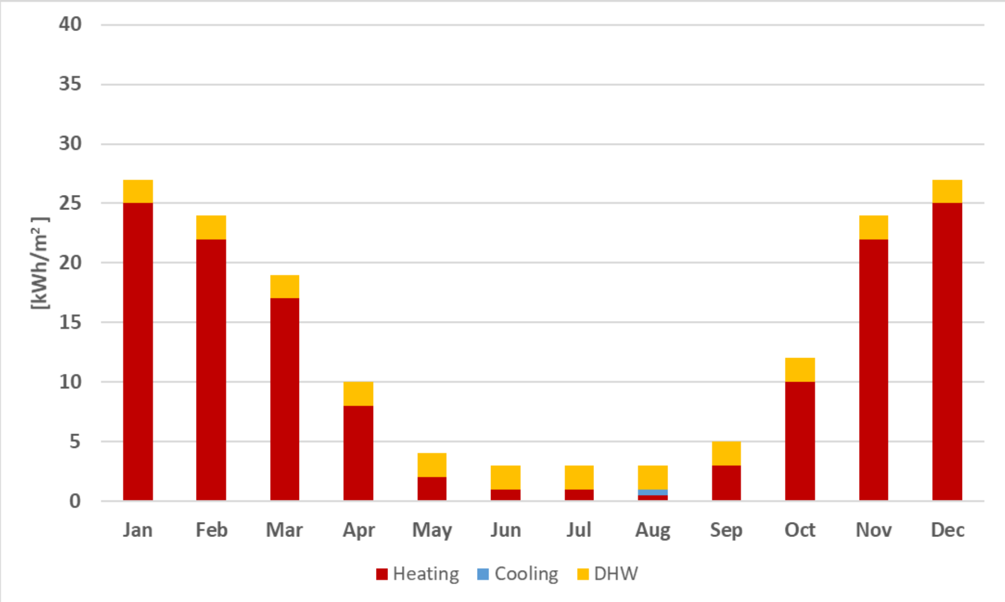

Figure 11: Monthly energy needs for heating, cooling and DHW of MFH building located in Helsinki, ENTRANZE

The results show that the heating is needed through all the year. Indeed, a small portion of heat is demanded in the summer during the hottest months of the year (June, July August). From September, the heating demand rapidly increases, reaching a maximum in January and December (around 25 kWh/m^2) to decrease again during the spring months. Cooling demand is only required in August (around 0.5 kWh/m^2). DHW demand can be considered constant during the year (between 1 and 2 kWh/m^2).The average annual energy consumptionfor MFHs in Finland, obtained from the project INSPIRE [6], is shown in Table 8.

Table 8: Average annual energy consumption by end use in MFHbuildings in Finland, source: INSPIRE database

End Use	*Average annual energy consumption*
Space heating [kWh/m^2]	*205*
DHW [kWh/m^2]	*36*
Space Cooling [kWh/m^2]	*10*
Lighting [kWh/m^2]	*9*
Electricity (lighting, appliances, cooking) [kWh/m^2]	*64*

3.1.2 Germany

A reference multi-family house in Germany is a detached building is typically between 4 and 6 stories high, with dwellings of an average size of 58 m². Table 9 reports the U-values for multi-familyhouses from 1969 to 2001.

Table 9: Average U-values for multi-family houses in Germany from 1969 to 2001, source: TABULA

Component	*1969-1978*	*1979-1983*	*1984-1994*	*1995-2001*
	U-value [W/m²·K]	*U-value [W/m²·K]*	*U-value [W/m²·K]*	*U-value [W/m²·K]*
Roof	*0.51*	*0.43*	*0.36*	*0.32*
External wall	*1.00*	*0.80*	*0.60*	*0.40*
Ground floor	*0.77*	*0.65*	*0.51*	*0.40*
Window	*3.00*	*3.00*	*3.00*	*1.90*
Door	*4.00*	*4.00*	*4.00*	*2.00*

The roof of multi-familyhouses is typicallymade of concrete with a layer of insulation with variable thickness.The external wall is made of masonry with light bricks or light mortar. To reduce the U-value, a layer of insulation is usually added to the constructions built after 1995. Windows usually have a plastic frame with dual-pane glazing and the door of multi-familyhouses is made of metal. Recently,this type of building integrates a thermally improved door with a reduced U-value. Usual and advanced refurbishments aim to reduce the transmittance increasing the insulation on the roof, and on the external wall together with the use of windows with double/tripe glazing argon filled and doors with insulation layers.

Old MFHs(1969-1978) have an energy need for space heating of around 120 kWh/m^2 per year with 10 kWh/m^2 per year needed for DHW. In German multi-family houses, 25% of space heating is provided by district heating most commonly fuelled with natural gas. A heating system built after 1995 can integrate a condensing boiler or system that uses wood pellets as fuel reducing the primary energy consumption for the space heating. Figure 12 reports the value of the monthly energy demand estimated for an MFH building considering Berlin as a reference case.The energy demand values were calculated in the project ENTRANZE considering the following U-values:

- Wall: 1.44 W/m^2·K
- Roof: 1.17 W/m^2·K
- Basement: 1.50 W/m^2·K
- Glass: 2.11 W/m^2·K

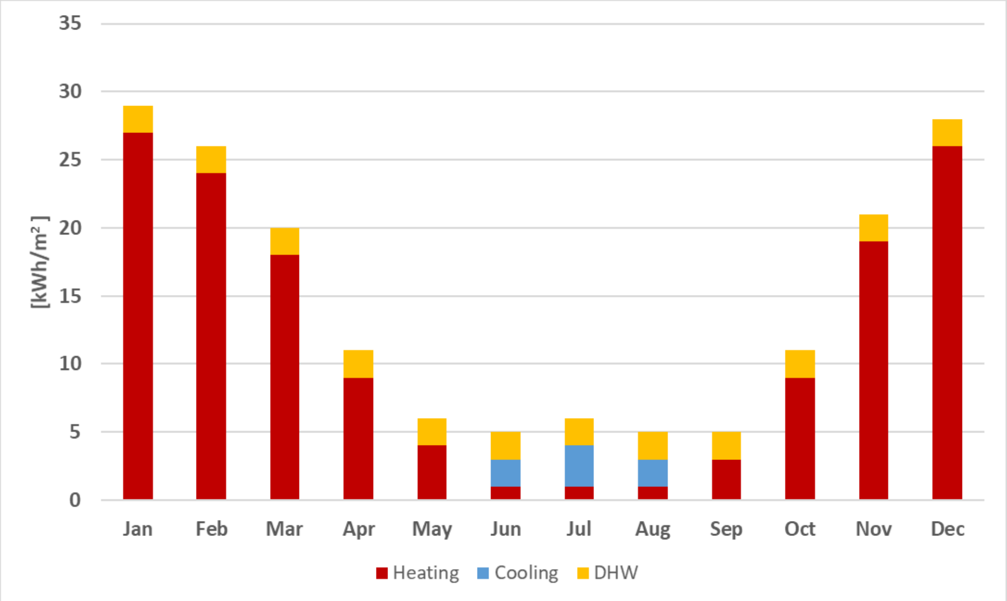

Figure 12: Monthly energy needs for heating, cooling and DHW of MFH building located in Berlin, ENTRANZE

Figure 12 shows that heating is needed through all the year. From September, the heating demand rapidly increases, reaching a maximum in January and December (around 27 kWh/m^2). Cooling demand is required in the summer months, with the highest demand in July (3 kWh/m^2). DHW demand can be considered constant during the year (between 1 and 2 kWh/m^2).

The average annual energy consumption for multi-family house in Germany, obtained from the project INSPIRE [6], is shown in Table 10.

Table 10: Average annual energy consumption by end use in residential buildings in Germany. Source:INSPIRE database.

End Use	*Average annual energy consumption*
Space heating [kWh/m^2]	*180*
DHW [kWh/m^2]	*28*
Space Cooling [kWh/m^2]	*7*
Lighting [kWh/m^2]	*4*
Electricity [kWh/m^2]	*36*

3.1.3 United Kingdom

Most of the cities of the United Kingdom such as Londonconsist of Victorian houses characterized by red brick exterior walls.Reference floor area is of 447 m^2 for buildings built before 1965 and 994 m^2 for recent buildings. Table 11 reports the U-values for multi-family houses from 1945 to 2009.

Table 11: Average U-values for multi-family houses in United Kingdom from 1945 to 2009, source: TABULA

Component	*1945-1964*	*1965-1980*	*1981-1990*	*1991-2003*	*2004-2009*
	U-value [W/m²·K]	*U-value [W/m²·K]*	*U-value [W/m²·K]*	*U-value [W/m²·K]*	*U-value [W/m²·K]*
Roof	*2.30*	*1.50*	*0.40*	*0.35*	*0.25*
External wall	*1.60*	*1.60*	*1.60*	*1.60*	*0.35*
Ground floor	*0.40*	*0.40*	*0.40*	*0.40*	*0.23*
Window	*4.80*	*3.10*	*3.10*	*3.10*	*1.85*
Door	*3.00*	*1.80*	*1.80*	*1.80*	*1.80*

Table 11 shows that in some of the building elements of a multi-familyhouse in the UK there are no consistent improvements during different construction ages. The roof is the element that, during the different construction ages, was subjected to major developments with a substantial reduction of the U-value. In the oldest constructions, the door was typically made of wood that was replaced by PVC for the constructions built after 1965. Usual and advanced refurbishments aim to reduce the transmittance increasing the insulation on the roof, in addition tocavity walls and the use of double glazed windows. The buildings built after 2004 reduce the transmittance of the wall with the use of cavity walls with insulation.

The technical system of old buildings uses electrical storage heaters for space heating and electric immersion heater to produce DHW. The energy need for heating can be estimated around 162 kWh/m^2 per year with a DHW demand of around 10 kWh/m^2 per year. The primary energy consumption for old buildings (1945-1964) can be estimated around 438 kWh/m^2 with 15% of the total value used to produce DHW. Today most of the buildings install a gas central heating system using a condensing combi-boiler combined also with the hot water heating system. The average annual energy consumption for a multi-family house in the United Kingdom, obtained from theproject INSPIRE [6], is shown in Table 12.

Table 12: Average annual energy consumption by end use in residential buildings in United Kingdom, source: INSPIRE

End Use	*Average annual energy consumption*
Space heating [kWh/m²]	*170*
DHW [kWh/m²]	*38*
Space Cooling [kWh/m²]	*4*
Lighting [kWh/m²]	*7*
Electricity [kWh/m²]	*53*

3.1.4 Greece

The classification and the characterization of buildings in Greece varies according to the climatic zone related to the HDDs. Considering Athens as a reference case, it can be included in climatic Zone B of the national legislation(800 < HDDs< 900).In this case, the reference floor area is of 1428 m^2 for buildings built before 1980 and 808m^2 for recent buildings. Table

13 shows the average U-values of the building elements for multi-family houses building in Greece from 1980 to 2010.

Table 13: Average U-values for multi-family houses in Greece from 1980 to 2010, source: TABULA.

Component	Until 1980	1981-2000	2001-2010
	U-value [$W/m^2{\cdot}K$]	U-value [$W/m^2{\cdot}K$]	U-value [$W/m^2{\cdot}K$]
Roof	3.05	3.05	0.5
External wall	2.20/3.40	2.20/3.40	0.70
Ground floor	3.10	2.75	0.5
Window	4.70	6.10	4.10

The roof is typically a conventional flat roof with a layer insulation added in the recent constructions. The external wall can be made of double brickwork plastered in one or both sides, and load bearing structures. The floor is made of slabs on grade until 2001, while for recent construction, pilotis with an insulation layer can be used. Windows until 2001 used single glass with wood (until 1980) or metal frame (1981-2001). Recent windows in multi-familyhouses are double-glazed with a metal frame. Usual and advanced refurbishment includes insulation in both roof and walls and the use of double pane windows.

In multi-familyhouses in Greece, space heating is provided by constant temperature non-condensing boiler fuelled with oil with a central distribution. DHW can be provided with low-efficiency solar collectors or electric heaters. In building built before 1980 the energy needed for heating can be estimated around 40 kWh/m^2 per year and 15 kWh/m^2 per year for DHW. The annual energy consumption therefore varies considering the equipment installed and can vary from 115 kWh/m^2 to 138 kWh/m^2 per year. The energy demand for space heating is reduced in recent buildings to 24 kWh/m^2 per year. At the existing state, the annual energy consumption for space heating and DHW varies according to the equipment installed from 82 kWh/m^2 to 110 kWh/m^2.The average annual energy consumption for amulti-family house in Greece is shown in Table 14.

Table 14: Average annual energy consumption by end use in residential buildings in Greece,source: INSPIRE

End Use	Average annual energy consumption
Space heating [kWh/m^2]	85
DHW [kWh/m^2]	11
Space Cooling [kWh/m^2]	27
Lighting [kWh/m^2]	9
Electricity [kWh/m^2]	57

3.1.5 Spain

In Spain, a multi-familyhouse can be a terraced house with 4 to 6 floors with a dwelling area of 86 m^2. Table 15 shows the average U-values of the building elements for multi-family houses built in Spain from 1937 to 2006.

Table 15: Average U-values for multi-family houses in Spain from 1937 to 2006, source: TABULA.

Component	*1937-1959*	*1960-1979*	*1980-2006*
	U-value [W/m²·K]	*U-value [W/m²·K]*	*U-value [W/m²·K]*
Roof	*1.67*	*1.61*	*0.56*
External wall	*2.94*	*1.64*	*0.60*
Ground floor	*1.26*	*0.71*	*1.39*
Window	*5.70*	*5.70*	*3.5*

The multi-family house constructionconsiststypically of a ventilated flat roof with concrete horizontal framework that can be refurbished adding a waterproof and an insulation layer.The external wall of the older construction (until 1959) is typically masonry with coating bricks while the most recent buildings have a cavity wall with insulation (after 1980). Windows are single glazed with metal frame that can be refurbished with double glazed windows. The energy need for heating is around 11 kWh/m^2 per year for old buildings (until 1959) that can be improved in the recent buildings to 3.9 kWh/m^2 per year.The demand for DHW can be estimated around 12 kWh/m^{2}per year. Space heating in old multi-family house building can be provided from a gas central heating system fuelled by gas or oil or directly with heat pump, gas or electric systems.Therefore, the primary energy consumptionfor space heating varies considering the equipment installed. The production of DHW can be provided by an oil/gas boiler or electric rod that can be refurbished with an instantaneous water heater or a thermal solar system..Figure 13 reports the value of the monthly energy demand estimated for an MFH building considering Madrid as a reference case. The energy demand values were calculated in the project ENTRANZE considering the following U-values:

- Wall: 1.46 W/m^2·K
- Roof: 1.92 W/m^2·K
- Basement: 1.30 W/m^2·K
- Glass: 5.70 W/m^2·K

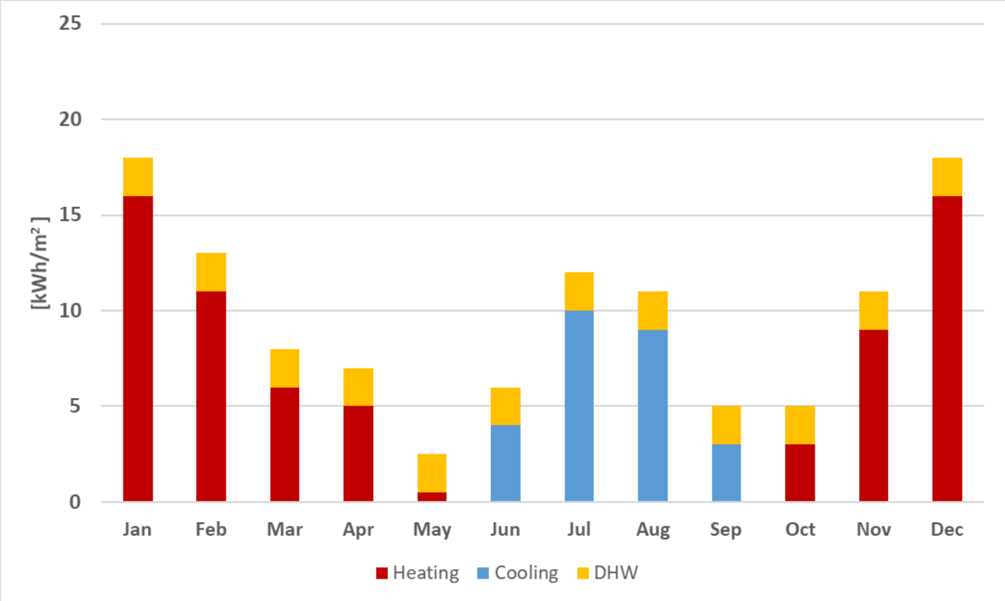

Figure 13: Monthly energy needs for heating, cooling and DHW of MFH building located in Madrid, ENTRANZE

Figure 13 shows that in Madrid the heating demand for MFH significantly decreases compared to the continental and Northern European countries. The months of highest heating demand are January and December (16 kWh/m^2), while the month with the lowest demandis May (1 kWh/m^2). During the summer, cooling is needed from June until Septemberand the highest cooling demand is on July (10 kWh/m^2). DHW can be considered constant during the year (between 1 and 2 kWh/m^2).The average annual energy consumption for multi-familyhouses in Spain is shown in Table 16.

Table 16: Average annual energy consumption by end use in residential buildings in Spain, source: INSPIRE

End Use	*Average annual energy consumption*
Space heating [kWh/m^2]	*80*
DHW [kWh/m^2]	*31*
Space Cooling [kWh/m^2]	*14*
Lighting [kWh/m^2]	*5*
Electricity [kWh/m^2]	*36*

3.2 Commercial buildings: offices, hotels, and hospitals

This section reports the characterization of commercial buildings. In particular, for the application of the SolBio-Rev system, three main buildings typologies were selected and characterized:

- Offices.
- Hotels.
- Hospitals.

Characterizing the structure of non-residential buildings is complex, due to the large varieties of different structure. Furthermore, there islow availability of data regarding the non-residential sector. In order to characterize the construction of such buildings and estimate the specific heat and cooling demand, the office and the school buildings defined in the project ENTRANZE[7]was taken as a reference for all the non-residential typologies selected. However, the demand and the energy consumption of the domestic hot water needs to be specified for each structure since it is strictly related to the use and the facilities that characterize each building typology.

3.2.1 Offices

An office can be an entire building, a part of the building or just a room that is used for the purpose of administration, clerical work, handling money, and communications. The main objective of an office building is to provide a comfortable, healthy and safe work environment for the users. Office buildings can be divided into different sections depending on the requirements. Due to the limited data available, only one country for each climate zone has been selected to represent and characterize the office building typology for Northern, Central and Southern Europe. According to the project ENTRANZE [7], as a reference office building was considered a 5 floor building with a S/V ratio of 0.33 and a net heated area of 2400 m^2. The construction characteristics vary from different countries and different zones. Referring to the ENTRANZE[7] database, the heating demand and the domestic hot water demand for the office building has been estimated through simulation by means of Energy Plus software. The energy demand was calculated considering an indoor set point of 21°C with a 30% of humidity in winter, and 26°C and with a 70% of humidity in summer. Ventilation ratewasconsidered to be 0.8 air changes/hour. The DHW demand is calculated byapplying the Standard EN 15316-3-1.

3.2.1.1 Northern Europe: Finland

Referring to Finland to represent the Northern Europe office building, typical construction materials include concrete and plaster. U-values characteristic for an office building in Finland arereported in the Table 17.

Table 17: Average U-values for office building in Finland, source: ENTRANZE.

Component	*U value [W/m^2·K]*
Wall	*0.46*
Roof	*0.39*
Basement	*0.52*
Glass	*3.20*

Considering Helsinki as a reference case, the value of the monthly energy demand estimated for an office building is reported in Figure14. The results show that the heating is needed through all the year. Indeed, a small portion of heat (less than 1kWh/m^2)is demanded in the summer during the hottest months of the year (June, July August) for space heating. From September, the heating demand rapidly increases, reaching a maximum in January (around 43 kWh/m^2) to decrease again during the spring (April). Cooling demand is only required in July and August (around 4 to 5 kWh/m^2).

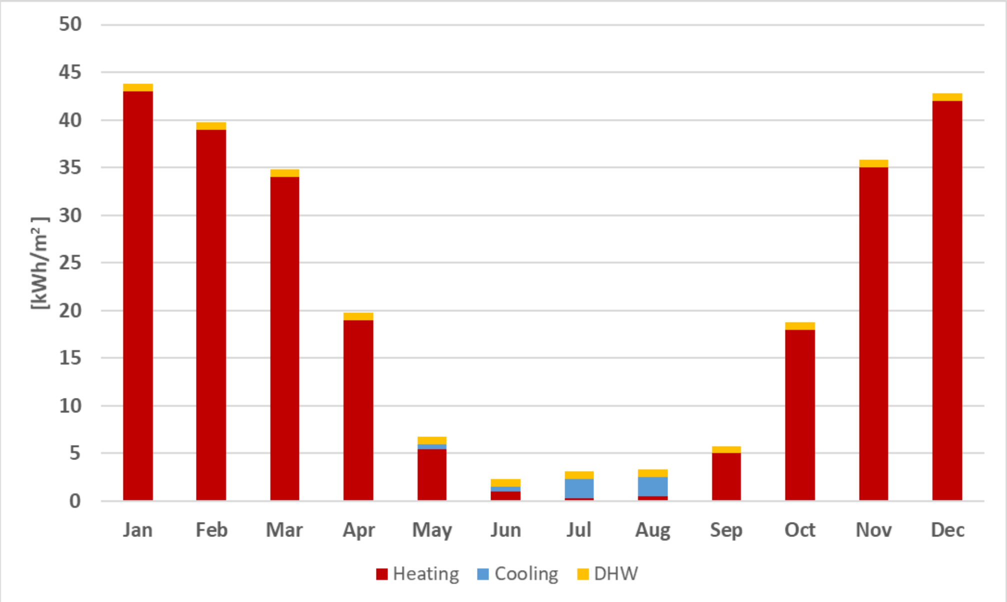

Figure 14: Monthly energy needs for heating, cooling and DHW of the office building located in Helsinki, ENTRANZE

In Finland, non-residential buildings are usually furbished with district heating systems. The average energy consumption for office house in Finland is shown in Table 18.

Table 18: Average annual energy consumption by end use in office buildings in Finland, source: INSPIRE

End Use	Average annual energy consumption
Space heating [kWh/m^2]	114
DHW [kWh/m^2]	-
Space Cooling [kWh/m^2]	21
Lighting [kWh/m^2]	30

3.2.1.2 Central Europe: Germany

Referring to Germany in the case of a central Europe office building, typical construction materials include concrete and plaster. U-values characteristics for an office building in Germany are reported in Table 19.

Table 19: Average U-values for office building in Germany, source: ENTRANZE.

Component	U value [W/m^2·K]
Wall	1.42
Roof	0.68
Basement	1.14
Glass	2.90

Considering Berlin as a reference case, the value of the monthly energy demand estimated for an office building is reported in Figure 15.

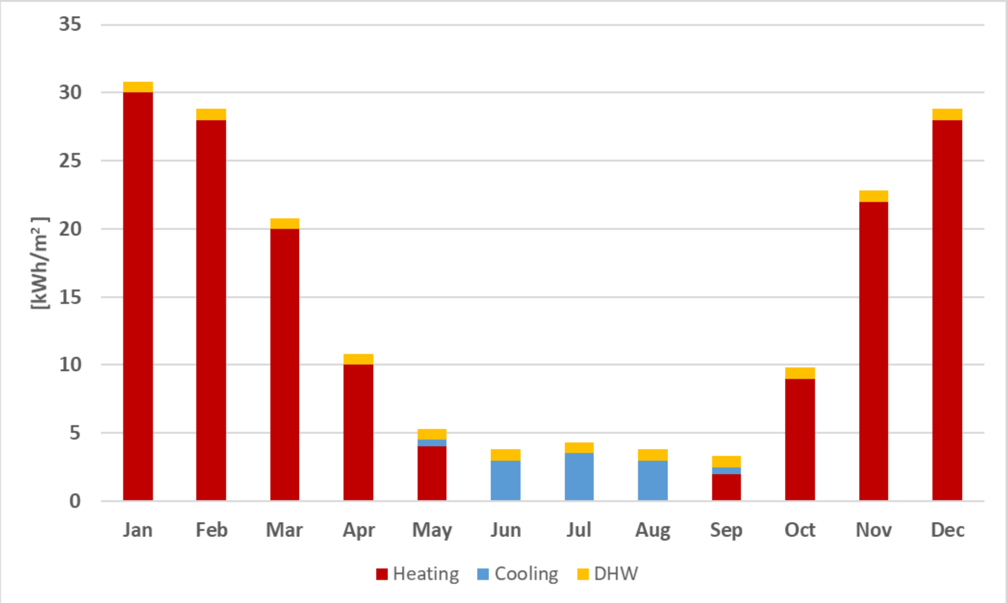

Figure 15: Monthly energy needs for heating, cooling and DHW of the office building located in Berlin, source: ENTRANZE

Figure15 shows that the heating demand in Germany is drastically reduced, compared to the Northern European countries, due to the milder conditions of the climate. In this case, heating in summer is not needed and only cooling is required. The highest heating demand happens in January, with a value of 30 kWh/m^2. The cooling demand in summer is relatively low and almost constant during June, July and August (around 6 kWh/m^2 per month). Space heating in office buildings in Germany is usually provided by gas and oil boilers, while domestic hot water is provided by decentralized electric water heating. Cooling in old office buildings is usually provided with natural ventilation.The average energy consumption for an office building in Germany is shown in Table 20.

Table 20: Average annual energy consumption by end use in office buildings in Germany, source: INSPIRE

End Use	*Average annual energy consumption*
Space heating [kWh/m^2]	*140*
DHW [kWh/m^2]	*6*
Space Cooling [kWh/m^2]	*15*
Lighting [kWh/m^2]	*38*

3.2.1.3 Southern Europe: Spain

Referring to Spain in the caseof aSouthern Europe office building, typical construction materials include hollow brick, air gap, concrete, and plaster. U-values characteristics for an office building in Spain are reported in Table 21.

Table 21: Average U-values for office building in Spain, source: ENTRANZE.

Component	*U value [W/m²·K]*
Wall	*1.37*
Roof	*1.29*
Basement	*1.36*
Glass	*5.70*

Considering Madrid as a reference case, the value of the monthly energy demand estimated for an office building is reported in Figure16.

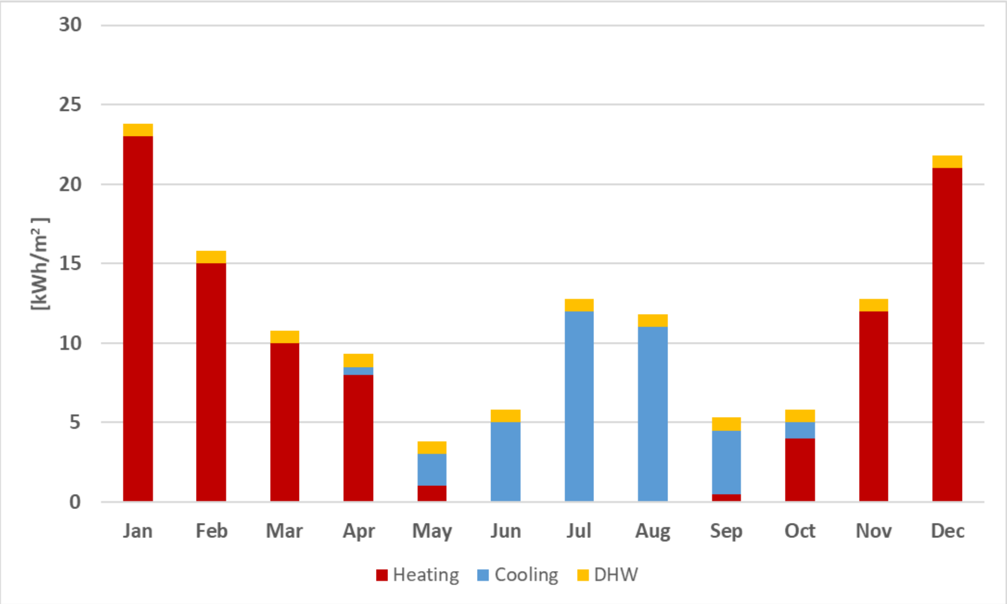

Figure 16: Monthly energy needs for heating, cooling and DHW of the office building located in Madrid, source: ENTRANZE

The hotter climate of Southern Europe reduces the heating demand in the colder months of the year. Figure 16 shows that the highest heating demand in office buildings happens in December and January (23 kWh/m²) and is reduced almost to zero in the period between May and September. The cooling demand calculated from ENTRANZE in this case, is higher than the other referenced countries showing a peak in July of 13 kWh/m². However, some of the available databases (INSPIRE) report that the heating demand for a large office building in Spain can be estimated around 51.7 kWh/m² per year with a cooling demand of 82 kWh/m² per year. Most of the heating demand in Spain is satisfied by electricity. Oil only accounts 23% of the energy use in the service sector. The average energy consumption for office buildings in Spain is shown in Table 22.

Table 22: Average annual energy consumption by end use in office buildings in Spain, source: INSPIRE

End Use	*Average annual energy consumption*
Space heating [kWh/m^2]	*54*
DHW [kWh/m^2]	*-*
Space Cooling [kWh/m^2]	*44*
Lighting [kWh/m^2]	*71*

3.2.1.4 DHW in office buildings

The demand for DHW in office buildings is mainly due to the use of cooking facilities and hygiene purposes. An analysis conducted by Ulseth et al. [9]the consumption of DHW in different buildings in Norway shows that DHW peak demand in the morning around 8:00 at 15:00 and late in the evening. The results from the simulation done in the project ENTRANZE shows that the demand of DHW calculated with the Standard EN 15316-3 is constant throughout the year and corresponds to a value of around 1kWh/m^2 per month. According to the data available, the DHW energy consumptions for each area selected are reported in the paragraphs above.

3.2.2 Hotels

Hotels can be classified as commercial buildings that provide accommodation to tourists. Europe has the world's largest hotel stock. Those buildings can be very different in terms ofdimensions, type of structure, and building configuration. Furthermore, hotels can be classified in different categories that mainly differentiate on the quality of the service offered to their customers. The classification used to be different for different countries. In 2015, 16 European countries (Sweden, Germany, Austria, Switzerland, Holland, Hungary, the Czech Republic, Estonia, Latvia, Lithuania, Luxembourg, Malta, Belgium, Denmark, Greece, Liechtenstein, and the Finnish region of Åland) agreed to participate at the Hotel StarsUnion that proposed a common hotel classification from one up to five stars. As mentioned above, in this deliverable the construction characteristics of the hotels are referred to the ones of the school due to their similar structure. In the project ENTRANZE, the reference building for a school is a two-floors construction with a U-shape and a heated surface of 3500 m^2. The S/V ratio is 0.46. The window area is small than the one selected for the office building (around 30%). The construction characteristics vary from different countries and different zones. Referring to the project ENTRANZE, the heating demand was estimated through simulation with Energy Plus software.The heating demand was calculated considering an indoor set-point of 21°C with a 0% of humidity in winter, and 26°C and with a 70% of humidity in summer.

3.2.2.1 Northern Europe: Finland

Referring to the typical construction materials of a hotel in Northern Europe, the ones of a school building in Finland, they include concrete and plaster. U-values characteristicsare reported in Table 23.

Table 23: *Average U-values for school building in Finland, source: ENTRANZE.*

Component	*U value [W/m^2·K]*
Wall	*0.62*
Roof	*0.43*
Basement	*0.70*
Glass	*2.00*

Considering Helsinki as a reference case, the value of the monthly energy demand estimated for a school building is reported in Figure17.

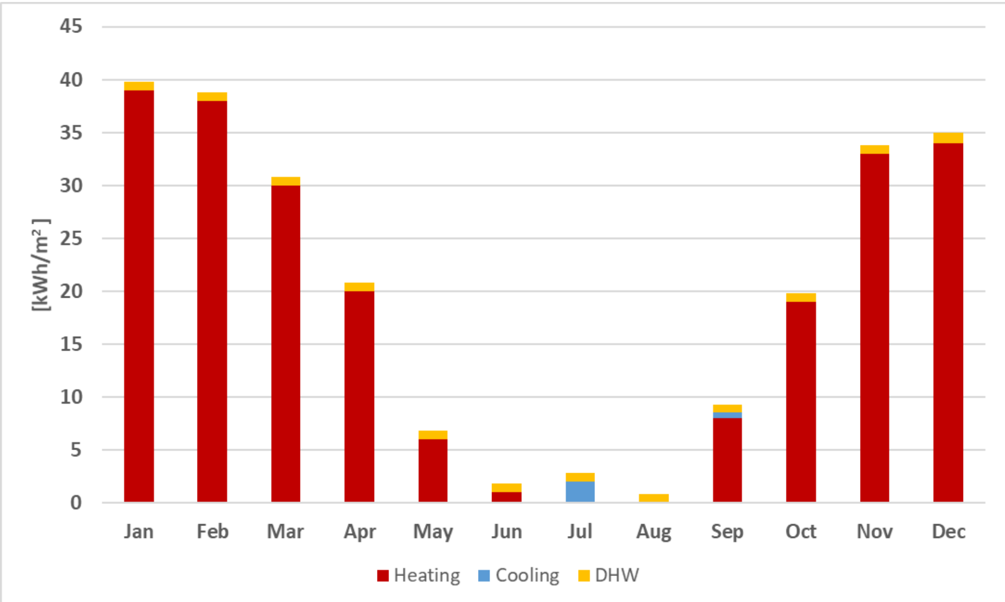

Figure 17: Monthly energy needs for heating, cooling and DHW of the school building located in Helsinki, source: ENTRANZE

The results show that the heating is almost needed through all the year except in July and August. The period from November to February shows the highest heating demand ranging between 35 and 39 kWh/m^2. A small amount of cooling is only required in July and August.

3.2.2.2 Central Europe: Germany

Referring to a hotel in central Europe a school building in Germany, typical construction materials include concrete, insulation,and plaster. U-values characteristics for an office building in Germany are reported in Table 24.

Table 24: *Average U-values for school building in Germany, source: ENTRANZE.*

Component	*U value [W/m^2·K]*
Wall	*1.42*
Roof	*0.88*
Basement	*1.14*
Glass	*2.90*

Considering Berlin as a reference case, the value of the monthly energy demand estimated for a school building is reported in Figure18.

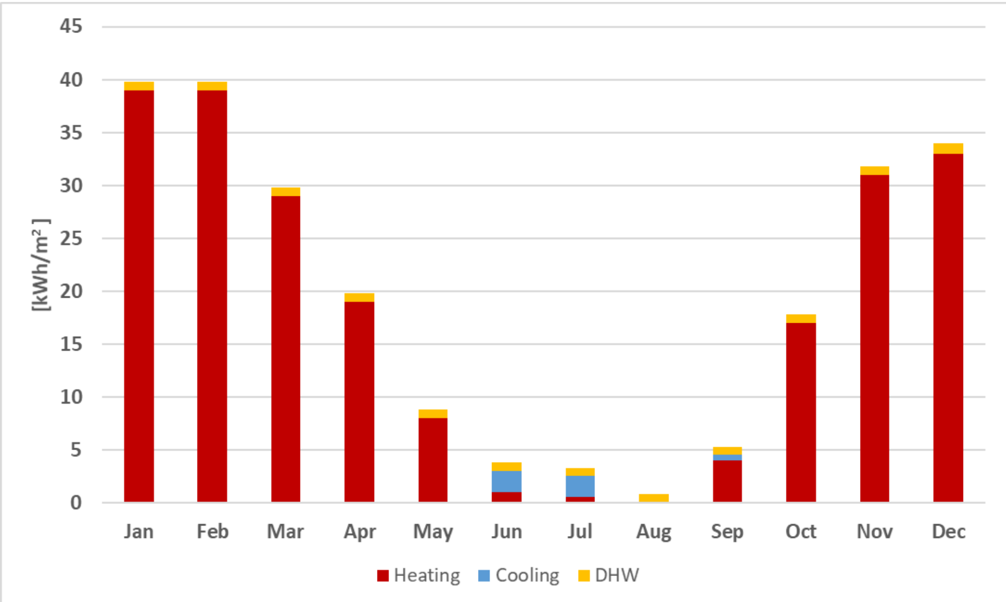

Figure 18: Monthly energy needs for heating, cooling and DHW of the school building located in Berlin, source: ENTRANZE

Figure 18 shows that the heating demand for a German school building is similar to the one shown from Finland. The highest heating demand happens in January and February, with a value of around 38 kWh/m^2. In November and December, the value is slightly lower, around 32 kWh/m^2. The cooling demand in summer is relatively low and absent in August. In June, a small amount of heating (around 1kWh/m^2) is required.

3.2.2.3 Southern Europe: Spain

Referring to a Southern Europe hotel, a school building in Spain, typical construction materials include hollow brick, air gap, concrete, and plaster. U-values characteristics for a school building in Spain are reported in Table 25.

Table 25: Average U-values for school building in Spain, source: ENTRANZE.

Component	*U value [W/m²·K]*
Wall	*1.37*
Roof	*2.19*
Basement	*2.56*
Glass	*5.70*

Considering Madrid as a reference case, the value of the monthly energy demand estimated for a school building is reported in Figure19.

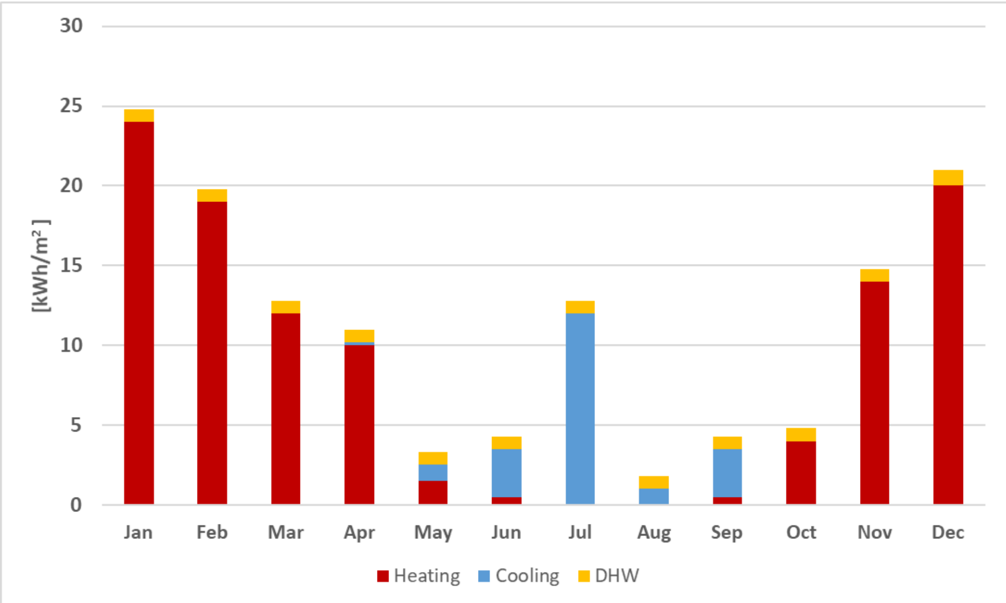

Figure 19: Monthly energy needs for heating, cooling and DHW of the school building located in Madrid, source: ENTRANZE

The hotter climate of Southern Europe reduces the heating demand in the colder months of the year. Figures show that the highest heating demand in office buildings happens in January (24 kWh/m^2) and reduces almost to zero in June and September. However, the cooling demand, in this case, is higher than the other referenced countries showing a peak in July of 13 kWh/m^2.

3.2.2.4 Energy consumption and DHW demand in hotels

The project HES (Hotel Energy Solutions) [10]reports that the energy consumption for most of the hotels can be considered in the range of 200-400 kWh/m^2 per year, therefore it can be considered an average of 305-330 kWh/m^2 per year.Figure 20reports the typical contribution of the hotel end usesin the total energy consumption[11].

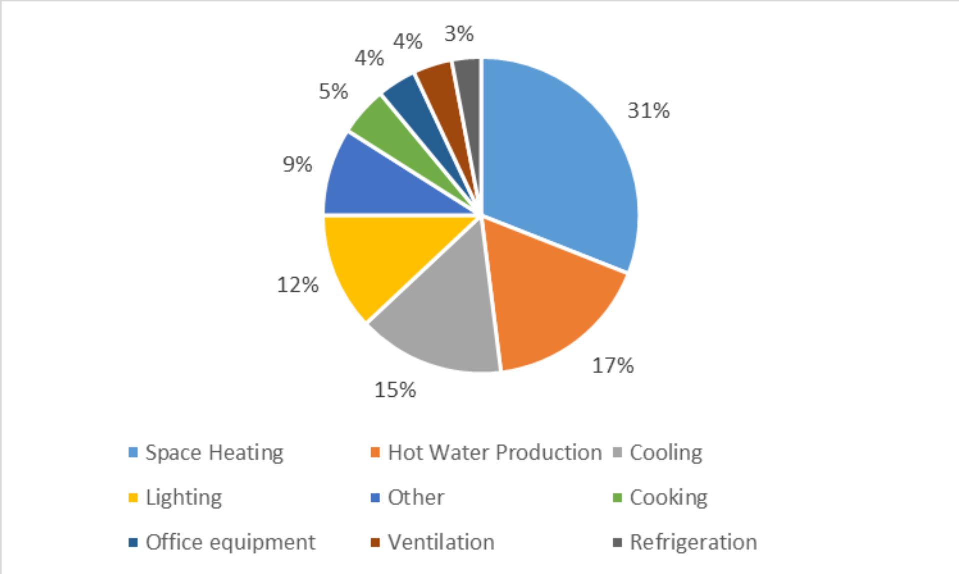

Figure 20: Typical total energy consumption by end use in hotels, source:HES, Leonardo Energy[10,11].

Providing DHW in hotels is necessary to the guest rooms, laundry, cleaning, and food services. Its consumption accounts for 10-40% of the energy used in hotels[12]. A study from Cobacho et al.[13] shows that washbasins and showers have a higher consumption of DHW. The laundry service in hotels highly influences the total water consumption. The total water consumption per tourist in hotels of different countries was estimated by Gössling et al.[14],as reported in Table 24.

Table 24: Daily water use per tourist in hotels, Gössling et al. [13].

Country	*Litres per person per day*
Finland	*150*
Germany	*200*
UK	*200*
Spain	*400*
Greece	*400*

The water consumption is higher for luxury hotels. A study from Rico-Amoros et al.[15]conducted for different hotel categories in Spain, reports that the total water consumption can be estimated, for a 1 star hotel, to be 174 litres per tourist per day, but for a 4 stars hotel it can be estimated 316 litres per day. However, most studies conducted on the estimation of the energy consumption in hotels, consider the amount of the total water without specific information on the hot water. A study conducted by Barberan et al. [16]in a hotel located in Zaragoza (Spain) reports a total water consumption of 108 litres per person per day from which 25% is accounted for DHW. Cobacho et al.[13] accounts for a Spanish hotel 34% of hot water in the total daily water energy consumption. From the studies available, the hot water consumption in hotels can be therefore considered in the range of 25% to 50% of the total water consumption.

According to different studies in Southern European hotels, the production of DHW can be considered efficient if its demand is below 220 kWh/m^2 for large hotels (more than 150 rooms) and below 120 kWh/m^2 for small hotels (with less than 50 rooms)[12]. However, there are potential savings of DHW that can be estimated for the hot water consumption. Those measures include efficient DHW production equipment, control strategy, and the integration of solar facilities. For that purpose, regional and national programs started to be proposed and implemented in different areas to improve the efficiency of the equipment and the integration of renewable energy, such as solar energy systems to increase the efficiency of the hot water production [17].

3.2.3 Hospitals

Hospitals can be defined as buildings where health services are provided. Those buildings are characterized to provide treatment for inpatient state (or overnight). Hospitals can be both by public or private. Compared to the other building typologies, hospitals have extra requirements. Indeed, they have to always ensure, for example, high air quality and cleaning standards that drastically increase the energy consumption. Also, in this case hospitals can be characterized by different dimensions that usually depend on the number of beds.

3.2.3.1 Construction characteristics and energy demand

As mentioned above, to define the construction characteristics for hospitals is complex due to the poor availability of data and the missing of a proper building classification and characterization. Therefore, the construction characteristics and the profile of the energy demand for both heating and cooling can be estimated referring to a school building due to their similar structure.

Therefore, the results can be referred to the ones shown in the previous section for Northern, Central and Southern Europe.

3.2.3.2 Energy consumption and DHW demand in hospitals

Although hospitals belong to a building typology that requires a high energy demand, there is limited availability of data that characterize the energy consumption.

Madrid Energy Foundation[18] reports that the annual average consumption for hospitals is around 40,000 kWh. In Germany, a study from the Fraunhofer-Institut für Umwel-, Sicherheits- und Energietechnik reports that the average annual energy consumption of hospitals is 24,670 kWh of heat and 7,786 kWh of electricity per bed[19,20]. Another study from Gonzalez [21]analysed the energy consumption of 23 public hospitals located in various German locations determining that the average annual energy consumption is 23.41 MWh per bed and 0.27 MWh per m^2.Figure 21reports the contribution of the hospital end usesin the total energy consumption [22,23].

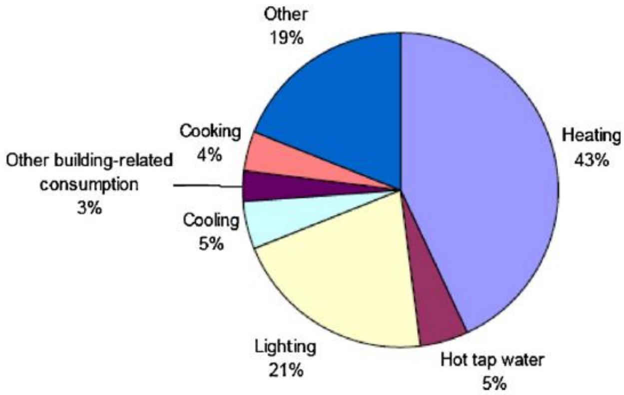

Figure 21: Typical total energy consumption by end use in hospitals, source: Heur[23].

In hospitals, DHW is mostly used for hygiene propose, cleaning and cooking services. The consumption is usually related to the number of beds in the hospital.

In European hospitals, the daily consumption of DHW can be estimated in the range from 80 to 130 l/bed [12] with a daily energy consumption that varies from 0.015 GJ/bed to 0.025 GJ/bed per day [24]. Calcedo et al.[25]analysed the annual average water consumption in 13 public hospitals in the region of Extremadura in Spain, monitoring the water use from 2010 to 2014. Results show that the mean annual consumption of DHW water was 92.96 m^3 per bed and 0.59 m^3 per built surface area. Two studies published in 2005 and 2006 from Katsanis et. [26]report that in new Greek hospitals the consumption for hot water varies from 0.017 GJ/dbed to 0.023 GJ/dbed. The energy consumption to supply hot water can be considered almost constant through the year. Bujak[24]analysed the heat consumption for DHW in two Polish hospitals with a capacity of 715 (hospital A) and 810 beds (hospital B). The mean annual value was calculated based on a 4-year period. The results show that the average annual energy consumption for the two hospitals tested was 6,088 GJ and 6,620 GJ for case A and case B, respectively. Results show that the hour with the highest DWH demand occurs between 8:00 and 19:00. A study conducted on a Norwegian hospital from Ulseth et al. [9]shows that the daily profile of the heat demand shows a peak on the DHW consumption at 8.00 with a similar profile for both weekdays and weekends with an average heat consumption of 7.1 W/m^2.

3.3 New and renovated buildings

The Europe 2020 strategy led to establish the Energy Performance of Buildings Directive (EPBD)2010/31/EU that requires all the new buildings to be nZEBs by the end of 2020. An nZEB can be defined as a building with high energy performance. The EPBD establishes the minimum requirements and sets the standard guidelines to calculate the energy performance.

The calculation takes into account several parameters, such as the thermal characteristics, the heating and cooling systems, the design of the building and also the contribution and integration of renewable energy sources. Therefore, all the EU members have to define a national plan that integrates the requirements for energy performance of buildings. The next section reports a survey of the information from the project BUILD UP[8]and the literature available for each country selected for the building characterization.

3.3.1 Finland

In Finland, the energy efficiency in buildings is regulated by the National Building code. The new building code of 2012 defines the requirements of the building energy consumption that is calculated taking into account the energy source, setting a maximum value of the overall energy consumption, depending on the building typology. The decree that defines the basis of nZEBs in Finland was released by the Ministry of Environment on 2014. The performance calculation for new buildings follows a national method based on CEN standards. The minimum requirements stated in the new building code of 2012 are shown in Table 25.

Table 25: Minimum requirements for new buildings in Finland, source: BUILD UP

Component	*U-value [W/m²·K]*
Roof	*0.09*
Floor (base floor bordering on outside air, building component against the ground, base floor bordering on crawl space)	*0.09/0.16/0.17*
Window	*1*
Door	*1*

In the new building stock, the maximum overall energy consumption is calculated considering the primary energy factor. The primary energy factor is lower for renewable energy sources and sources of district heating/cooling. The maximum value of the primary energy consumption for apartments building is 130 kWh/m^2 per year. For existing buildings, the improvement of energy efficiency can be done following three options: acting on the energy efficiency for each building element, acting and evaluating the energy consumption requirements for a building taking into account building class and acting, and evaluating the overall energy consumption requirements according to the primary energy source.

3.3.2 Germany

The parameter of design and construction of buildings in Germany is defined by the Building regulations law (Bauordnungsrecht). In the German legislation, the Energy Saving Act is a fundamental document for energy efficiency in buildings. Although it does not contain detailed specifications, these documents regulate the governmental ordinances related to the building energy performance. The energy performance requirements are defined by the Energy Saving Ordinance (EnEV). The efficiency of new residential buildings is determined with a comparison with a reference building with reference U-values design and components. This can be determined with two different calculation methods (DIN V 4108-6 combined with DIN V 4701-10, or the DIN V 18599). For the existing residential buildings, conditional requirements are mandatory in the case of a major renovation, such as replacement of the windows and glazing, and insulation on the external wall. For non-residential buildings, DIN V 18599 is a mandatory calculation method to define energy performance. The requirements are similar to the one of the residential buildings, with some differences related to the systems (lighting, ventilation, air conditioning) that are installed in non-residential buildings, and the different use of the building.

The multi-familyhouses constructed after 2010 have a reference floor area equal to 1305 m^2. The thermal power is supplied by a gas central heating system that integrates a condensing boiler, thermal solar system, and ventilation system. Table 26shows the building elementsand the corresponding U-values for the multi-familyhouses built after 2010. For the new residential buildings, the energy performance requirements are related to the ones of a reference building that defines the limit of the maximum primary energy demand (Table 27). New residential buildings have also to meet technical specification such as the use of condensing boilers and central hot water production with a solar system. At the nZEB ambition level, a CHP system should be also integrated into the heating system.

Table 26: Average U-Values for multi-family houses in Germany built after 2016, source: TABULA

Component	*Description*	*U-value [W/m·K]*
Roof	*14 cm insulation on ceiling + roofing*	*0.25*
External wall	*11 cm of external insulation brickwork + plaster (external insulated render system)*	*0.29*
Ground floor	(bottom) slab + 12 cm external insulation	*0.29*
Window	*windows with triple glazing, argon filled, low-E*	*1.10*
Door	*entry door with insulation layer*	*1.3*

Table 27: Characteristics of reference residential building in Germany, source: BUILD UP

Component	*U-value [W/m²·K]*
Roof	*0.20*
External wall	*0.28*
Ground floor	*0.35*
Window	*1.3*
Door	*1.8*

3.3.3 United Kingdom

In the UK, the building regulations are statutory instruments that have to ensure that all the policies are applied. The energy requirements are mainly defined in terms of CO_2 emissions that in the case of a new or renovated building has to be lower than the reference building. The energy efficiency is rated with the Energy Performance Certificate (EPC) that takes into account the characteristics of the building and the energy consumption according to the occupancy profile. The new residential buildings, in addition to reducing CO_2 emissions, have also to target a Fabric Energy Efficiency rate [kWh/m^2],which expresses the amount for space heating and cooling. Four ApprovedDocuments (AD) support the implementation of the EPBD in new and the existing residential and non-residential buildings.

The multi-familybuilding type constructed after 2010 has a reference floor area equal to 994 m^2. The thermal power for domestic heat and hot water is supplied with new gas condensing boiler that can be improved at nZEB ambition with the integration of a solar panel. Table 28 reports the U-values for a typical multi-familyhouse in England built after 2010. The thermal energy required for heating and DHW is 49 kWh/m^2 and 15kWh/m^2 per year, respectively, with a primary energy demand of 84.6 kWh. Those values can be reduced at nZEB level to 32.3 kWh/m^2 and 64.3 kWh kWh/m^2, respectively.

Table 28: Average U-Values for multi-family houses in UK built after 2010, source: TABULA

Component	Description	U-value [W/m^2·K]
Roof	Pitched	0.16
External wall	Cavity walls with insulation	0.28
Ground floor	post 2010	0.21
Window	Wood	1.85
Door	PVC	1.80

The heating and energy generation measures for nZEBs require the installation of equipment that includes electric air source heat pumps, solar water heating, mechanical ventilation heat recovery, and photovoltaics. Table 29 shows the requirements for the existing building for both residential and non-residential sector. The current requirements for new residential units specifyan annual primary energy consumption of 99 kWh/m^2 for a mid-floor apartment. For the new non-residential buildings, the primary energy consumption varies according to the building typology (Table 30).

Table 29: Requirements for the existing building for both residential and non-residential sector in UK, source: BUILD UP

Reference Building	U-value [W/m^2·K]
Cavity walls	0.55
Solid walls	0.3
Window	1.6
Roof	0.18

Table 30: Primary energy consumption requirements for the new non-residential building in UK, source: BUILD UP

Reference Building	kWh/m^2 per year
Office (Air Conditioning)	155
Office (Natural ventilation)	87
Hotel	487
Hospital	246

3.3.4 Greece

In Greece, the building regulations and the planning rules are included in the New Building Code (NOK). The implementation of energy performance is a responsibility of the Ministry of Environment, Energy and Climate change that issued in 2010 a new regulation for the energy performance in the buildings (KENAK) with full implementation in 2011. The new regulation introduces the definitions of nZEBs requiring that a minimum demand of 60% of DHW has to be covered with renewable energy sources. The building in Greece is classified into nine energy classes. The evaluation of the energy class is based on the estimation of the primary energy consumption compared to a reference building. The minimum acceptable corresponds to a primary energy consumption equal to the one of the reference building (Class B).

The Energy performance certificate is obligatory after 2011 and an energy performance study must be conducted in all the new buildings and the existing renovated buildings. The characteristics of the residential buildings in Greece can be classified according to the heating degree days (HDD). This mainly influences the heating demand and the primary energy consumption required. Therefore, also the requirements of the U-values of a residential building depends on the climatic zone. Table 31 reports the average U-values of the building element of a multi-familyhouse located in the climatic zone B built after 2011. They have a typical floor area of 808 m^2.

Table 31: Average U-Values for multi-family houses in Greece built after 2011, source: TABULA

Component	*U-value [$W/m^2{\cdot}K$]*
Roof	*0.45*
External wall	*0.45*
Ground floor	*0.50*
Upper floor	*0.71*
Window	*3.00*

The construction consists typically of a conventional flat roof with insulation and walls made of double brickwork plaster on both sides with insulation.

The floor can be an insulated pilotis and windows are double glazed with a synthetic frame. The energy demand for space heating can be reduced to 17 kWh/m^2 per year with 15 kWh/m^2 per year for domestic hot water. The primary energy consumption can be estimated around 40kWh/m^2 with the 25% used to satisfy the hot water demand.

The heat for space heating can be provided by new-non-condensing fuel oil boiler with outdoor temperature compensation and a central distribution or an air source heat pump. At nZEB level, this can be improved installing a condensing low temperature boiler and solar collectors that can cover 60% of the space heating demand. DHW can be provided by a new oil boiler with storage tank and immersion resistance that can be replaced at nZEB level with solar collectors. Table 32 shows characteristic of a reference building in Greece.

Table 32: Characteristic of reference building in Greece in climatic zone B, source: BUILD UP

Component	*U-value [W/m²·K]*
Roof	*0.45*
External wall	*0.5*
External floor	*0.45*
Floor over ground	*0.90*
Window	*2.00*

3.3.5 Spain

The building regulation in Spain that defines the basic requirements is the LOE (Ley de Ordenación de la Edificación de España). The actual certificate that regulates the energy efficiency in buildings is the Royal Decree 235/2013 (Documento Basico de Ahorro de Energia—DBHE) and includes the obligation for all the new energy buildings to be nZEB after 2020 (after 2018 for public buildings)[27]. The nZEB definition is addressed in the DBHE 2016/2017 (Energy Saving Basic Document). The main indicators used as a basis of an nZEB in Spain are primary energy use, energy demand for heating and cooling, and the building CO_2 emissions. Since the buildings performance is related to their location, the "Documento descriptivo climas de referencia" divides the county in six different climatic zones and four summer climate zones. The multi-familybuilding type constructed after 2007 has a reference floor area equal to 1419 m^2. Table 33 shows the average U-values of the main building components. In recent buildings, the thermal power is supplied with a gas central heating system characterized by poor efficiency and a thermal solar system. An improved system can integrate, instead, a new condensing boiler aiming at a new biomass boiler at nZEB level.The national minimum requirement estimates the energy needed for heating of 3.5 kWh/m^2 per year due to the Mediterranean climate, and a primary energy demand of 42.1 of 3.5 kWh/m^2 per year.The ambition at nZEB level is to reduce the thermal energy demand at 1.5 of 3.5 kWh/m^2 per year with a primary energy consumption of 3.5 kWh/m^2 per year.

Table 33: Average U-Values for multi-family houses in Spain built after 2011, source: TABULA

Component	*Description*	*U-value [W/m²·K]*
Roof	*Flat roof: one-way framework with pre-stressed joint*	*0.45*
External wall	*Brick wall render system)*	*0.52*
Ground floor	One-way framework with prestressed joint with insulation	*0.56*
Window	*Metal frame, single glazed, no thermal break*	*3.37*

4 Conclusions

The aim of this deliverable is to define the input boundary conditions for the numerical assessment of the performance of the SolBio-Rev system.

Firstly, a limited number of concerned climates was characterized to be taken as a reference in the analysis of the SolBio-Rev system performance. In particular, five different location have been selected to represent the Northern, Central and Southern European climate. In particular, the cities selected were Helsinki, Nuremberg, London, Athens, and Madrid. The climate data for each location were collected from TRNSYS, Meteonorm database evaluating the main parameters such as mean ambient temperature, relative humidity, and solar radiation. To describe the need for heating and cooling, Heating Degree days (HDDs) and Cooling Degree days (CDDs) are defined for each location.

After the climate characterization, four main categories of residential and non-residential buildings have been identified and characterized for the potential application of the SolBio-Rev system. In the categories of residential buildings, multi-family houses have been characterized for each of the location chosen as a boundary condition for the SolBio-Rev system. For the commercial buildings, three main typologies were selected and characterized. In particular, the typologies selected are offices, hotels and hospital buildings. The large variety of non-residential structures makes the building characterization complex, resulting in the absence of a proper methodical way to define and classify al the typologies.

With the data available from other European projects and the scientific literature, a survey was conducted to define the main construction characteristics and the energy demand and the specific energy consumption of the category selected.

The third category of recent and renovated buildings has been characterized. In particular, the introduction of the Energy Performance of Buildings Directive for different EU countries was discussed and the minimum requirements for the building performance efficiency were collected. The data reported can serve as guidelines for the future project activity and evaluate the applicability and the potential of the SolBio-Rev system.

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