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TESIS DOCTORAL

Economical and primary energy optimization of solar thermally driven heat pump (STDHP) systems for summer and winter use along Europe

Presentada por Juan Rodríguez Santiago para optar al grado de doctor por la Universidad de Valladolid

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Dedication

Dedicado a mi mujer y a mis hijos.

Por las horas no pasadas con ellos en estos años.

.

Quote

Ever tried,
Ever failed.
No matter,
Try Again.
Fail again,
Fail better.

Samuel Beckett

Lo intentaste,
Fracasaste.
No importa,
Sigue intentándolo.
Fracasa otra vez,
Fracasa mejor"

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Summary

The work realized evaluates a finite number of solar cooling technologies along Europe. With this scope it was needed to create a classification for the different European Climate conditions in order to have an structure in which the obtained results could be classified. Based on the climatic classification there were evaluated:

- Solar Resources for different building conditioning technologies
- Building demands
- Combinations of different solar technologies when applied in a predetermined building
- Economical and energetic potential of each technology by climatic zone

As a conclusion it was studied the common optimization of a building design and the renewable solar thermal facility that should cover heating, cooling and domestic hot water demands. This last point was treated from an energetic and economic point of view.

Sumario

El trabajo realizado en este documento evalúa el potencial de diversas tecnologías de climatización solar basadas en colectores térmicos instalado s a lo largo y ancho de Europa.

Se ha necesitado de una clasificación de los climas europeos para poder ordenar los resultados siguientes por categorías. Basado en estas tecnologías se ha evaluado:

- *La cantidad de energía susceptible de ser captada en función de la tecnología a aplicar*
- *La demanda energética de un determinado edificio.*
- *La combinación de diferentes configuraciones de sistemas solares térmicos que pueden ser aplicados en el edificio preseleccionado.*
- *El potencial económico y energético de cada una de las tecnologías para todas y cada una de las zonas climáticas estudiadas.*

Como conclusión se he estudiado la optimización del edificio y el sistema de energía renovables, que permiten un mayor ahorro energético y menores periodos de retorno de inversión

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1. Introduction

This PhD thesis was born from the work done by the author along 2005-2006 to evaluate the Solar Cooling possibilities in Spain and how a thermal solar system should be built to be energetically and economically feasible. Computing the Spanish energy demands obtained for a wide set of climatic data, it was seen that in most of the places, although Spain is to be considered as one of the warmest European places, heating demands are higher than cooling ones. It means,building energy savings and domestic solar energy consumption must be mainly focused on heating season, introducing the idea of evaluating these technologies around Europe, where most of the climates present demand profiles, in absolute terms which are bigger during the heating season when compared with the cooling one.

Under the umbrella of the International Energy Agency, Solar Heating and Cooling Program (IEA SHC) Task 25,38,…, Heat Pump Program (Annex 24,34,44…) or the different European Research projects, financed under FP6, FP7 and lately H2020 as were Climasol, Rococo, SolarCombi+, Alone,…the scientific Solar thermal community is hardly working to evaluate DO's and DON'T's of solar cooling. But after some years evaluating solar cooling possibilities, the experts still do not find the perfect solution to make the technology mature and perfectly competitive in comparison with compression chillers.

Results of these projects coincide on the idea of collecting the maximum solar energy during the heating season to make feasible the solar cooling system along the year, compensating the high costs of a thermal chiller that it is only used for a third of the year, in the best cases. In this environment, the reversible use of Sorption Chillers as Heat pumps, permits the utilization of the solar cooling facility widely in the year and as a consequence, increases the economic potential of the technology, making it competitive in the actual heating and cooling markets.

A combination of different statistical tools, Geographical Information Systems and self-programmed algorithms, in Visual Basic and LabVIEW, are able to evaluate solar thermal resources and building demands. They were used to organize the results obtained in categories that facilitates the treatment of the really great amount of data obtained from the simulations.

1.1 Solar Heating and Cooling challenges

Clausius' statement of second law of thermodynamics "It is not possible that at the end of a cycle of changes heat has been transferred from a colder body to a hotter body without producing some other effect", established the irreversibility of heating and cooling processes. These processes have two associated consequences: from one side the need of external energy inputs and on the other side, the entropic increase related to every process.

Cooling processes generally rely on the use of two different pressure levels between where, latent heat exchanges occur; therefore process temperature becomes constant, allowing evaporation and condensation temperatures under and above the ambient temperature respectively.

Traditionally, the external energy input needed to drive cooling cycles have been produced by animal traction, as happened with Edmon Carré's chiller, by electrical energy delivered to a motor that drives a compressor or by the direct use of thermal energy. In this last case, the energy introduced to the cycle comes indirectly from an engine that transforms thermal into mechanical energy or in a direct way through the use of sorbent processes, thermochemical…The way of obtaining this thermal energy vary: Fossil fuels, nuclear energy, solar energy, etc..

Solar Heating and Cooling can be defined as a dynamic process which *consumes* energy collected from the sun to energy in two different low temperature levels. In this way, thermal processes take advantages of a renewable energy source to cover heating and cooling demands in buildings and industrial processes, contributing to a carbon dioxide emission reduction. Moreover, the use of sorbent processes doesn't contaminate the environment or destroy the Ozone layer with the use of inorganic natural refrigerants as can be water, lithium bromides and chlorides, ammonia and zeolites among others.

It can be distinguish two different kinds of Solar Heating and Cooling (SHC)systems: those based on electrical devices driven with solar radiation collected with photovoltaic collectors or thermo-solar facilities and on the other side, the ones based on sorption machines, activated by the heat delivered by the solar thermal collectors to establish two pressure levels in which the refrigerant fluid can be condensed and evaporated.

The application of these Solar Thermal Heating and Cooling (STHC) technologies based on sorption processes depends on the development of control strategies and design ratios related to the location where they are installed and the kind of load to be satisfied. The correct design parameters allow to afford a maximum level of achievement of the solar radiation, reducing backup periods and increasing the user satisfaction level.

In the last years, it was an important increase in the number of solar cooling facilities and developments of new sorption technologies, helped by the progressive price increase of fossil fuels and the effect caused on the electricity prices. These effects lead on the research and development of alternative technics to produce heating and cooling based on renewables.

SHC applications are mostly divided in two groups, refrigeration and air conditioning. For the first case, the cooling operation temperatures should be close to Zero degrees Celsius and sometimes under this value, while for air conditioning tasks it is enough in most of the cases to reach values around 10ºC (This value depends on the existing latent load into the air conditioned zone).On contrary, when the controlled zones are to be heated, the required temperatures would depend on the kind of transference effect leading the energy exchange and the terminal equipment in charge of distributing the heating. Different temperature levels around the sorption machine influence the energy flows moving in evaporator, condenser and desorber, decreasing importantly machine efficiencies from the optimal operational mode. These decreasing effects should be controlled with the introduction in thermal loops of heating/cooling storages which synchronize energy production and energy demand,minimizing time gaps in which there are no enough solar resources to cover the controllable loads.

In the case of building thermal comfort, controlling the envelope characteristics establish influences of future weather conditions on the internal ambient. Aspects as orientation, shadowing, wall and windows insulation levels, affect importantly on the energy savings and demands of air condition facilities to keep controlled the occupied volume around a desired comfort set point.To achieve an energetic sustainability, it is not enough in most of the climates, to have a low energy demand building. It is also needed to outfit it with facilities based on renewables that decreases CO_2 emissions.

STHC technologies are a good option to consider if they meet the following conditions:

- Adequate efficiencies. Thermal Heat Pumps (THP) and solar technologies should be improved, as well as their dimensioning methods.
- Competitive prices when compared with the classical compression systems, in terms of investment and exploitation costs.
- Reducing maintenance to achieve longer operational times, increasing yields and decreasing operational costs.

1.2 Objectives

The objective followed in this work is the study of four different solar thermal facilities combined with a predetermined building around Europe, considering for the task:

- two different thermal collectors:
  - Flat plates
  - Evacuated tubes

- A solar facility combined with/without sorption heat pump to produce:
  - Only heating and domestic hot water
  - Heating, domestic hot water and cooling.

- An standard 100 m2 building with enough insulation to be accepted in the European building norms active for each of the studied countries.

The study delivers in a first approximation, the potential that each of the technologies has around Europe, taking into consideration the number of collectors needed to be installed, the size, in case of existence, of the Thermally Driven Heat Pump (TDHP) and backup periods for the chosen facilities. It has been taken for this study 515 typical meteorological years in hourly format TMY2.

An ad-hoc Visual Basic based software has been made to evaluate for each one of the studied locations, the hourly demand of a determinate building in terms of heating, cooling and domestic hot water, combined with the solar energy collected by two different solar plants in combination with low energy distribution systems installed in the house. In this way, the four different solar facilities can be confronted from the point of view of solar technologies, solar pumped heating and solar cooling potential, delivering a set of indicators to evaluate each of the studied combinations.

In a first step, the studied building was simulated around Europe, with identical solar collectors, sorption technologies and operative prices to obtain for each location, which of the studied technologies fits better in that particular climatic conditions. Once the first European overview is done, the developed software allows a further optimization of the problem, from the building and facility point of view, to achieve better energetic and/or economic results around a given location.

1.3 Document Structure

The present document is developed under the following structure:

Chapter 2: Previous works and methodology, introduces the actual statement of the technologies used in the work, their expected future and how the proposed combination between solar driven thermal heat pumps and low energy buildings, could theoretically increase the set building/system efficiency from an economical and energetic point of view.

*Chapter 3: Climatic Distribution.*The large amount of weather files studied made logic the creation of weather classifications where buildings and solar facilities could be packed in groups with similar behaviour. Two way of climatic parameterization where compared for the European zone and a determined raster was defined to divide the European climates into 49 different climatic zones represented in map and matrix mode. Maps and matrices will be extensively used through the document as a helping tool to evaluate the obtained results.

*Chapter 4: Building definition.*The reference building is described there, as well as the interactions that a building has with the environment and how heating and cooling demands relate to them. Each one of the factors affecting building internal conditions and comfort is deployed from a mathematical point of view and sorted into the referenceclimatic zones.

*Chapter 5:Solar System Definition.*The active solar technologies studied were here related to weather conditions and evaluated for different temperatures and layout scenarios.

*Chapter 6: Combination between building and solar system..*Active and passive elements, solar facilities and buildings, are linked in this chapter to study their common evolution and how good do they fit together in the climatic zones. The combination is evaluated and compared under a certain number of different parameters as solar collector area needed for each case, or how the prices, for each of the components included in the active system and the energies replaced, could evolve modifying the economic viability of the solar installation for the studied building.

Chapter 7:Evaluation of different sets Building/System for a determinate climate. As an example of the possible optimizations to be done in each case, it has been chosen a city where modifications on building properties clearly change solar facility optimization results. The scope of the process is decreasing building demands along the year as much as possible, keeping stable the solar facility usability. Thatmeans a decrease of fossil fuel dependencies, better solar system efficiencies, lower economical costs and shorter returns of investment.

Chapter 8: Conclusions

2. Previous works and methodology

Given the ambit of knowledge in which the thesis is developed, it was considered important to analyse different aspects of the current state of the art, as astarting point to identify the needs of applied research and the problems that are intended to be solved within this work. This study of the state of the art, frames the work into the respective technological and scientific fields.

2.1 State of the art

The basements of this work are mostly Solar Cooling technologies and the possibility of using the thermal chiller in reverse mode along the cold season. This situation obliges to revisit, in first place, solar cooling improvements, and later on, the evolution of thermally driven heat pumps used in heating mode.

2.1.1 Solar cooling

Several technologies were available to produce cold using thermal sources with temperatures over the ambient ones, as happens in the solar cooling case. Florides et al, 2002 did an overview on Solar cooling methods, classifying them in three main categories: sorbent systems (absorption and adsorption), mechanical systems and specific ones. Some other similar references can be found in Gupta et Al. 2008, Kim and Infante 2007, Best 2007, Henning 2004 or Duffie et Al.1991)

Table 1 shows as a resume, a classification for solar thermal cooling technologies, depending on the way the refrigerant fluid is used. Processes can be defined as closed when the fluid goes through different thermodynamic processes continuously or open, when the working fluid is being constantly renovated.

Table 1: Solar thermal cooling technologies

Process	Closed cycles Cold water production		Open cycles Air conditioning	
Sorbents	**Liquid**	**Solid**	**Liquid**	**Solid**
Pairs	$LiBr/H_2O$ H_2O/NH_3 $LiCl/ H_2O$ $LiNO/NH_3$	Silica-gel/ H_2O Act. Carbon/CH_4 $BaCl/NH_3$	$CaCl_2/ H_2O$ $LiCl/ H_2O$	Silica-gel/ H_2O Zeolita/ H_2O
Tecnology	Absortion	Adsortion	Dissecant liq.	Dissecant cycle
Power [kW]	4,5-5000	8-1000	20-350	-
EER	0,7-1,3 (SE-DE)	0,3-0,6	0,5-1	< 1
Temperatures [°C]	75-110 (SE) 130-160 (DE)	55-90	45-90	45-70

Among the technologies exposed, systems based on absorption technologies stand out over the others, by the number of existing facilities and wide range of cooling powers. (K4-Res-H 2006, Balaras 2007, Kim and Ingante2008, IEA 2011, Mugnier et Jakob 2012) But, overall, it is due to the efficiencies associated to sorption technologies.

Absorption machines, although they were developed firstly along the 19^{th} century, haven't had a continuous evolution from the point of view of development and distribution, being its evolution intimately related to the conventional fuel prices.

Nogués 2001, relates how the use of sorption chillers were quite usual after the 2^{nd} World War in both domestic and industrial markets because:

- They were gas driven machines, a cheap and easy to obtain fuel
- Lithium Bromide-Water machines were just developed, being obtained better yields when compared with the classical Ammonia-Water ones, although cycle temperatures wouldn't admit other uses out of air conditioning
- Low reliability of electrical grids, causing important economic losses when electrical systems were in charge of conserving perishables.

The energetic crisis in the early seventies increased fossil fuel prices and the massive construction in the developed countries of power plants, integrated in more efficient electric grids,stopped the evolution of thermal chillers. The substitution of sorption technologies was quickly done with the emergence of new compression chillers, highly efficient and independent of cooling towers that decreased the installation costs. Balaras 2007 and Henning 2007 demonstrate that although the efficiency, when calculated in base to total energy, is higher, when compared in primary energy terms, efficiency for both compression and sorption cycles are similar.

After these years, research and development of sorption machines was mostly happening in India and Japan. The availability of LPG's and geothermal energy in Japan, helped on the expansion of sorption technologies that in 1975 where widely used as the compression ones. (Nogués 2001)

Since 1995, fundamental research in sorption processes increased. Main causes were:

- Farman et al, 1985, discovered the constant degradation of the ozone layer, explained previously with CFC's catalysis, in 1975 by Molina and Rowland. CFC's where the refrigerant gases used for compression cooling.

- Increase of electrical tariffs, associated to fossil fuel price increase and the maintenance and custody of wasted nuclear fuel residuals.

- Utilization of solar thermal and other low temperature technologies capable of driven the sorption chillers to produce cold water.

Mitchel 1986, shows a collection of solar cooling facility yields, based on absorption machines. Most of the facilities underperform but the efficiencies related variate due to:

- Existence of components with high energy demands as cooling towers, ventilators and pumps working mostly under wrong control specifications.

- Over dimensioning of facility components, being operated the chiller, most of the time, in part load conditions, with short cycling periods, and as a consequence, low efficiencies. (Lazzarin 1980, Blinn 1979).Both effects are caused by a lack of confidence on the existing dimensioning methods, or the unavailability in the market of a product adapted to the demanded cooling loads.

Alongthe 20th century last two decades, an important number of IEA programs and EU financed projects were developed with the scope of definitely push solar cooling technologies, creating some short of best practises books and some reliable dimensioning methods to take advantage of the technology. IEA Solar Heating and Cooling program initiated with the Task 25 and Task 38 the creation of a database where recorded data, layouts and experiences accumulated from existing facilities were put together. Collaboration among participants of this IEA Tasks existed under a variation of national and international financed programs as the European Frame Programs 6, Intelligent Energy programs, and Frame Programs 7, that gave another turn to the Solar cooling evolution. Projects like Climasol (Eu Altener 2002), Solarthermie2000 (German founded project, 2000-2002), IEE Best Results (2005-2007), IEE Solair (SACE 2007-2009), EU FP6-Rococo (2006, 2008), IEE Solarcombi+ (2008-2010), FP7 Alone (2009-2013), developed different solar cooling systems with the intention of having enough real data to learn about the technological problems associated and find solutions that allow a further expansion.Nevertheless, the numbers of real installations, and from those, the fully monitored ones, deliver not many usable data. (Henning, 2004, Balaras et al. 2007)

References found in Kim and Infante, have been updated and presented in the following Table 2. Other facilities, with less amount of monitoring are remarked into the Task 38 deliverables divided by low power (<35kW cooling power) and over that size.

Table 2: Reference to real facilities with commercial chillers

Reference	Climated Area [m^2]	Cooling power[kW]	Collector Area [m^2]	Collector's efficiency	COP	Global efficiency
Ward and Löf (1975)	140	10	71,3	0,20-0,25	0,48-0,70	-
Ward et al. (1976)	140	10	71,3	0,30-0,35	0,30-0,70	-
Van Hatten and Dato (1981)	160	4	36	0,30	0,54	0,11
Bong et al. (1987)	-	7	32	-	0,58	-
Al-Karaghouli et al. (1991)	-	211	1.577	0,50	0,618	0,31
Yeung et al. (1992)	-	4,7	38,2	0,375	-	0,08
Hammad y Zurigat (1998)	-	5,25	14	-	0,85 (puntual)	-
Best and Ortega (1999)	-	90	316	0,26-0,29	0,53-0,73	0,26-0,36
Li and Sumathy (2001)	-	4,7	38	0,35	0,55	0,07
Assilzadeh et al 2004	-	3,5	35	-	-	-
Syed et al. (2005)	80	35,17	49,9	0,49-0,55	0,23-0,42	0,06-0,11
Zambrano et al. (2008)	-	35,17	151	-	0,6 (un día)	-
Ali et al (2008)	270	35,17	108	0,35-0,49	0,37-0,81	-
Agyenim et al (2010)	82	4,50	12	-	0,58-0,66	-
Marc et al. (2010).Praene et al. (2011)	170	30	90	0,20-0,43	0,30-0,41	0,08
Bujedo et al. (2011)	200	35	50+32	0,43	0,57	-
Marcos et al. (2011)	-	42	5	0,30	0,55	0,08
Martinez et al. (2012)	200	17,6	38,4	0,29	0,69	-

RHC-Platform, 2012, indicates that, as it has been previously said, the limited practical experience is one of the most important barriers to develop solar cooling facilities, being necessary mayor knowledge diffusion. “So far, mainly pilot plants and a few commercial plants have been in operation, limited practical experience and know-how is one of the major barriers to widespread installation of solar air-conditioning and refrigeration systems. Only a small number of professionals are well informed on both solar thermal and air-conditioning in buildings. Due to this limited experience with solar cooling and refrigeration systems, measures are needed to encourage the dissemination of existing know-how and improve system quality” (sic).

As a result, this platform suggests two different ways of expanding solar cooling markets.

- Theme 1: Improving solar thermal cooling systems components.
- Theme 2: Improving performance, integration and costs of solar cooling systems.

And as a consequence, it deduces that sorption based solar cooling systems depends on:

- New designs that take into account solar cooling particularities.
- New control strategies to maximize efficiencies, minimizing exploitation costs and reducing return of investment periods when compared with conventional systems.
- Development of adequate dimensioning methodologies to avoid bigger as needed facilities, estimating in a realistic way real system behaviours adjusted to user needs.

From the results obtained in the above mentioned projects, came the potential to use the chillers in heat pumps mode during winters and to combine solar thermal collectors connected to their evaporators. IEA Heat Pump Program Annex 34 (2008-2012) looked deeply into thermal heat pumps while IEA Solar Heating and Cooling program Task44/HPP Annex 38 (2011-) joint forces to connect every kind of heat pump with solar collectors.

Ziegler F, 1999, 2002 and 2009 describe last performances of sorption heat pumps, made a summary of the sorption technologies for heating and cooling, comparing the technologies and describing the challenges to reach a commercial statement. Frank E, 2010 classifies the combinations between Solar Thermal and Heat Pump systems.

Nuñez T. (2005 and 2008) describes the development of a sorption chiller and heat pump able to be driven with solar thermal technologies and further design improvements, where the solar collectors where always connected to the desorber of the machine. Mateus T, 2009 evaluated a similar technology in different European locations.

Haller and Frank, 2011 and Bunea M, 2012 evaluated the potential of using heat from solar thermal collectors into heat pump evaporators, optimizing the use of both technologies when working combined in winter mode.

2.1.2 Thermal Heat Pumps

Thermal heat pumps, and in the case used in this work, sorption machines, need of two different substances presented as a brine. One of them acts in the cooling cycle as refrigerant, taking the heat provided by an external fluid needed to be cooled, and the other substance, absorbs and desorbs the refrigerant, causing two pressure levels and consequently different temperatures, needed to realize a basic cooling cycle. (Evaporation, expansion and condensation)

Jakob 2008 analysed the commercial machines available with low cooling powers and also some prototypes still in development phase. Although there are a considerable amount of pairs registered and tested, able to be used in thermal pumps, three pairs commercially predominate over the others:

- Pair Lithium bromide-Water (BrLi-H2O).
- Pair Ammonia-Water (NH3-H2O).
- Pair Lithium chloride-Water (LiCl-H20).

Some other pairs with potential to be used in sorption machines are: ClBa-NH3 (Rivera et al. 2007, Le Pierrès et al 2007) and LiNO3-NH3 (Rivera et al. 2011).

From a working point of view, sorption machines are composed by four interconnected zones, evaporator, condenser, absorber and desorber, defined thermodynamically by two different pressure levels:

- High pressure (HP): condenser and desorber
- Low pressure (LP): evaporator and absorber.

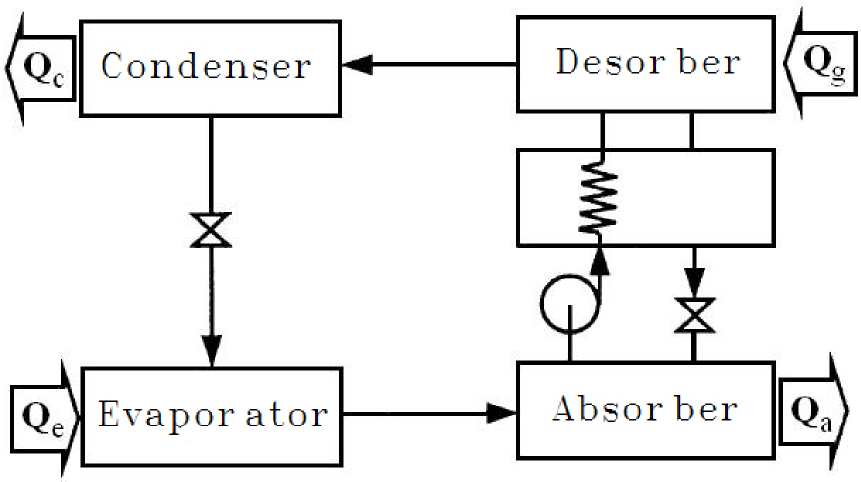


Figure 1: Working diagram for a single effect absorption chiller

In Figure 1, it is seen the functional interrelation of each one of those elements as well as the heat fluxes associated to them. The connection of the studied machines with external circuits, allow a thermal exchange with three different temperature levels:

- Evaporation temperature (ET): correspondent with the thermal level of the fluid that should be cooled to realize air conditioning processes. It is the lower thermal level around the machine, and it should be defined by the characteristics of the equipment in charge of conditioning the occupied areas. Depending on the use of radiant distribution, the utilization of fan coils and other convection based systems or the need of evacuating latent loads, the evaporation temperature varies. In our studied case, as it be explained later on, the evaporator will be connected to the cooling demand of the building in summer case and to the solar thermal collectors in winter case to take advantage of the energy collected from the sun.

- Condenser and desorber temperature (CT): corresponds to the thermal level of the heat pump, mostly via cooling towers, geothermal exchangers, or a low temperature heating distribution system in case that the heat pump works in heating mode. Along the cooling demand periods, the temperature is hardly linked to the ambient climatic conditions. This thermal level is intermediate between the Evaporation temperature and the desorber one. Both condenser and absorber dissipate the generated heating form the absortion processes and the injected energy needed to separate the components of the working pair.

- Desorber temperature (DT): corresponds to the thermal level of the heating source acting as a thermal compressor, and it is always connected to a high temperature element. In our case, the thermal source would be boiler during the heating season, heat pump working mode, and the solar thermal facility when working in cooling mode. It's defined a minimum thermal level for the machine, under which, the system works with low performance ratios, and in case of solar driven cooling mode, there is a maximum limit that should not be exceed to avoid a decrease of the solar cooling facility performance. As it is explained in following chapter 5, solar thermal collector efficiency decreases with an increase of fluid temperatures when ambient conditions are fixed.

Sorption cycle initiates in the evaporator with the energy exchanged given by the external low temperature source. In this part of the cycle, low pressure fixed a low boiling temperature of the refrigerant that vaporize and goes to the absorber mixing with the absorbent fluid. This exothermal process must be controlled around the level defined by ET, increasing the solubility of the refrigerant fluid in the solution. The diluted solution is pumped to the desorber, (high temperature and pressure) where an external source delivers energy to separate refrigerant (newly sent to the evaporator) and absorbent fluids (sent to the absorber) to continue the thermodynamic cycle.

As a resume of working modes:

- Cooling mode: The energy delivered to the evaporator (cooling) it is used in the processdriven by the desorber and evacuates to the condenser.

- Heating pump mode: The energy evacuated through the condenser (heating) is used for lowexergy heating purposes. Energy is introduced in the sorption machine by the evaporator (around 10ºC) and the desorber (around 75 ºC).

A particularly interesting representation for LiBr-water machines is the so called Dühring diagram that allows the visualization of the LiBr-Water solution, as a function of temperature, concentration and pressure. It should be remarked that for high concentration and low pressure states, LiBr solution crystalizes, stopping the thermal processes and putting at risk the absorber.

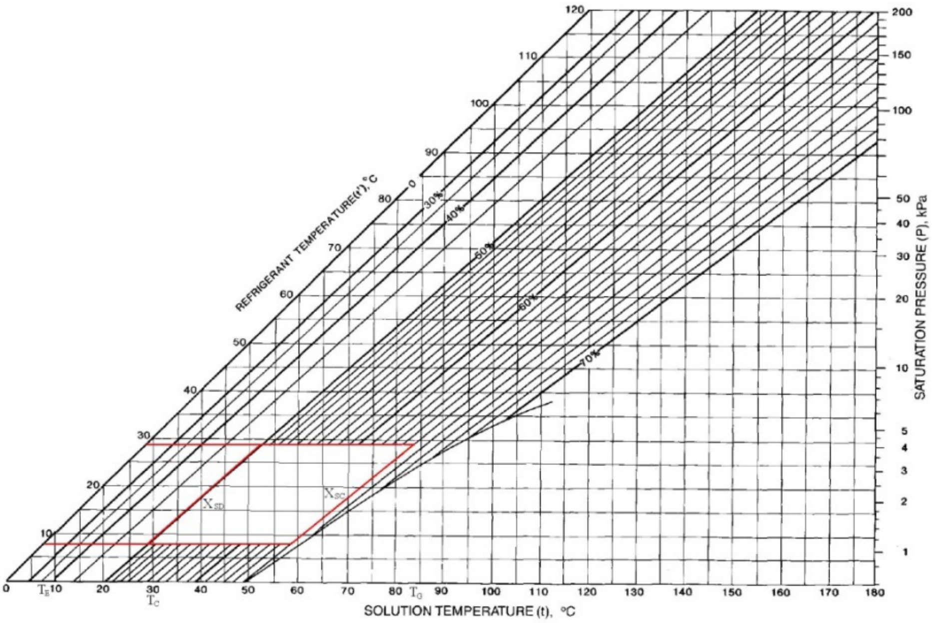


Figure 2: Dühring Diagram (Source: ASHRAE)

As it can be understood form the operation curves of a typical example of low power absorption machine, the clasical YAZAKI WFC10, Figure 3, the machine performances are very dependent on the thermal fluxed surrounding. (Herold et al., 1996; Eicker, 2003) describe how the variation on the input temperatures in each of the four thermal sources from which the chiller/heat pump is driven, affect their performances and Bujedo 2014 describe the optimal values in which the machine should work to be driven by solar thermal collectors. He mentioned that in order to obtain the maximum energy from the machine working in chiller or heat pump mode, the temperatures should be as follows:

- To decrease the energy delivered by the backup boiler, and increase the condenser dissipation, condenser temperatures should be as low as possible and desorber ones should be closed to the maximum temperature accepted by the heat pump.

- To increase the energy extracted by the evaporator, their temperatures should be closed to the upper part of the machine specifications (Evaporation inlet temperature around 12ºC)

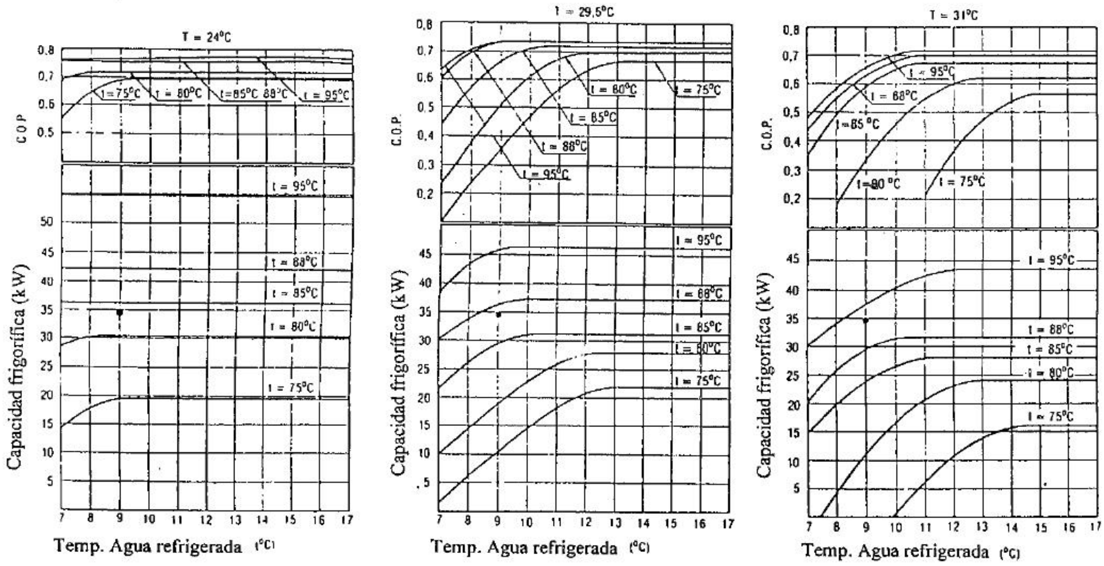


Figure 3: Operational curves for a YAZAKI WFC10 (Source: YAZAKI)

Moreover, in solar cooling mode, where the energy delivered by the solar facility is a highly important value, to increase the system solar fraction, control set points for the solar facility should be close to 75ºC and condenser temperatures as low as possible.

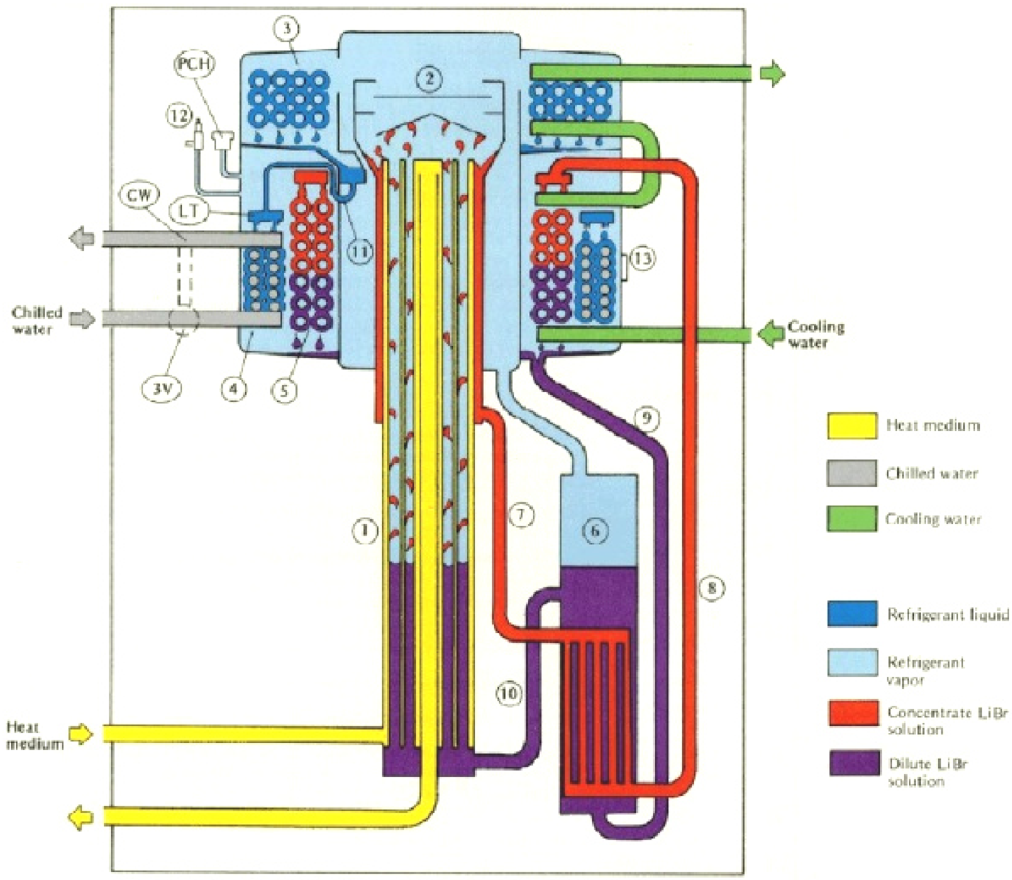


Figure 4: Absorption machines design [Yazaki WFC-10] (Source: ESESA)

2.1.3 Distribution systems used in this work (Radiant slabs)

Radiant systems have been used in a regular way in North and Central Europe, (Olsen 1997) where the ambient temperatures are usually low. Radiant slabs systems show the following advantages (Saunier Duval, 2005):

- Distribute the temperatures in a uniform way, reducing the need of creating air movement in the occupied zones.
- As the emitting surface areas are large, the system allows the use of moderated flow temperatures that increases the production yields of both heating and cooling generators.This characteristic stimulates the use of renewables as:
    - Radiant heating driven with solar collectors
    - Radiant heating driven with heat pump condensed energy, increase the sorption process efficiency in winter seasons.
    - Radiant cooling driven with the heat delivered to theevaporator. The relative high slab temperatures needed to cool the zones labs, maximize chiller efficiencies, moreover when combined with cooling ceilings.
- Radiant slabs used for heating and cooling decrease the investment costs of having two different distribution systems used seasonally.

But show also some inconvenient:

- Higher initial costs than a single typical system based on radiators or fan-coils.
- High inertia effects which complicates control when quick demand changes happen.
- Possibilities of superficial condensations when internal relative humidity is high. It is obligatory to install superficial temperature probes to control that dew point temperatures are not reached.
- Temperature profile created by radiant slabs, measured in vertical is similar to the ideal comfort one in heating mode, but contrary when used in refrigeration.
- Lack of experience and exploitation data in real installations when working in cooling mode.

De Carli et al., 2002, established that the use of radiant systems need of adequate control strategies to take advantage of the slabs particularities, as they are the high inertial masses and the important time constant associated to them. De Carli also claims for the development of guidelines and tools to achieve nearly optimal behaviour as a function of the different climatic zones and demand profiles.

Lim et al. 2006, presented different ways of controlling cooling radiant floors focused on avoiding superficial condensations on the high inertial slabs.

Ren et Al. 2010 overview low temperature radiant distribution technologies to be used in combination with renewable energies, purposing new components.

2.2 Why Solar Thermally Driven Heat Pumps

The work developed by the author since 2004 was based on identification, dimensioning, controlling and optimization of solar cooling facilities, but always from the point of view of increasing the efficiencies of a classical solar cooling layout. In Rodriguez, J. 2007 this optimization scope delivered as a result, a group of ratios to relate the number of collectors installed for a solar cooling system with the thermal storage size and the due cooling power to be installed. Those values defined the influence of heat accumulation and nominal chilling power when related to the collector surface area installed, avoiding:

- Over-dimensioned water tanks for a determinate collector area and available radiation. Thoseneed of longer charging periods to reach the selected temperature needed to stationary drive the machine desorber. This longer time, in case of being the desired temperature reached, uncoupled cooling demand and solar heating production, decreasing the total efficiency of the facility.

- Under-dimensioned water tanks that are quickly warmed up, but they don’t store enough energy to deal with the desorber demand in case of lower solar radiation availability than expected. This smaller tanks, also cannot store enough energy in lowbuilding demand periods where there is still enough solar potential. Their small sizes led to higher storing temperatures and as a consequence, lower solar system efficiency.

- Over-dimensioned solar platforms, that produce excessive energy in the central part of the day and the sorption machine and the accumulation system is not able to dispose. The thermal level of the primary fluid returns to the collectors at higher temperatures than desired, decreasing the solar plant efficiency by overheating it. Stagnation temperatures could be reached, damaging the collectors and decreasing the economic viability of the facility.

- Under-dimensioned solar platforms, that doesn’t produce enough energy to drive the solar cooling cycle in the central parts of the day, consuming larger fossil fuel amounts to deliver a determinate cooling power to the building.

The results obtained were coincident with lately published dimensioning norms as the IEA Task 38 results are, but the facility efficiencies and return of investments were incompatible with an expansion of the technology. It was also seen in that MSc work, that in order to achieve shorter backup periods, the utilization of the components, mostly the chiller, shouldn’t be limited to the cooling season and the solar thermal platform should deliver more heat along the heating season, where building demands are higher, although solar availability is a small resource compared with other times of the year. These last results are also coincident with the ones obtained by SolarCombi+ project (SC+) and ROCOCO project, among others.

On the base of the exposed previous results, this work tries to evaluate a system that produce energy all along the year, minimizing the size of the complete installation to facilitate the achievement of acceptable payback times.

The integration of sorption heat pumps into the solar heating system of the building exploits the combination of two different effects:

- *Utilization of the condenser flows to activate low temperature heating systems*. Data provided by the manufactures of different sorption machines; show how the optimal values for the condensing temperatures of their products stay between the 24 and 31 degrees Celsius when entering the machine. With these condensing operational temperatures, the machine deliver to “our heat sink” (building demands) flow with temperatures around the 29 to 36ºC, being supposed a design ΔT=5K. That values perfectly fit in the ranges demanded to drive low temperature heating systems as radiant floors, and permitting an increase of winter savings, and as a consequence, total savings of the systems along the year .

- *Utilization of the collectors in the evaporator of the sorption machine*. Total radiation collected by the solar plant in winter period is much lower thanalong the summer time, but the use of this energy in low thermal levels, around a maximum value of about 20ºC, maximizes the efficiency of the collectors and allows the heat pump to increase the thermal level of this energy connected to the evaporator until the needed 29-36ºC with high conversion rates.

Those two effects working in combination with a heater (always present in a solar facility), that provides power with temperature levels rounding the 80ºC to the heat pump desorber, increases the energy delivered by the solar facility and decreases the fossil energy demanded by the building in numbers theoretically closed to a 37%. Sorption machines with COP’s around 0.65 in chilling mode, have efficiencies of 1.65 when relating the energy exiting the condenser with the energy delivered to the desorber. It means, a 37 % of the energy delivered to the building will be, in case of enough solar availability, saved by driving the TDHP evaporator with thermal solar collectors

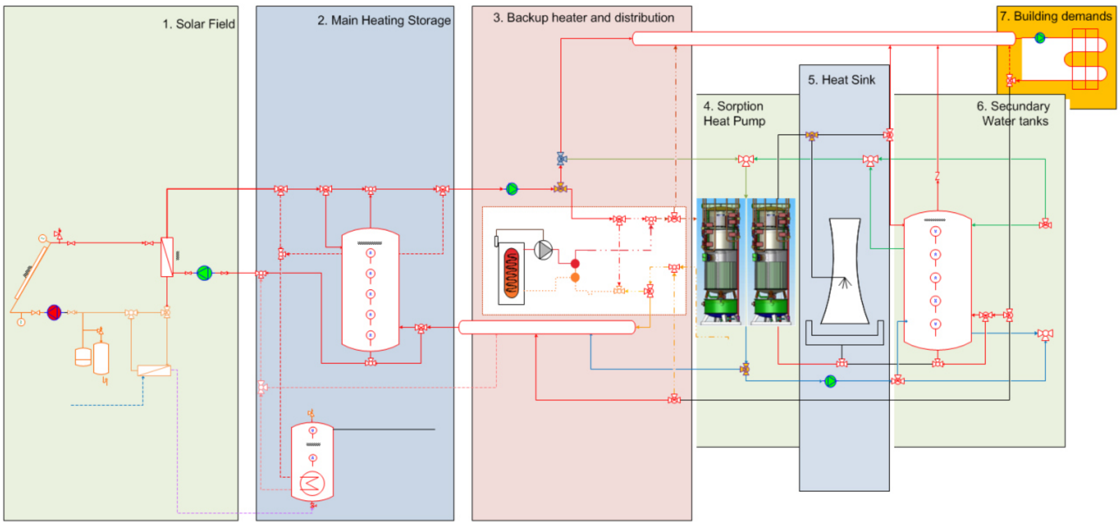


Figure 5: Proposed TDHP layout to be studied in this work

The proposed layout, in a general way, it is described in Figure 5. From left to right it have been disposed a solar thermal platform hydraulically separated from the rest of the facility with a heat exchanger to allow the utilization of glycol in the external circuit that avoids fluid freezing while the internal pipes work with water as energy transporting fluid (Numbered 1). Two different hot water tanks where designed, one for hot process water storage and the other for DHW, to remark the idea of thermal stratification needs. This solution is an acceptable possibility to avoid legionella problems (Numbered 2). Both storage tanks are connected to a diverter valve that adjusts water thermal levels to the demand needs with the potential use of a water boiler.

In case of having enough power collected from the solar system, a diverter valve sends the fluid directly to a hot water distribution pipe that feed the different systems installed. If not, the existing boiler drives the system in backup mode (Numbered 3).

A thermal heat pump (Numbered 4) is sited after the collectors and the boiler. It can be connected to those components in two different ways:

- *Summer mode:* Solar thermal collectors and boiler are together potential heat sources connected to the desorber.

- *Winter mode:* The boiler is connected to the desorber while the solar collectors drive the evaporator, delivering the machine hot water with a thermal level ranging from 12 degrees, correspondent to thelower system performance,to 20 ºC where the highest performance level is reached. Once the balance point of 20ºC is reached, the solar collectors could potentially fully drive the radiant slabs without the need of fossil fuels. The boiler is switch off and the collectors would be connected directly to the radiant distribution system without passing through the heat pump.

After the heat pump, there is a cooling tower, that representsa sink where the condenser energygoes in chiller mode (numbered 5), and one secondary energy storage able to work, in summer mode as cooled water storage, and in winter mode as heating water storage (Numbered 6). The main mission of this tank is to accumulate tempered water previously produced and have it available to be distributed into the building in times where the renewable heating/cooling production doesn't exist or it is not enough to cover building demands. As it was previously explained, on the hot side of the machine, connections with the heat pump will be done through evaporator and condenser, for cooling and heating mode respectively.

A final connection of the complete facility stays with the number 7, correspondent to the building radiant systems in charge of delivering heating and cooling into the controlled areas.

This layout has been partially replicated since 2007 by remodelling existing installations or designing new ones where the conceptual designs could be tested. Data collected in the following systems are being used to tune up controls and new installation designs:

- The existing solar facility installed in Cartif building 1, described in Poncela et Al 2001, was modified in 2007 to allow direct connections between the evaporator of an existing YAZAKI WFC-10 to the building radiant slabs. The hardware changes realized focused the idea of increasing cooling water demand seen by the chiller (the sorption chiller was in a first time, connected to seven fan coils with a total cooling demand much lower than the nominal chilling power of the machine). Nowadays, higher evaporation temperatures and an stable demand profile leads to higher efficiencies registered in the facility as explained in Bujedo et Al. 2014

- Conceptual designs were done for a solar thermally driven heat pump with geothermal connection installed in Cartif Building 2. In this case, the system was planned to tap the stability in one of the three thermal levels (geothermal condenser).This situation facilitates the system control and also increases the total system efficiency. Further details of the facility can be found in Macía A, 2009 and Macía A, 2013

- Design and installation of a laboratory where thermal heat pumps could be tested in a wide range of temperatures and different hydraulic connections that validate the proposed layout. COSMO lab is installed and running in EURAC research Institute (Bolzano) (Sparber 2007,Rodríguez, 2009)

- Conceptual designs of a district heating connected heat pump installed nowadays in SEL Headquarters, Bolzano, with the idea of stabilising desorber temperatures and investigate the potentials of thermal heat pumps when connected to district heating rings. This facility allow testing different controls based on desorber temperatures for a determinate building cooling demand eliminating the variability of solar radiation.

2.3 STDHP Proposed working mode

A Solar Thermally Driven Heat Pump facility (STDHP) conceptually works in three different ways explained along the following three subchapters, in which the system layout represents the different energy sources and building demands with a coloured scale (red means the highest thermal level and dark blue the lowest, while grey denotes pipelines not used in each specific operation mode).

2.3.1 STDHP Summer time working mode

Along the summer, the facility behaves as a typical solar cooling system delivering cold and domestic hot water to the building.

- The solar platform collects energy with relatively high temperatures, around 80ºC, to drive DHW systems and the machine desorber. The backup boiler is active to cover building demands when the solar system is not providing enough energy. (Red colours correspond to the hot water outing the collectors and the boiler and orange ones to the returning flows and "ready to use" DHW.)
- The evaporator delivers cold water to the radiant surfaces, able to extract the internal excessive heat of the building, cooling demand. (Soft blue lines)
- The condenser discharges the energy exceeds into the ambient. (green lines)

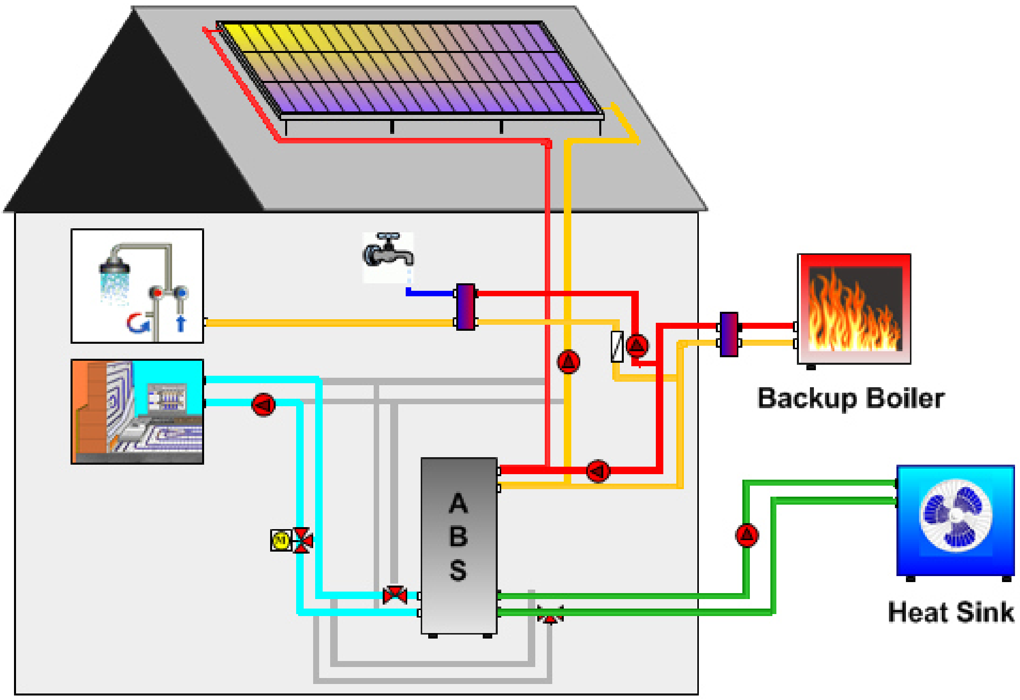


Figure 6: Solar Cooling working modus (storages are not represented) (Source Sparber)

2.3.2 STDHP Winter time working mode

Along the winter season, when there is no enough solar radiation available to reach at least 40ºC into the storages, the solar plant delivers energy to the evaporator of the heat pump with temperatures under 20 degrees and always over 10ºC to avoid crystallization problems. (yellow lines).It has being supposed that in winter time there is no enough radiation to store water with 40ºC able to drive building demands or 60ºC needed for DHW.

- The boiler delivers energy to the DHWS and the desorber of the heat pump (red lines) until the energy level of the fluid coming from the collectors reach the minimum temperature needed to feed directly the heating systems without need of the heat pump. In this moment, DWHS pass to be controlled by the boiler and the radiant floors are driven by the solar thermal plant, prioritizing the DHWS over building heating.
- The condenser of the sorption heat pump delivers hot water with enough temperature to be melted into the house, compensating building heating demand. As explained in previous lines, when the solar plant would reach similar temperatures as the condenser ones, the heat pump is to be switched off and building energy demands are to be driven directly by the solar plant.
- Heat sink is kept off.

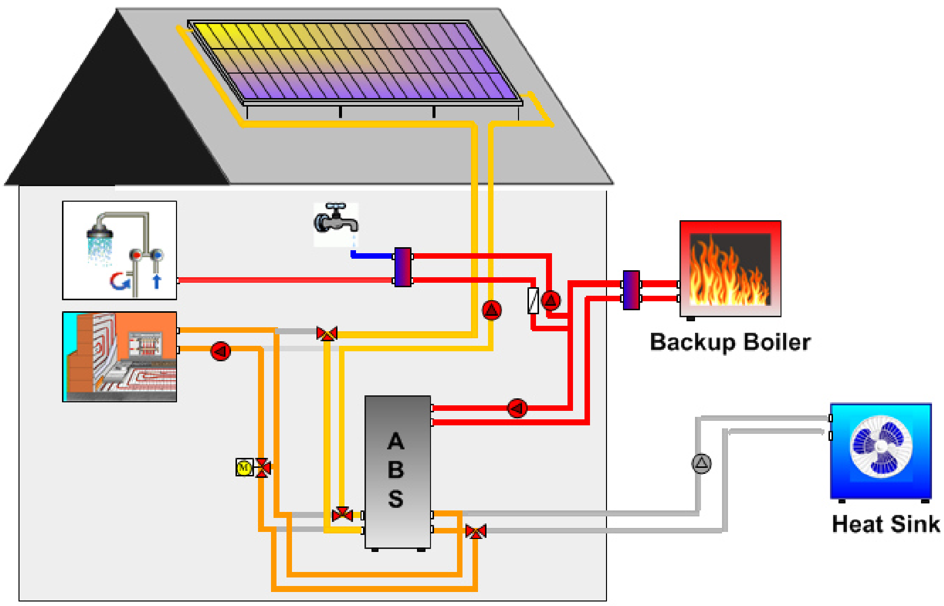


Figure 7: Solar Heat pump heating working modus (storages are not represented) (Source Sparber)

2.3.3 STDHP Spring/Autumn working mode

For intermediate seasons, the solar plant only delivers DHW or radiant heating to the building (when demanded) without using thermal heat pumping effects.

- Solar systems collect energy that is delivered to the building through the radiant slabs and warm DHW. That last load is always prioritized over building heating.
- Backup boiler is kept in standby, only to attend building loads and DHWS when solar facility is not able to do it.
- Heat pump is switched off.
- Heat sink is switched off.

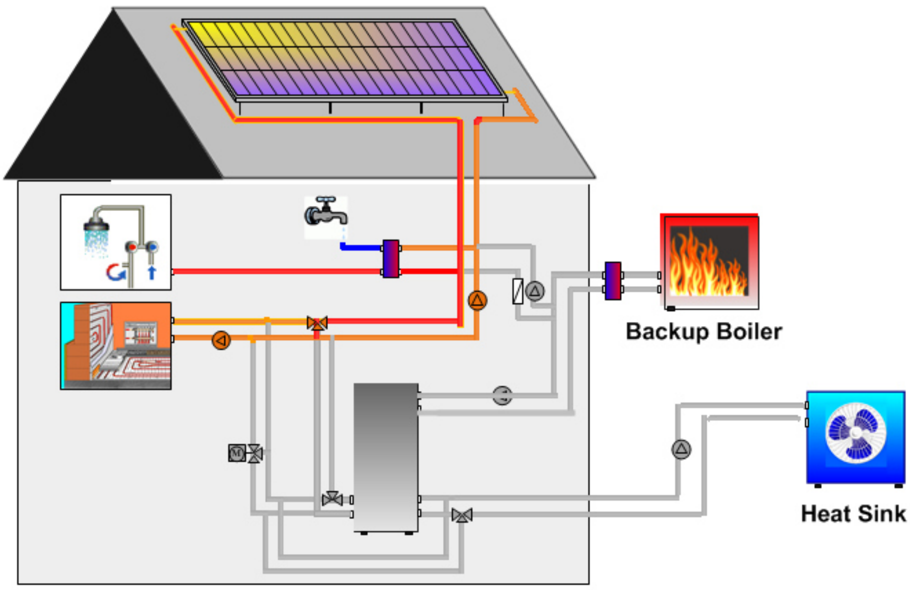


Figure 8: Solar heating working modus (storages are not represented) (Source Sparber)

2.4 Methodology

Following chapters of this work evaluate the possibilities of different solar thermal technologies around Europe, being studied the energetic and economic influence of parameters correspondent to:

- *Facility*: Two different layouts are compared. The first one uses the collected energy only for heating and DHW while the second scopes also on cooling production. Both systems differ on the integration in the loop of TDHP's.

- *Different types of solar thermal collectors: The* utilization of two different solar thermal collectors, representing flat plate and evacuated tube technologies, is studied.

- *A well isolated house with fixed parameters and physical characteristics represents the building object of study*. Its demands, heating, DHW and in some cases cooling, will be satisfied with the energetic production of the four possible solar thermal layouts.

- *Different climatic conditions.* The set formed by the building and each one of the solar thermal layouts is to be studied in 515 locations around Europe to compare the potentials of each technology.

A sideways glance to the potential number of combinations to be studied, derived, first of all, into the creation of a common methodology to dimension solar plants, and lately the obtained results should be sorted by climatic zones in which the building and its correspondent solar facilities are placed.

Solar plants sizing was optimized to cover completely each month the smaller of the heating/cooling demand of the house, minimizing the exceeding energy produced along the year and optimizing the economic costs. In a first approximation, it is evaluated winter and summer demand peaks for each location and compared with the available solar radiation during this period, obtaining as a result two different collector areas that fully cover "*heating+DHW"* and "*cooling+DHW"* demands. The smaller of both results define, in a first iteration, the season of the year to which the facility will be optimized.

Figure 9 and Figure 10 represent as an example of the methodology, the heating and cooling demand calculated for the building described in Chapter 4, placed in Valladolid (Spain). As it can be seen in Figure 9, the peak corresponding to the summer demand (blue solid area) is a little bit higher that winter one (red solid area) but the radiation available (green line) during the months of June and July is approximately 4,5 times the one of December and January.

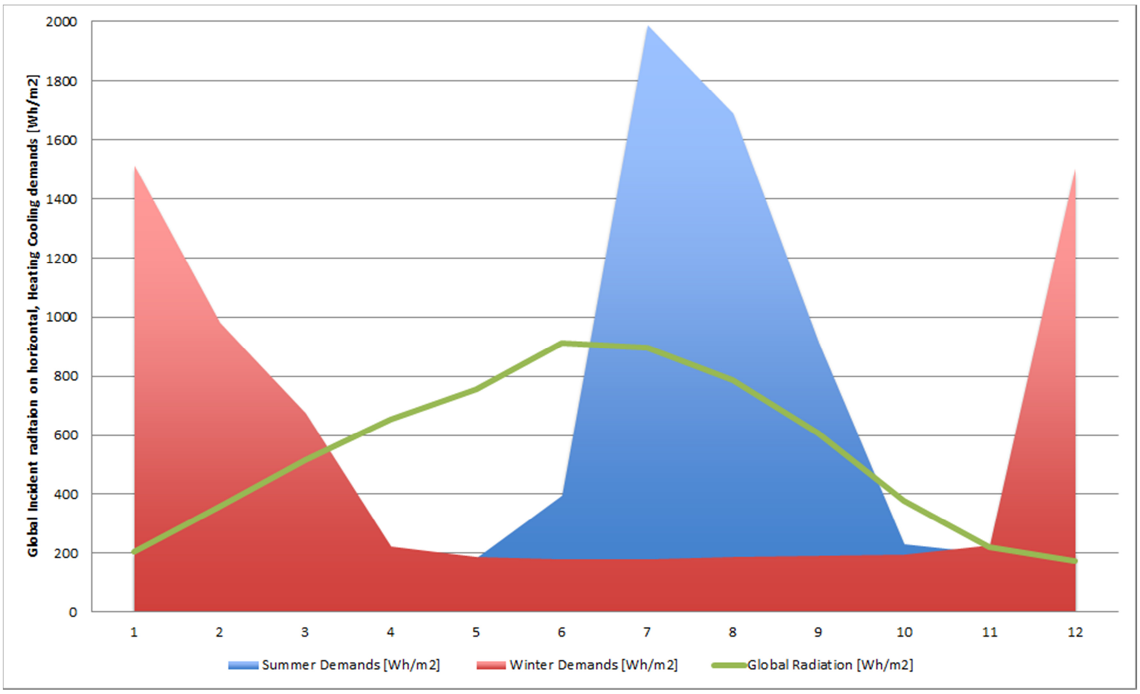


Figure 9: Monthly heating and cooling energy demands and energy global radiation on horizontal along the year.

Moreover, the different thermal levels needed to deliver heat in winter to the building terminal elements (maximum temperatures of 40ºC) and in summer to the sorption machine (around 80ºC), combined with ambient conditions as dry air temperature and available solar radiation,modifies the efficiencies of the chosen collectors. In order to calculate which is going to be the collector area installed in the building to maximize the use of the collected solar radiation, two different cases are been calculated:

- The amount of solar collectors needed to completely cover in a monthly base the cooling and the DHW demand, considering the sorption machine and the collector efficiencies for temperatures around 75ºC. Set point temperature to be reached by the solar plant to assure firstly the production of DHW and lately drive the sorption machine, assuring enough energy to satisfy both demands.[Bujedo,2014]
- The amount of collectors needed to cover the heating and DHW demand, prioritizing the one that requires lower thermal level with higher efficiency in the solar plant. As the solar facilities are considered as a backup source, the existing boiler will take care of the demands that need of higher thermal levels.

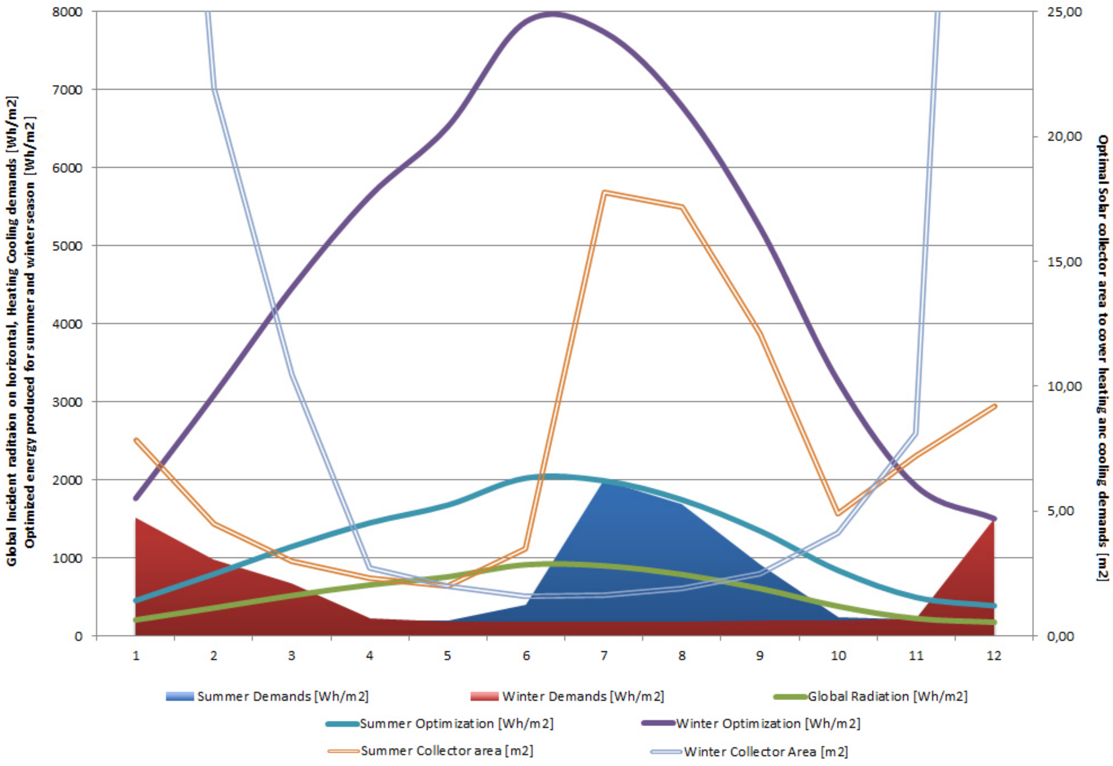


Figure 10: Heating and Cooling energy demands along the year (combined with Collector area optimization)

Figure 10 increases the values represented inFigure 9with the optimal collector areas that covers heating and cooling demand, calculated in a monthly base. It is seen that the maximum areas needed to satisfy completely the summer demand are lower than the amount obtained to do it with the winter one. This result determinesthe season to be optimized in a second step, where the calculation periods are being narrowed from a monthly calculation time range to a daily one. In the following simulation phase, different facility configuration are tested to find which one is the optimal for the set building-THDP-collector-climatic condition avoiding excessive collected radiation and minimizing machines, pumps and collectors sizes.

The process here described is repeated for each one of the climatic conditions available, obtaining a multidimensional matrix that contains:

- The location of the simulation, classified by climatic parameters. It allows the comparison among results obtained for different places,
- And the optimal collector area for each one of the collectors evaluated, the number of working hours for each one of the configurations studies, the fossil energy saved or the economical returns of investment for each case of study.

Joining all these results by climatic characteristics, allow the researchers a wide knowledge of the possibilities for each one of the systems installed in places with comparable climatic conditions.

3. Climatic Distribution

To achieve the objective of evaluating a set of different solar facilities in combination with the building demand around Europe, a total of 515 weather files were collected in format TMY (Typical Meteorological Year) from databases distributed with two well-known, and widely accepted softwareas Trnsys and Meteonorm are.

From the total amount of data files, there were only used 375 TMY files resulting after an elimination process that avoided the duplication of locations separated less than 10 km (It can be appreciated in t**Fehler! Verweisquelle konnte nicht gefunden werden.**hat in Switzerland, northern Italy, southern England, and in some other points distributed along the map, there are duplicated points that were eliminated for this study)

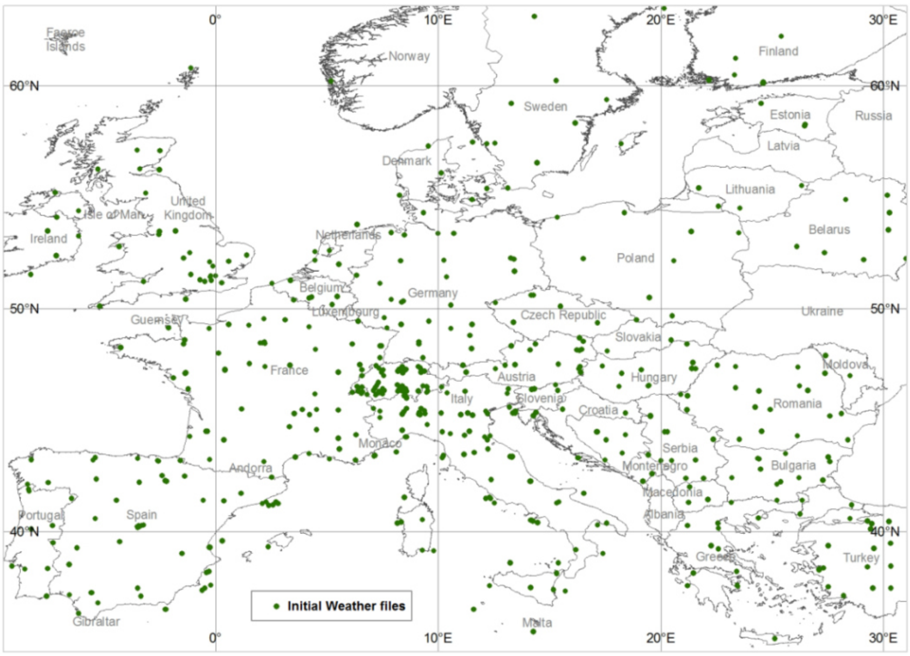


Figure 11: Greographical distribution of the 514 weather files used for the study

The weather formats used are typical meteorological years in version TMY and TMY2. The files contain hourly information collected in the respective weather stations, written in a particular way.On the basis of a macro file obtained from the National Renewable

Energy Laboratory (USA) web page,*[http://rredc.nrel.gov/solar/pubs/tmy2],*it was obtained for the definitive locations the following hourly values:

Table 3: TMY and TMY2 includedparameters

Name of the city	**Country**	**Latitude**	**Longitude**	**Altitude over sea level**
		Direct Normal radiation		
		Diffuse Horizontal radiation		
		Cloudiness factor		
		Dry ambient temperature		
		Dew Point temperature		
		Relative Humidity		
		Atmospheric Pressure		

And on the base of the read values, an ad-hoc created Visual Basic based macro, calculates further parameters based in EN 15927-5 and EN 15927-6:

Table 4: Weather parameters calculated with TMY and TMY2 files

Name of the city	**Country**	**Latitude**	**Longitude**	**Altitude over the sea level**
		Heating Degree Days		
		Cooling Degree Days		
		Daily Direct Normal radiation		
		Winter Climatic Severity		
		Summer Climatic Severity		
		Enthalpy Climatic Severity (ECS)		

The obtained results will help to divide the European climates intocategories that define every location by two indexes related to the heating and cooling period. In this way it is assured that in places with similar index values, buildings and facilities there installed, will behave in similar way under the same occupancy profiles.

Different ways to classify climates were studiedin this chapter, being realized some test with real monitored buildings to assure the capability of the method.

3.1 Geographical evaluation:

The psychometric diagram delimitates into trapezoids the acceptable living conditions for winter and summer season. As can be seen in Figure 12, for an humidity of 50%, temperatures of 21°C in the heating season (blue trapezoid), and 25°C in the cooling one (pink) assure the inside quality.

Moving the red point to the left on the 50% relative humidity curve, the amount of energy that the building loses in winter time to the environment is lower. The contrary happens in summer time with the blue point.

To define parameters proportional to the building loads, it was decided to evaluate as internal conditions, 21°C in winter time, and 26°C in the summer season (Figure 13)

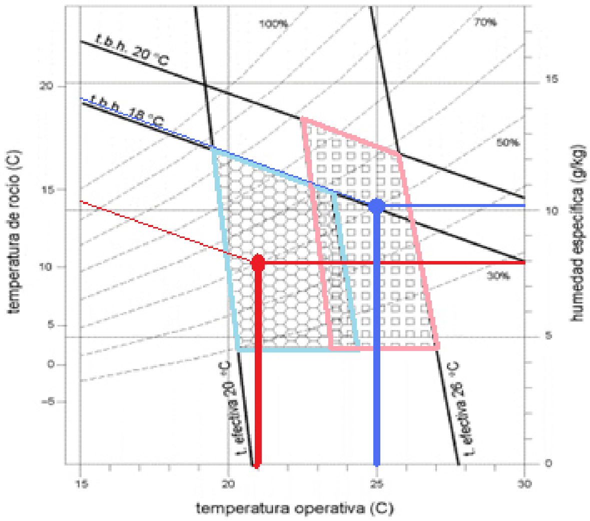


Figure 12: Optimal comfort conditions on a psychometric diagram

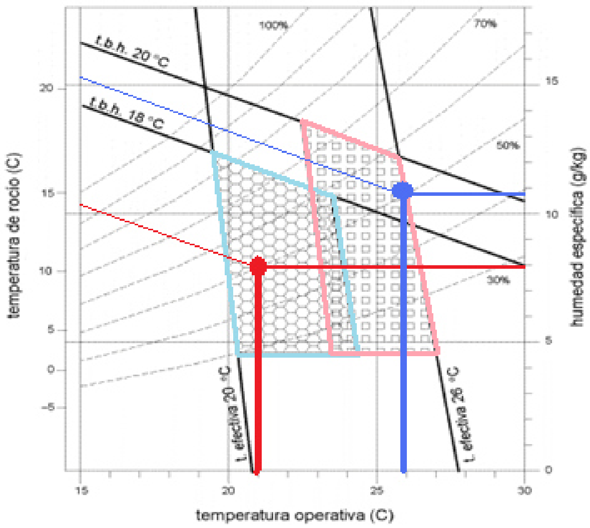


Figure 13: Ambient conditions selected within this work.

3.1.1 Geographical evaluation based on degree days

3.1.1.1 Heating Degree Days (HDD's)

This parameter is a quantitative index designed to reflect the energy demand needed to heat a building. It is used to have an initial evaluation of the amount of energy lost by the envelope of the building

The value is derived from daily temperature observations and calculated as the yearly sum of the difference in degrees between a base temperature that define the internal building ambient temperature (typically 21ºC is the temperature where the maximum level of acceptance, MPV) and the external dry temperature.

Equation 1: Heating degree days (base 21ºC)

$$HDD = \sum_{h=1}^{8760} \frac{(21 - T_{amb,h})}{24} \approx \sum_{d=1}^{365} (21 - T_{amb,d})$$

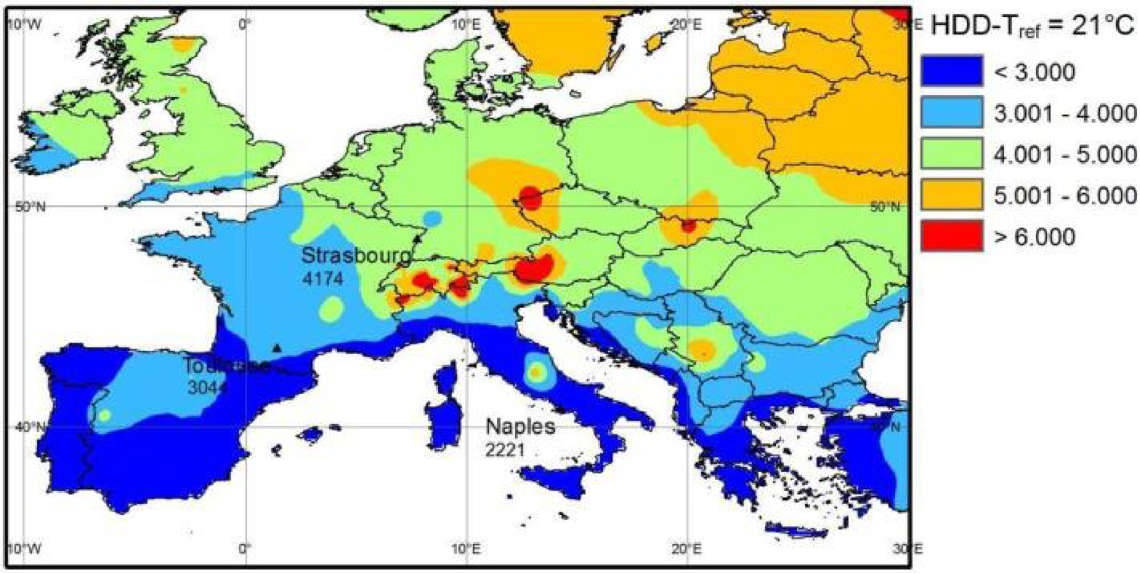


Figure 14: Heating degree days in Europe

HDD values computed for all the considered climatic files goes from the minimum one of 1322 degree days (Messina, IT) to the maximum one of 8590 degree days (Karasjok,NO). As it can be seen in Figure 14 under the line limited by latitude 58 N there is nearly no place with HDD values over 6000 out of some red points corresponding with mountains located in the Alps (several points in Switzerland, Italy and Austria and Hungary), mountainous places around Fichtelberg (border between Germany and Czech Republic) and locations around the Carpathian Mountains (Slovakia)

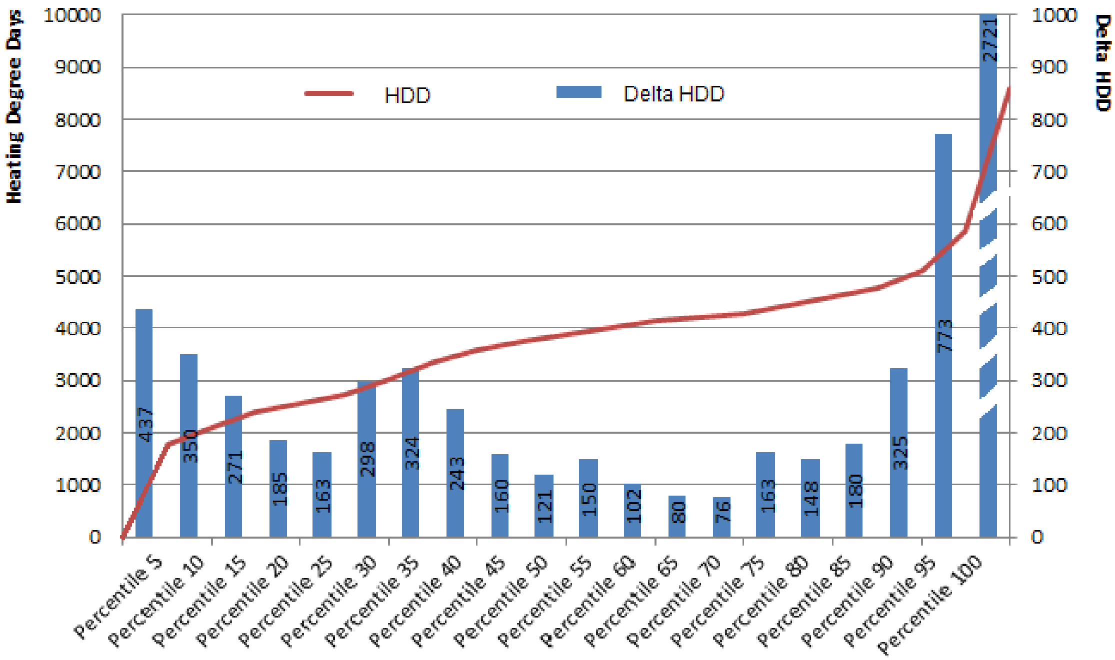


Figure 15: HDD cumulative distribution (HDD) and Percentile 5% interval amplitudes(Delta HDD).

The HDD distribution corresponding to the complete set of 375 climatic points has being divided in 20 intervals with equal amount of cities (5% percentile). It can be appreciated in Figure 15 how the last two intervals, containing 37 cities, cover an amplitude of 3494 HDD's from the total difference between Messina and Karasjok of 7270 (approximately a 48% of the total interval) That value denotes that a 10 % of the cities have winter climatic conditions much harder than the other 90%. It is also seen in the previously mentioned figure that HDD around 4000 are the most frequent values around the studied European places. The correspondence of Figure 14 and Figure 15 can be described as follows:

- Green zones of the Figure 14 correspond to percentiles between 40 and 80%
- Dark blues correspond to the 0 to 10% Percentile
- Yellow ones to the 95% Percentile
- Red positions correspond to the 100% (Mostly Nordic countries and mountain places)

3.1.1.1.1 Winter Heating Degree Days (WHDD)

It has being defined the parameter WHDD in the same way as it happened with the HDD with the unique difference of counting the number of degrees under 21 only during the months of December, January and February in order to test the clima-hardness of a determinate location out of the winter period. As it could be expected, the warmest European locations concentrate 97% of the HDD during winter month's values that decreases when moving to the north until a minimum data of 76% corresponding to the Nordic countries. The existence of these divergences, allow the exploitation of the solar facilities longer in time, during periods when solar radiation is higher than in December to February.

Equation 2: Winter Heating Degree Days (base 21ºC)

$$\mathrm{WHDD} = \sum_{h=8016}^{1416} \frac{(21 - T_{amb,h})}{24} \approx \sum_{h=01.Dec}^{28.Feb} (21 - T_{amb,d})$$

3.1.1.2 Cooling Degree Days

Cooling Degree Days parameter (CDD) is defined in a similar way as HDD. It is used to evaluate the gains obtained by the building due to the external temperatures. Summer internal reference temperature taken is 26ºC.

Equation 3: Cooling Degree Days (base 26ºC)

$$CDD = \sum_{h=1}^{8760} \frac{(T_{amb,h} - 26)}{24} \approx \sum_{d=1}^{365} (T_{amb,d} - 26)$$

In this case, the corresponding absolute values to the cities goes from the 0 (many cities that does not need any cooling production to cover the demand correspondent to the conduction and convection effects through the envelope) to the 382,78 of Kilis,TR.

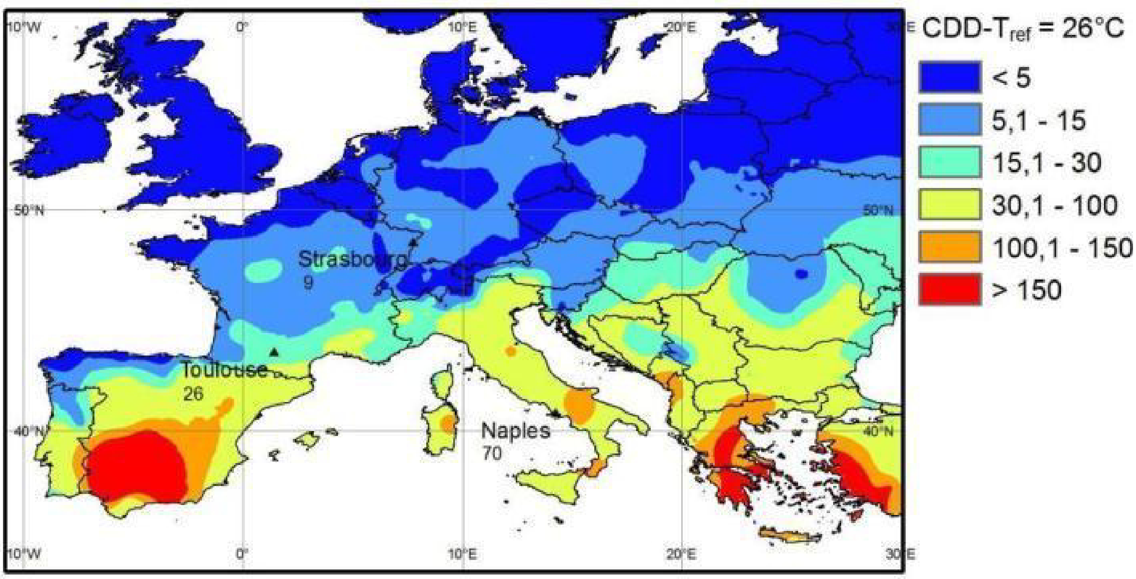


Figure 16: Cooling degree days in Europe

Figure 16 and Figure 17 represents the geographical and cumulative distribution of the CDD for the studied locations. In the first representation, it can be seen how the places with representative CCD values are placed under the latitude 45N as could be expected (south Europe) with higher values under the latitude 40N where the values overpass the 150CDD. Attending to the second figure, it is clearly seen that 65% of the studied locations don't have appreciable CDD values, a 5% of the cities cover half the CDD amplitude (percentile over 95% cover an interval of 170CDD) while the other 30% of the locations represent 171 CDD).

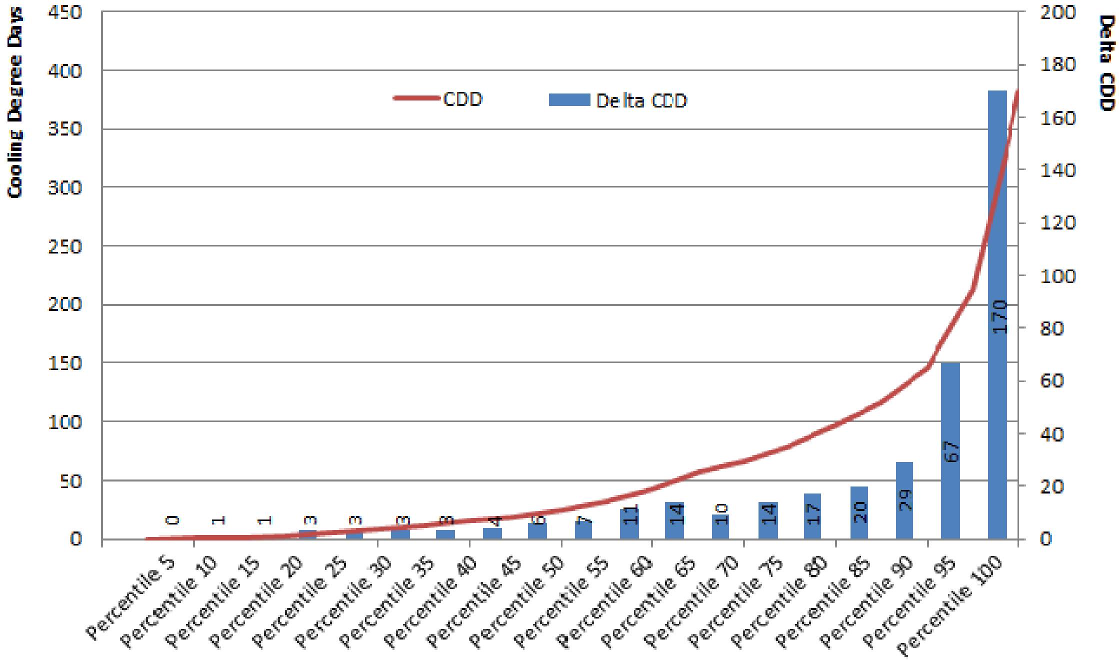


Figure 17: CDD cumulative distribution (CDD) and Percentile 5% interval amplitudes (Delta CDD).

The minimum 1322 HDD from Messina are nearly 4 times the maximum CDD value, remarking the idea of the higher importance of heating against cooling around all Europe. (At least when considering only, as it is the case of HDD and CDD, the effects associated to the building envelope)

3.1.1.2.1 Summer Cooling Degree Days (WHDD)

It has being defined the parameter SCDD in the same way as it happened with the CDD with the unique difference of counting the number of degrees over 26 only during the months of June, July, August and September in order to test the clima-hardness of a determinate location out of the summer period. As it could be expected, the ratios between CDD and SCDD demonstrate that only a 15% of the studied zones count with CDD's out of the summer period. (That 15% of the cities locate less than the 97% of the CDD during the summer)

Equation 4: Summer Cooling Degree Days (base 26ºC)

$$SCDD = \sum_{h=1}^{8760} \frac{(T_{amb,h} - 26)}{24} \approx \sum_{d=1}^{365} (T_{amb,d} - 26)$$

3.1.2 Geographical evaluation based on Climatic severity indexes.

As noticed by Brian Ford et al., Markus et al 1984 developed a technique which allows characterizing the hardness of any given climate on a building of known characteristics. This technique is carried out by means of the calculations of the Climatic Severity Index (CSI), a single number on a dimensionless scale which is specific for each building and location.

The advantage of the Climatic Severity Index (CSI), in contrast to the simple degree day total, is that it takes in account a further climatic variable (radiation).

The CSI used in this documentis defined as the dimensionless relation between the heating or cooling demand of a given building in a specific locality, divided by a reference locality. The thermal engineering group of the University of Seville first presented this definition in a project entitled 'Dwelling Energy Labelling'. Using a building thermal simulation program called Passport+, the heating and cooling demands of a large number of buildings of various types were calculated for all 50 Spanish capitals. The CSI was then calculated as the relation of those demands divided by that obtained for the same building for a specific reference locality where Madrid was found to be the best reference locality as its climate is situated in the middle of the entire range.[Sanchez de la Flor et al.]

Two different winter climatic conditions could be considered identical if the heating demand is the same for a certain building. Then, we could say that both winter climatic conditions have the same Winter Climatic Severity (WCS).

The same definition is valid for cooling demand and the term used would be Summer Climatic Severity (SCS). It could happen that two different climatic conditions have equal Winter Climatic Severity (WCS) and different Summer Climatic Severity (SCS), and vice versa. [Ford B et Al.]Furthermore, it can be said that a given climatic condition is 'x' times more severe than another if the energy demand of a certain building is 'x' times higher in the first case than in the second.

As it will be seen in the following subchapters, these two newly introduced indexes join to the importance of the envelope and its energy losses, a new term with the radiation that affects the building demand in two different ways:

- Increasing the superficial temperature of building's external walls. Higher external temperatures reduce the temperature difference between the intern of the occupied zones and the ambient, decreasing the envelope energy losses during winter time and increasing the energy gains in summer.

- Delivering the building a direct solar gain through the windows that helps to contain the energy demand during the heating season, but increases the building needs in summer time during the day.

The introduction of Climatic Severity Indicators filters the "monotony" of the European Degree Day distribution pointing out cold zones with high solar radiation in winter time and others with low radiation in summer time. The first zones are interesting for solar heating facilities and in the second one decrease the expectation on solar cooling applications.

3.1.2.1 Winter Climatic SeverityIndicator (WCSI)

In order to analyse the influence of the exterior conditions over the heating demands of a given building using the concept of Climatic Severity Indicator, it is necessary to express the relation between the CSI and the common climatic variables. WinterCSI it is defined as an index that parametrize how extreme are the studied zones along the winter season when ambient temperatures and solar radiation is computed.

Equation 5: Winter Climatic Severity Index [171]

$$winterCSI = a \cdot Rad + b \cdot WHDD_{20} + c \cdot Rad \cdot WHDD_{20} + d \cdot Rad^2 + e \cdot {WHDD_{20}}^2 + f$$

a	b	c	d	e	f
$-8{,}35 \cdot 10^{-3}$	$3{,}72 \cdot 10^{-3}$	$-8{,}62 \cdot 10^{-6}$	$4{,}88 \cdot 10^{-5}$	$7{,}15 \cdot 10^{-7}$	$-6{,}81 \cdot 10^{-2}$

Where:

- $WHDD_{20}$ is the mean value of the heating degree-days (December, January and February) with a base temperature of 20 °C
- Rad the mean accumulated global radiation over a horizontal surface (in kWh/m2) for the same months.

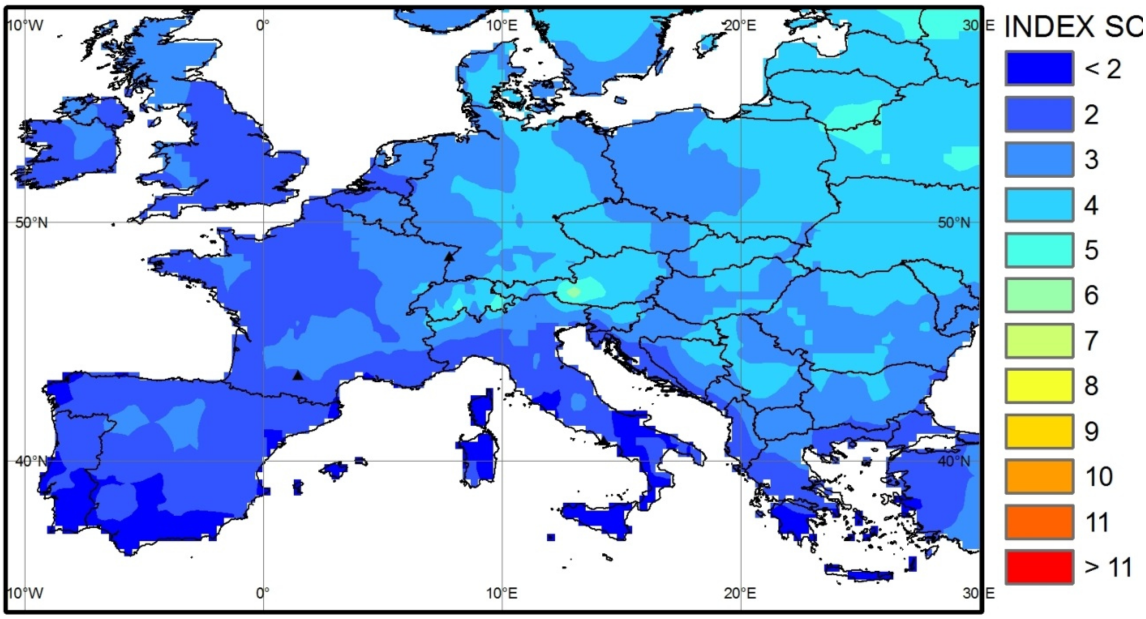


Figure 18: Winter Climatic Severities in Europe

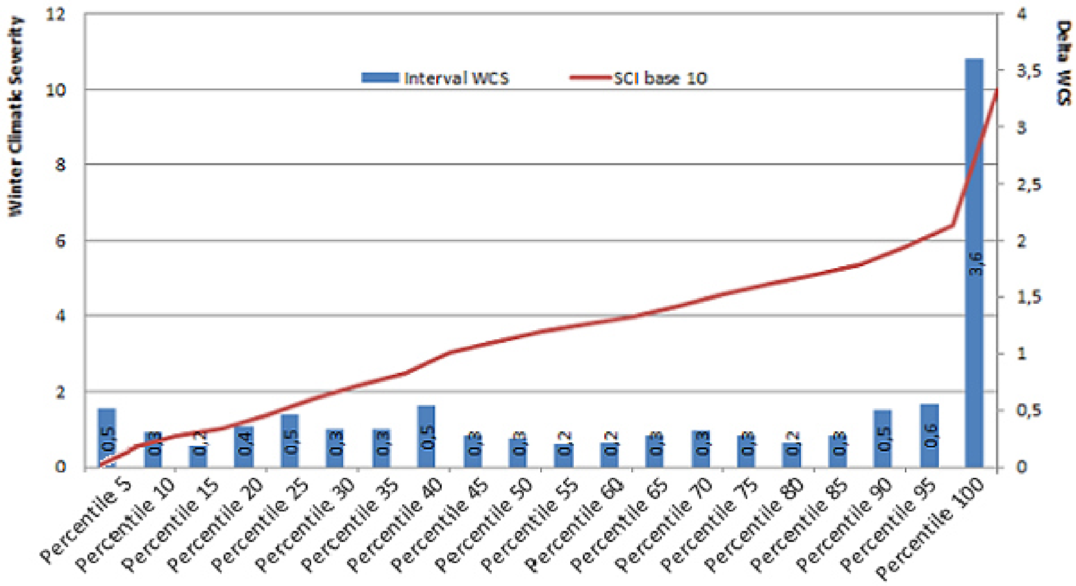


Figure 19: WCS's cumulative distribution and amplitude of the interval 5% Percentile

Figure 19 represents how the percentiles 5%, group the studied places based on a WCS division. It is easy to see that the intervals of each percentile has an average around 0,35 winter severity units of the total length of 10. (Both Winter and Summer Climatic Severities have being re-dimensioned after their calculation to an interval 0-10 that allows a more clear understanding of the severity's magnitudes).

Only the last defined interval is completely different to the others, and corresponds to Nordic locations and some central European climates with high altitudes. Comparing the distributions of the WCS and HDD presented in Figure 19 and Figure 15, the climatic severities create 19 city groups with similar parameter amplitude and a 20th one that contains a 5% of the cities with appreciable differences to the ones contained in the previous interval, while the 5% percentile distribution of the HDD does not maintain an homogeneous amplitude of the intervals.

3.1.2.2 Summer Climatic SeverityIndicator (SCSI)

In the same way as it was defined the WCS,it is developed the Summer Climatic Severity (SCS), weighting the influence of the solar radiation as an added parameter related to the gains that a building obtain from the external weather conditions during summer time.

It is calculated as follows:

Equation 6: Summer Climatic severity Index[171]

$$summerCSI = a \cdot Rad + b \cdot SCDD_{20} + c \cdot Rad \cdot WHDD_{20} + d \cdot Rad^2 + e \cdot WHDD_{20}{}^2 + f$$

a	b	c	d	e	f
$3{,}724 \cdot 10^{-3}$	$1{,}409 \cdot 10^{-2}$	$-1{,}869 \cdot 10^{-5}$	$-2{,}053 \cdot 10^{-6}$	$-1{,}389 \cdot 10^{-5}$	$-5{,}434 \cdot 10^{-1}$

Where:

- SCDD is the mean value of the cooling degree-days (June, July, August and September) with a base temperature of 20 °C.
- Rad the mean accumulated global radiation over a horizontal surface (in kWh/m2) for the same months.

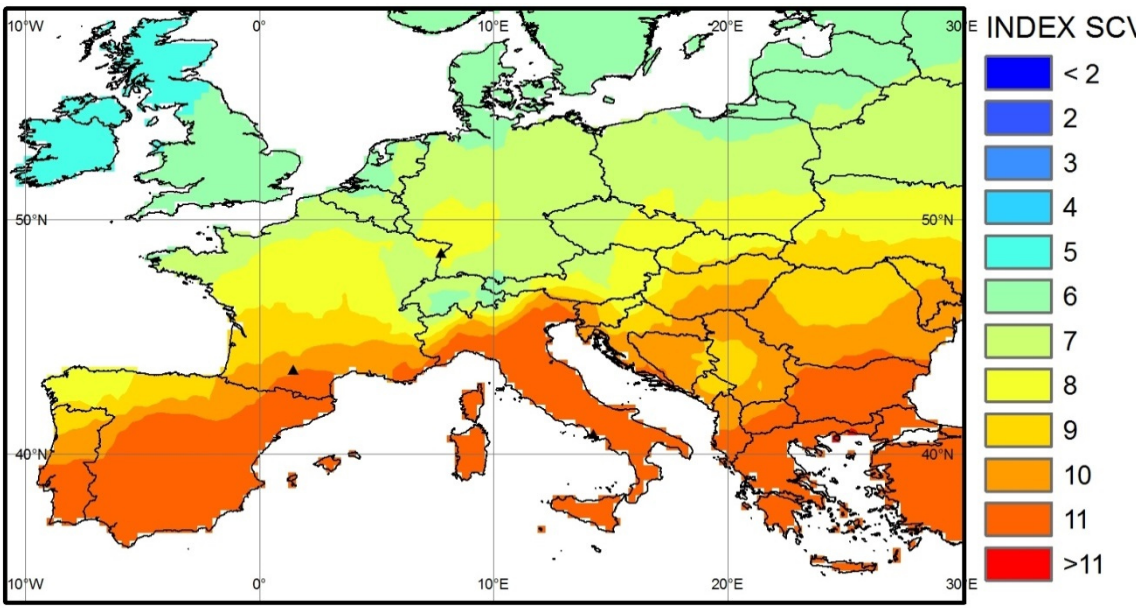


Figure 20: Summer Climatic Severities in Europe

Figure 20 and Figure 21 show in two different ways the distribution of the locations in base SCS's and shows that 0,25 points of the SCS 10 units interval, corresponds to 50 percent of the studied climatic conditions in summer case. It means that most of the European locations have a non-severe summer.

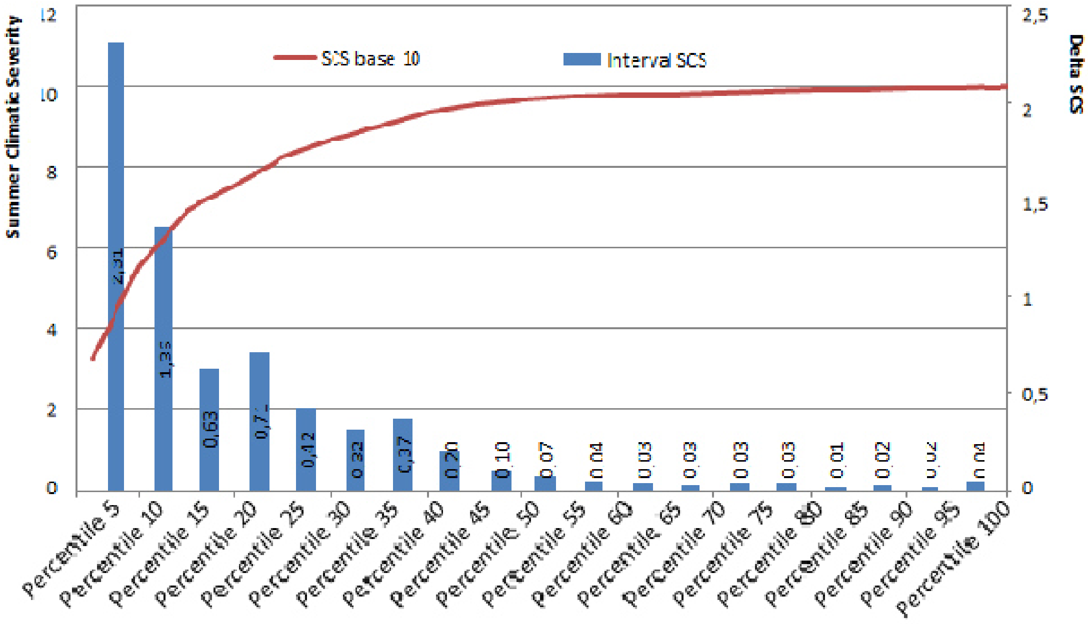


Figure 21: SCS cumulative distribution and amplitude of the interval 5% percentile

3.1.3 Enthalpy latent days index

Until this moment, it has been evaluated Europe in a base of 4 different parameters, two mainly for summer time and another pair for winter, that can relate the energies demanded by a building to the external temperature and radiation. Both weather characteristics affect sensible loads but it is also needed a new component to compute latent loads considering the humidity that will enter the occupied zones via infiltrations and ventilation

Huang et al 1986 and Sailor, 1998 introduced the use of enthalpy latent days (ELD) to incorporate the influence of humidity on energy consumption.

Enthalpy latent days are the summation of enthalpy differences between the outdoor air enthalpy h_0 and enthalpy at the outdoor air temperature θb and a reference absolute humidity x_b

Equation 7: Enthalpy latent days index

$$ELD = \frac{1}{24} \cdot \sum_{i=1}^{24} [h_0(\theta_0, x_0) \; - \; h_b(\theta_0, x_b)]$$

$$\theta_{0,i} > \theta_b \; ; \; x_{0,i} > x_b$$

Usually there is no latent load considered during heating seasons due to the inexistence of heating systems to control the air humidity out of the AHU installed in big office or public buildings, so it has not being considered for the following chapters of this work. Nevertheless, ELD is an important parameter to be considered in large building evaluation.

3.2 Application of CSI's to evaluate different building consumptions.

The scope of this approach is to compare two different methodologies for the assessment of building performances under modified outdoor conditions. As shown by Sánchez F et al., the great diversity of characteristics of the open spaces surrounding buildings can modify general energy balances and consequently affect thermal performance. One of the methods will relate the building demand to the Heating degree days and the other one to a modified Climatic Severity index.

The main equation for the CSI simplified model is defined as follows, including the modification to use the absolute (measured) value of Net Fossil Energy Consumed (NFEC) instead of CSI. NFEC and climate data (Rad, HDD) are derived from the measured and simulated values obtained from the specific building data loggers.

Equation 8: Correlation of the NFEC based on Climatic Severities Theory

$$NFEC = a \cdot Rad + b \cdot HDD + c \cdot Rad \cdot HDD + d \cdot Rad^2 + e \cdot HDD^2 + f$$

In Appendix A, there were compared the two methodologies (HDD vs. CSI) for the assessment of building performance under modified outdoor conditions when applied on three buildings, with different typologies, and located in three different climatic conditions, in order to obtain a method classification, based in accuracy, under a variety of parameters.

NFEC for each of the three buildings were computed comparing the two methodologies in three different time intervals, to study the capacity of both methods to discover inertial behaviour of the buildings. HDD's and CSI's evaluate the building consumes in a diary, weekly and monthly interval. For each one of the studied examples, exploded in Appendix A; the approximation which used radiation and temperatures fitted better the building behaviours than the one based on heating degree days (HDD)

In summary, the results obtained in the Appendix A, are exposed inTable 5.

- Building demands are more accurately calculated when solar radiation and external temperatures are computed in the study (CSI method), compared with the classical HDD ones.

- Increased evaluation times reduce the differences between methods for both well isolated buildings, ZUB and Cartif,.where control strategies are common for the complete building. TUC building presents an exception in the defined behaviour caused by the independent control of each one of its occupied zones and high time variability ofzone occupancy profiles.

Table 5: NFEC setting: Result comparison obtained with CSI method against HDD method for the three studied buildings and three different time intervals

CSI vs HDD (%)	ZUB Building (D)	TUC Building (Gr)	Cartif Building (Sp)
Daily	21.84%	14.01%	71.43%
Weekly	19.6%	24.76%	30.39%
Monthly	12.17	16.51	9.54

3.3 Conclusions of this chapter

It has been demonstrated the higher accuracies of CSI's method against the Degree Day one to obtain heating and cooling demands for three different buildings sited in three different climatic regions. Climate severity indexes contain more information than the degree day to evaluate the demand of a building and as an extrapolation of the result, to evaluate the different climatic zones in which Europe is divided to get a clear view of the different pairs, summer and winter severity.

For summer cases, it was demonstrated the importance also of the humidity in short time intervals. ELD method doesn't sum any improvement when applied in a monthly or seasonal base(Appendix A). This result allows dividing Europe in different summer zones based only on normal climatic severities (radiation and degree days) without considering latent disturbances.

This chapter divide Europe in 49 summer/winter indexes combinations that will be finally used to study the importance of the solar technologies.Table 6 and Table 7 define the interval limits for which the European distribution was done.

It should be noticed, that in order to have a 0-10 interval for both indexes, the resulting values of applying SCS (-8.977 to 1.16) and WCS (1.534 to 18.72) were lineary distributed in the interval. (Equation 6 and Equation 5, respectively).Negative values for SCS are caused by the use of coefficients for Spanish climatic conditions that are not expected so cold in the case of the Summer severity.

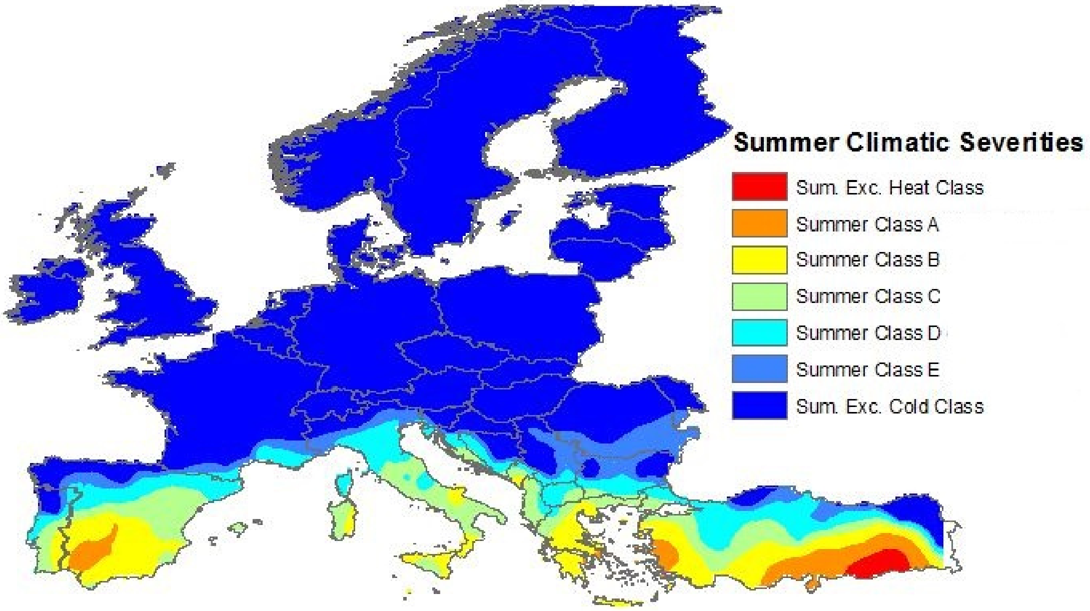


Table 6: Interval definition for Sumer Climatic Severities

	Minimum SCS value	Maximum SCS value
SCS Exc. Hot	0	2.42
Class A	2.43	7.07
Class B	7.08	8.54
Class C	8.55	9.25
Class D	9.26	9.66
Class E	9.67	7.79
SCS Exc. Cold	9.8	10

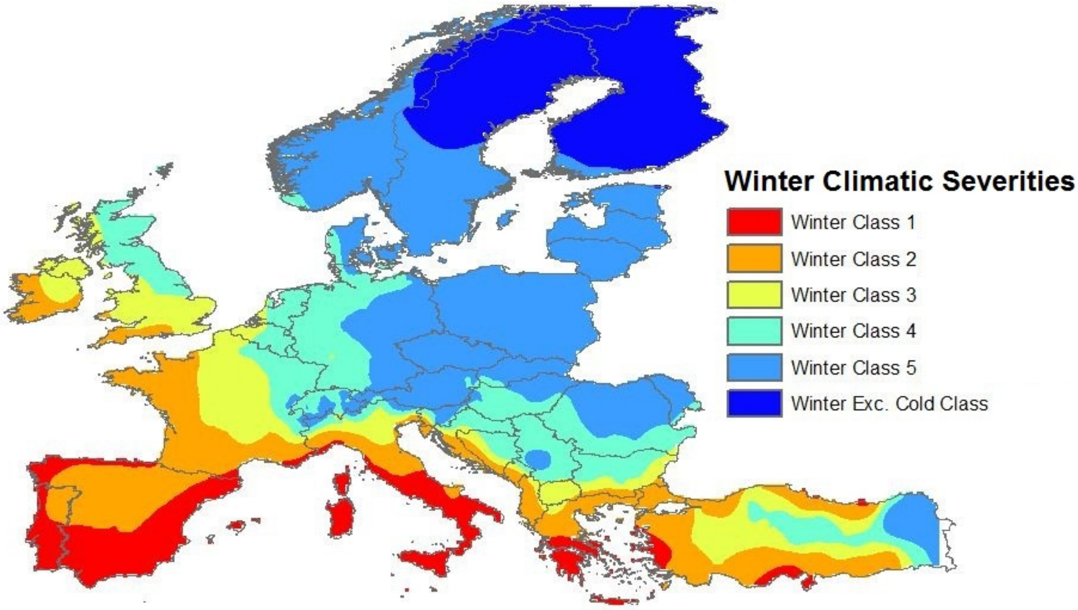


Table 7: Interval definition for Winter Climatic Severities

	Minimum WCS value	Maximum WCS value
WCS Exc. Hot	---	---
Class 1	0	1.53
Class 2	1.54	3.06
Class 3	3.07	3.96
Class 4	3.97	4.97
Class 5	4.98	7,64
WCS Exc. Cold	7.65	10

Table 8 and Table 9describe numerically the final distribution of the European Climates based on a Severity Index Classification, by number of evaluated weather stations and percentage of the total studied climatic conditions placed in each category.

Table 8: Number of European Cities from the total studied ordered by WCS and SCS index

		Summer Climatic Severities's						
		Exc. Hot	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Hot	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Class 1	*5*	28	21	10	1	2	*6*
	Class 2	*3*	15	12	18	7	7	*11*
	Class 3	*0*	0	11	6	16	13	*27*
	Class 4	*0*	0	0	7	14	7	*45*
	Class 5	*0*	0	0	2	6	14	*51*
	Exc. Cold	*0*	*0*	*0*	*0*	*0*	*0*	*10*

Table 9: Percentage of studied cities classified by climatic severity indexes

		Summer Climatic Severities's						
		Exc. Hot	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Hot	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
	Class 1	*1,33%*	7,47%	5,60%	2,67%	0,27%	0,53%	*1,60%*
	Class 2	*0,80%*	4,00%	3,20%	4,80%	1,87%	1,87%	*2,93%*
	Class 3	*0%*	0%	2,93%	1,60%	4,27%	3,47%	*7,20%*
	Class 4	*0%*	0%	0%	1,87%	3,73%	1,87%	*12,00%*
	Class 5	*0%*	0%	0%	0,53%	1,60%	3,73%	*13,60%*
	Exc. Cold	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*2,67%*

Appendix B sets into the proposed classification, weather parameters as HDD; CDD,CSI, Dry bulb temperatures, Global radiation on horizontal plane along the year, etc.

4. Building definition

The way the building was simulated, it is done on the base of solving in hourly steps all the physical equations that affect building demands, considering one unique occupied zone with a determinate geometry, air volume, internal thermal capacities, … working under predefined external weather conditions and internal scheduled loads. A solver based on a mix of transference functions and thermal balances via conduction, convection and radiation equations lately exposed, was developed to obtain an approximation of the building demands along the year. This work does consider a single zone building as the usual cooling and heating domestic devices only deliver energy to one private final client.

The main difficulty associated to the building thermal simulation, comes through the cooling demand evaluation. While in case of heating every internal gain is positive for the system, occupancy loads, electrical equipment, lighting, contribute to increase the thermal level and as a consequence, decrease the heating demand, during the cooling periods all that loads become and added effort to the air conditioning systems in their effort to keep temperature and humidity controlled in-between determinate boundaries that assure internal thermal comfort. This comfort is controlled in the domestic building market during winter time mostly with a unique variable that is the internal dry air temperature, while during the cooling season two measurements are needed to control sensible and latent loads, dry air temperature and humidity. Sensible loads increase the air temperatures while latent ones affect to the amount of steam that the air mass contains. (Human body reacts to relative humidity values out of the interval 35 to 65 percent, where out of comfort conditions are defined. All energytransferences are calculated to satisfy the temperature and humidity values settled for the occupied zones to assure maintenance of occupant thermal comfort.

In this work, it has not been considered other different comfort types, as can be air quality, thermal asymmetries or draft effects created by the air movement that mostly are not evaluated in the domestic market.

4.1 Constructive description of the studied building

A building model has been defined for the development of the evaluation tool with two different objectives:

1. To evaluate a common building, insulated enough for Europe, in different European climates

2. To allow the possibility of commonly optimize a building and its correspondent solar thermal system a determinate location, assuring the simulation tool user a wide enough possibilities set to test different orientations, materials, insulation, windows, glasses…

Building shapes are presented in a schematic way in Figure 22. The studied building has walls oriented every 45 degrees, beginning from the south orientation (0º), and for each one of the surfaces, it can be defined the wall area, the window percentage for that wall, and the coefficients that define walls and glasses to be simulated (emissivity's, g- factors, U's, etc…). Floors and roofs can be defined separately allowing the definition of multi-storey buildings based in a repeated floor area. Further data as the hourly occupancy rates and loads scheduling, are also defined to be lately able of obtaining valuable simulation results.

The initial building size, used for the simulation, was chosen from the values published by INE (Spanish Statistic National Institute), that describe as the typical Spanish family house a 93.75m^2 living area space usually distributed in three rooms plus kitchen and bathroom. The typical occupancy number is four people that work or go to school until around 18:00 during the working week and spent more time at home Saturdays and Sundays.

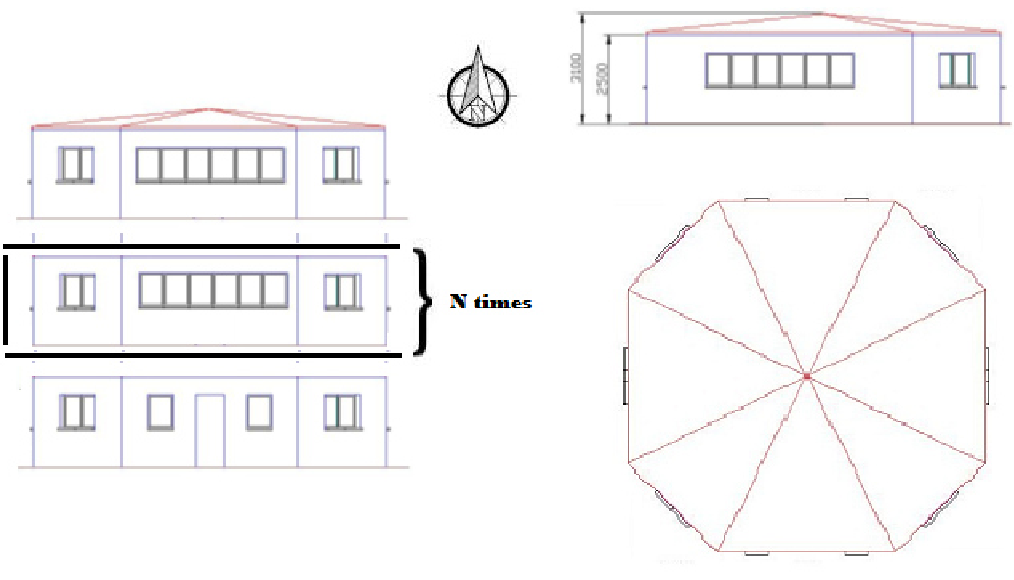


Figure 22: Schematic view of the simulated building

As a resume, the characteristics of the simulated building are:

- Single floor occupied space with 2,5 meters as constant height
- Ground contact and roof existence (options included in the simulation tool to allowthe calculation of intermediate floors or ground floors in multi-storey buildings
- Occupants (Hourly occupancy profile) with a metabolic rate close to 1met (resting or low work profile) [ISO 8996] and each one of them dressed at home with 1 clo level clothing [ISO9920]
- Domestic Hot Water profile defined in Jordan U and Vajen, K, 2001.
- Hourly electrical consumes defined.
- External walls defined by their orientation, % windows, thermal transmittances, wall emissivity, glass solar factor, external convection coefficients…(Table 10 and

- Table 11)
- Summer defined from May, 15th to September, 15th
- Comfort temperatures to be satisfied:
- Summer temperature 25ºC
- Winter temperature 21ºC
- Humidity control during summer time limited by 50% (relative humidity)
- Fix ventilation rate: 0.5 air renovations by hour

Table 10: Areas and window Percentage by external wall of the simulated building

	Area [m2]	**%Windows**
North Surface	36	20
North East Surface	0	0
North West Surface	0	0
East Surface	12	20
West Surface	12	20
South-East Surface	12	20
South-West Surface	12	20
South Surface	12	20
Roofs Horizontal	100	0

Table 11: Simulation parameters related to the external surfaces

Average U Walls (w/o windows)	0,5	W/m2K
Average U Windows	1	W/m2K
Average U Roofs	0,35	W/m2K
Average U Floor	0,45	W/m2K
Average Glass Solar factor (g)	65	%
Walls Emissivity factor	0,6	
Roofs Emissivity factor	0,7	
External convection coefficient	16	W/m2K

4.2 Building loads and equations.

Maintaining the internal thermal comfort for the occupants, controlling temperatures and humidity levels as a function of the internal activity is the aim of calculating all the external loads occurring for a determinate time period on a defined controlled occupied zone.

Every phenomena that modifies internal temperatures (sensible load) or the amount of water vapour contained in the air (latent load) generates a thermal load which sum is defined as total load.

As a definition, a thermal load is the powerand water vapour, communicated to the ambient air of a determinate zone. Cooling loads are heating power that should be removed from the space to maintain a desired internal air temperature, while the heating loads are opposite.

This concept differs from the energy needs or demands that are defined as energies supplied (by a heating/cooling system) in order to raise/lower the internal temperature to the required minimum/maximum level (the set-point for heating/cooling);[Ashrae fundamentals]

For the calculation of this chapter it has been followed the methodology proposed in *EN ISO 13790*.

It wasconsidered,as problem simplification, an ideal energy distribution system that delivers to the thermal zone the exact energy that maintains a required thermal level. In reality the delivering system are not perfect, so they don't have a 100% efficiency to communicate the thermal energy to the zones, and the control systems are never provided with a "perfect" forecast strategy that fit the energy delivering with the actual and future demands.

Example 1: Heating is provided in time stepτ=0 to keep the temperature controlled in a time instant, but the sun provides an added load that overheat the ambient for the timestepτ=n+1. In this case the heating system delivered more energy that the needed one.

Example 2: The sum of all thermal loads for a determinate winter hour determines that the occupied zones need of a number of watts to keep 21ºC comfort condition. This number of watts is the building demand for the "time step i", and the next simulation timestep begins with 21ºC of initial air temperature (the heat demand was satisfied by the "infinite capacity" heating system installed). In "time step i+1" the process is done again but this time the result was positive, the house doesn't need energy to reach the 21ºC. In this situation the building demands no energy and the initial temperature for time i+2 is higher than the 21ºC defined as winter comfort set point. It must be said that the building is not allowed to work in heating and cooling mode during the same day, so it is accepted the overheating and overcooling of the zones during those periods.

Building loads can be related in two different groups, exploded in subgroups as described in Table 12. All building loads, independently of the calculation method used, were considered lineal in short time intervals as the ones used for the simulation (hourly base steps). The sum of the loads for each time step defines the energy demand and the thermal state of the building, determining the initial thermal parameters for the next calculation time. The loads are constant between time steps.

As seen in the last column of Table 12, out of the division between External/Internal or Sensible/latent loads, it is also described the need of simulating inertial effects caused by materials energy storage. Some of the cases are named as "Possible" remarking the feasibility of their calculation, but as the simulation time that it was considered in this work is one hour time step and the delays introduced by those loads are shorter, it was only calculated the delays introduced by walls energy storage. These calculations will be done with the use of Transfer Functions introduced by Mitalas while the rest of the loads will be solved directly with Heat Energy equations and mass balances for the load hour of interest.

Table 12: Matrix with the thermal loads calculated for building simulation

<table>
<tr><th>Load</th><th></th><th>Sensible</th><th>Latent</th><th>Inertial effects to be calculated</th></tr>
<tr><td rowspan="4">External</td><td>Transmitted through opaque external walls:
• Based on temperature differences
• Solar Radiation Collected</td><td>Yes</td><td>No</td><td>Needed</td></tr>
<tr><td>Transmitted through semi-transparent walls</td><td>Yes</td><td>No</td><td>No</td></tr>
<tr><td>Thermal bridges</td><td>Yes</td><td>No</td><td>Possible</td></tr>
<tr><td>Ventilation & Infiltration</td><td>Yes</td><td>Yes</td><td>No</td></tr>
<tr><td rowspan="4">Internal</td><td>Occupants</td><td>Yes</td><td>Yes</td><td>No</td></tr>
<tr><td>Engines and Machinery</td><td>Yes</td><td>Yes</td><td>Possible</td></tr>
<tr><td>Illumination</td><td>Yes</td><td>No</td><td>No</td></tr>
<tr><td>Own climate control facility (Heating and Cooling)</td><td>Yes</td><td>No</td><td>Possible</td></tr>
</table>

The transfer function method (TFM) (Mitalas 1972) applies a series of weighting factors, or conduction transfer function (CTF) coefficients to the various exterior opaque surfaces Energy Transmitted through opaque external walls

For the calculation of this chapter, there were considered the loads passing through the external walls, floors and roofs. These two last options only in case the user has ticked them to simulate a complete building and not only an inner floor, or the basement or the last floor of a multi-storey residential building.

The four effects calculated for this work that affects the energy flows are:

- Applied to walls and roofs:
    - Solar energy collected through opaque envelope
    - Thermal radiation emitted to the sky
    - Energy transmitted to the ambient
- Applied to floors or buried walls:
    - Energy transmitted to the ground

The hourly sum of these four values, for the determinate internal temperature obtained in that instant of time defines the total energy passing through the envelope.

4.2.1.1 Solar energy collected through opaque envelopes

The heat flow by solar gains that reaches a building element k, $\Phi_{sol,k}$expressed in watts is given by Equation 9

Equation 9: Incident solar gains on a building element k [57]

$$\Phi_{sol,k} = \mathrm{F}_{sh,ob,k} \cdot \mathrm{A}_{sol,k} \cdot \mathrm{I}_{sol,k} - \mathrm{F}_{r,k} \cdot \Phi_{r,k}$$

Where:

Fsh,ob,k: is the shading reduction factor for external obstacles for the solar effective collecting area on the surface k

***Asol,k*:** is the effective collecting area of surface k with a given orientation and tilt angle, in the considered space [m^2]

Isol,k: is the total solar irradiance, the mean energy of the solar irradiation over the time step of the calculation , per sqm of collecting effective collecting area[W/m^2]

Fr,k is the form factor between the building element and the sky

Φr,k is the extra heat flow due to thermal radiation to the sky from building element k [W]

In order to apply the Equation 9 to a building, it must be also defined which is the effective radiation area exposed to the sun with the following equation.

Equation 10: Effective collecting area[57]

$$A_{sol,k} = \alpha \cdot R_{se} \cdot U_c \cdot A_c$$

Where:

α=dimensionless absorption coefficient for solar radiation of the opaque part

R_{se}=is the external surface heat resistance of the opaque part [m2/kW]

U_c=thermal transmittance of the opaque part

A_c= is projected area of the opaque part

The combination of both equations permits the evaluation of the hourly radiations collected by roofs and walls. These radiations are instantaneous values whose influence on the occupied zones must be lately calculated due to the inertial effects introduced by storage capacities of the envelopes.

4.2.1.2 Thermal radiation emitted to the sky

In the same way that the building receives energy from the sun along daytime; there is a radiation of the building to the surroundings caused by the thermal level of the extern surfaces.

Equation 11: Thermal radiation emitted to the sky [57]

$$\Phi_r = F_r \cdot R_{se} \cdot U_c \cdot A_c \cdot h_r \cdot \Delta\theta_{er}$$

Where:

F_r=View factor between walls and the sky (1-0.5 for unshaded horizontal roofs and walls respectively)

R_{se}=is the external surface heat resistance of the opaque part [m2/kW]

U_c=thermal transmittance of the opaque part [W/ m2K]

A_c= is projected area of the opaque part [m^2]

h_r= is the external radiative heat transfer coefficient, [W/ m2K]

$\Delta\theta_{er}$= is the average difference betwwen the external air temperature and the apparent sky temperature [ºC]

The external radiative heat transfer coefficient, hr, expressed in watts per square metres per kelvin, may be approximated as given by:

Equation 12: Radiative heat transfer coefficient [57]

$$h_r = 4 \cdot \varepsilon \cdot \sigma \cdot (\varphi_{ss} + 273)^3$$

Where:

ε=is the emissivity for thermal radiation of the external surface

σ=is the Stefan-Boltzmann constant= 5,67*10-8 W/[m^2K^4]

φ_{ss}=is the arithmetic average of the surface temperature and the sky temperature expressed in Celsius

It is needed to fulfil in Equation 12, the emissivity factor to the sky and sky temperatures that are values not directly available inside climatic data files. There are some approximations in the bibliography , that fixes hr, to a value equal to 5 times the emissivity W/(m2K), which corresponds to an average temperature of 10 K, and a sky temperature correlation that fixes the temperature difference with the ambient one to 9 Kelvin in sub-polar areas, 13 Kelvin in the tropics and 11Kelvin in intermediate zones, but when compared the results with other bibliographical references found based on equations as Clark and Allen, 1978 , the values does not fit , so both temperature and sky emissivity are being calculated following:

Equation 13: Sky emissivity

$$\varepsilon_{sky} = 0.711 + 0.005 \cdot T_{dew} + 0.000073 \cdot {T_{dew}}^2 + 0.013 \cdot \cos(m) + 0.000012 \cdot (P_{atm} - P_0)$$

Where:

T_{dew}=is the Dew Point temperature [K]

m=is the moment of the day (i.e: 0 hours is 0 and 23:59 corresponds to 1)

P_{atm}=is the atmospheric pressure [bar]

P_0=is the atmospheric pressure at the see level [bar]

Equation 14: Sky Temperature [K]

$$T_{Sky} = T_{dry} \cdot (\varepsilon_{sky} + 0.8 \cdot (1 - \varepsilon_{sky}) \cdot C_{sky})^{0.25}$$

Where:

T_{dry}=is the ambient Dry Air Temperature [K]

ε_{sky}=is the sky emisivity

C_{sky}=Sky coverage (% of the sky covered with clouds)

4.2.1.3 Energy transmitted to the ambient via convection and conduction effects

For the calculation of energy flows passing through massive walls it was used a method based on Transfer functions as it is the response factor method form Mitalas, which delivers accurate estimations of the building loads because it considers the transient nature of heat transmission effects. The proposed method uses the values of energy flows through the walls when applied a triangular temperature evolution, *2 hours amplitude and unitary size*, to one of the wall sides as represented in Figure 23

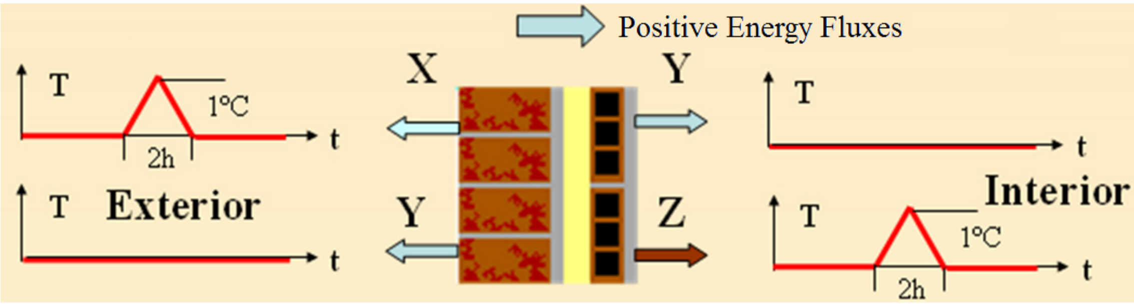


Figure 23: Representation of temperature excitation and superficial heat flows. (Source Soto)

This easy technique takes into account the important parameters affecting the building energy flows. Heat gains received by a constant temperature ambient are determined by the building physical description, climatic data and internal loads.

It is defined:

- X(j) : Heat energy flow entering the wall (time step i) through the external wall face when a triangulartemperature excitation is externally applied. (W/m2)
- Y(j) : Heat energy flow exiting the wall (time step i) through the internal wall face when a triangular temperature excitation is externally applied. (W/m2)
- Z(j) : Heat energy flow exiting the wall (time i) through the internal wall face when a triangular temperature excitation is internally applied. (W/m2)

Figure 24 represent typical values for the response factors. The determination of those coefficients can be done in an analytical form on the base of densities, heat capacities, conductivities and layer depth for each one of the different material layers that compose the wall.

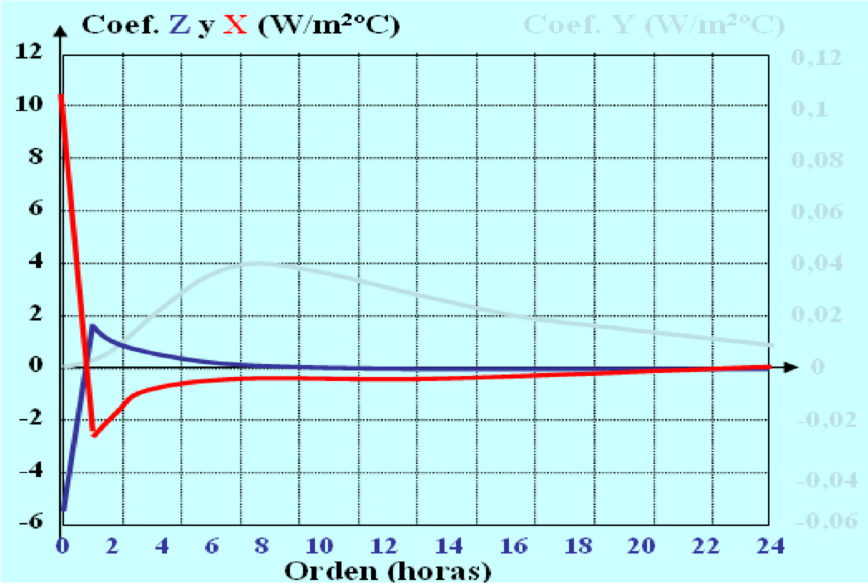


Figure 24: Responding Factors X,Y,Z .(Source Soto)

It can be determined the heat flow transferred to the studied wall (partly via convection and partly via radiation) applying Equation 15 and it is graphically represented in Figure 25

Equation 15: Heat flows through a wall

$$q_{cerr}(n) = \sum_{j=0}^{\infty} T_{ext}(n-j)Y(j) + \sum_{j=0}^{\infty} T_{\text{int}}(n-j)Z(j)$$

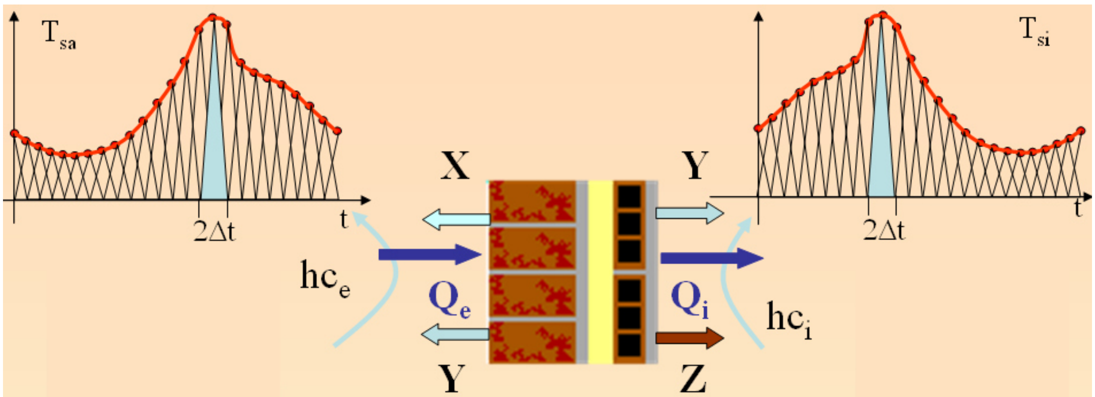


Figure 25: Sum of the triangle functions that compose real thermal excitations

As an interesting particularity of the Response Factors, that It has been used to calculate different wall's U, it can be affirmed that the sum of each one of the response factors is coincident in absolute value with the stationary Global Transmission Factor of the walls (U) as described in Equation 16

Equation 16: Relations among Global heat transfer coefficient and Response Factors

$$U = \sum_{j=0}^{\infty} Y(j) = -\sum_{j=0}^{\infty} Z(j)$$

4.2.1.4 Energy transmitted to the ground

This kind of energy transmission is a special case of the previous 0 where there are no quick variations of the internal temperatures, the zone is conditioned, or the external one, because ground temperatures do not suffer appreciable changes within time intervals around 1 hour (simulation time step) or one day (Response factor period considered for a wall in this work), simplifying this case calculation to the described Equation 17

Equation 17: Energy transmission through the floors to the ground [57]

$$q_{ground} = U_{floor} \cdot A \cdot (T_{zone} - T_{ground})$$

Where:

q_{ground} = rate of heat transfer [W]
U_{floor} = Global transmission factor of the floors[W/m²K]
A= heat transfer floor area [m²]
T_{zone} = internal zone temperature [°C]
T_{ground} = Ground temperature [°C]

Ground temperature was defined following the Kasuda equation that models the vertical temperature distribution of the ground given the mean ground surface temperature for the year, the amplitude of the ground surface temperature for the year, the time difference between the beginning of the calendar year and the occurrence of the minimum surface temperature, and the thermal diffusivity of the soil.

The European normative that calculates ground heat exchanges, divide them in two terms, a stationary part exposed in Equation 17and a transitory, calculated with the use of transference functions and response factors, to be applied on a one meter depth wall, completely insulated on its lower part. In this way, the energy losses are calculated by the stationary component, and both energy storage and release are calculated by the transitory element. In the studied cases, internal building temperatures are always around the desired set points, what suggests the nearly inexistence of transitory effects, and permits the authors a calculation simplification by studying only stationary effects.

Equation 18: Yearly ground temperature distribution

$$T_{ground}^{depth} = T_{mean} - T_{amp} \cdot e^{-depth\cdot\left(\frac{\pi}{365\alpha}\right)^{0.5}} \cdot cos\left\{\frac{2\pi}{365} \cdot \left[t_{now} - t_{shift} - \frac{depth}{2} \cdot \left(\frac{365}{\pi\alpha}\right)^{0.5}\right]\right\}$$

Where:

T_{ground}^{depth}**=** Ground temperature for a determinate depth and hour of the year. [ºC]

T_{mean} = Mean surface temperature (avg. air temperature can be an accepted approximation) [°C]

T_{amp} = Amplitude of surface temperature (max. air temperature minus mean air temperature) [ºC]

Depth = Depth below the surface [m]

α= Thermal diffusivity of the ground (soil) [m^2/day]

t_{now} = Current day of the year [day]

t_{shift} = Day of the year corresponding to the minimum surface temperature [day]

4.2.1.5 Study of the Energy Transmitted through opaque external walls around Europe

For the determined house characteristics, developed in Table 10 andTable 11, it was evaluated the importance of the external weather conditions.

The structure of the following nine matrices (Table 13to Table 21) is common to facilitate the understanding of the presented data.

First of all the sum of all the energy transmission through the external envelope presents an order of magnitude about the total energy passing through that walls. Table 13, Table 16 and Table 19 represents the sum of those energies for different studied periods, complete year, winter season and summer season.

Table 17 and Table 20 represent the amount of energy gain from the sun via external walls and roofs. (It can be seen that it is always a positive number with absolute number) and at last Table 15, Table 18 and Table 21 representing the energy loses to the sky.

When evaluating those tables, it can be noticed:

Yearly evaluation:Energy losses due to temperature difference lead the transference processes along the year

In every studied case, solar collected radiation through opaque external surfaces has similar magnitude as the energy lost to the sky, being this last concept always a little bit higher. This also means that to achieve the values presented inTable 13, energy lost by temperature difference is much higher than the energy collected directly through transparent elements (20% of the external wall surface in case of inexistence ofexternal shadows on the façade)

Table 13: Yearly energy losses through the Envelope[Wh/m^2]

Envelope Yearly losses		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-4048,10	-4691,78	-5455,74	-6783,89	-6213,92	-6579,31	-7074,86
	Class 2	-5790,44	-6157,42	-6845,40	-7609,15	-8486,33	-9256,08	-9922,67
	Class 3	---	---	-8054,31	-8291,77	-9207,23	-10144,87	-10611,51
	Class 4	---	---	---	-8909,03	-9544,56	-9646,16	-10674,19
	Class 5	---	---	---	-10001,58	-11504,34	-11668,87	-10994,19
	Exc. Cold	---	---	---	---	---	---	-13428,28

Table 14: Yearly energy solar gains through opaque external walls[Wh/m^2]

Yearly Solar Delayed gains		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	3436,86	3333,95	3217,12	2980,36	2668,02	3018,12	2576,15
	Class 2	3458,69	3163,91	2895,24	2824,29	2576,72	2603,54	2474,16
	Class 3	---	---	3040,90	2878,16	2367,45	2047,16	2338,56
	Class 4	---	---	---	2755,28	2482,63	2324,29	2225,14
	Class 5	---	---	---	3030,27	2374,10	2158,51	2281,06
	Exc. Cold	---	---	---	---	---	---	2007,09

Table 15: Yearly energy losses to the sky through the opaque external walls [Wh/m^2]

Energy Lost to the Sky		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-4010,53	-5213,39	-5286,69	-4771,97	-3198,19	-5248,43	-4340,73
	Class 2	-5243,46	-4976,47	-4891,79	-4563,41	-5201,08	-5637,31	-5785,46
	Class 3	---	---	-5051,85	-5180,33	-4708,78	-5014,50	-5358,56
	Class 4	---	---	---	-5109,21	-4909,54	-4459,35	-4775,80
	Class 5	---	---	---	-5850,33	-5545,91	-5525,85	-4940,53
	Exc. Cold	---	---	---	---	---	---	-5275,38

Winter evaluation:As it happened in the yearly evaluation, energy losses based in temperature difference processes are leading the transferences to the environment.

In every studied case the radiation collected is smaller than the energy losses via radiation to the sky. The difference between them is not anymore small, as it happened in the yearly evaluation. In warmer places the absolute value of the "losses to the sky" are twice the sun collected energy.

Table 16: Winter energy losses through the envelope[Wh/m^2]

Envelope Winter		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-4290,53	-4438,13	-4806,59	-5804,82	-5366,75	-4992,75	-5383,68
	Class 2	-6004,08	-5822,39	-6129,14	-6548,02	-6797,23	-7278,04	-7744,52
	Class 3	---	---	-7140,57	-7226,07	-7444,01	-7777,07	-8472,69
	Class 4	---	---	---	-7779,62	-7908,23	-7896,75	-8560,46
	Class 5	---	---	---	-8492,49	-9314,50	-9312,78	-8873,82
	Exc. Cold	---	---	---	---	---	---	-10793,05

Table 17: Winter sum of the solar gains through opaque external walls[Wh/m^2]

Solar Delayed Winter		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1866,65	1821,64	1742,24	1564,23	1436,49	1596,23	1366,67
	Class 2	1854,66	1664,94	1512,37	1453,64	1336,72	1328,10	1257,15
	Class 3	---	---	1562,44	1481,15	1209,64	1006,81	1161,26
	Class 4	---	---	---	1432,97	1275,51	1159,86	1111,96
	Class 5	---	---	---	1497,00	1233,69	1060,22	1151,64
	Exc. Cold	---	---	---	---	---	---	914,54

Table 18: Winter sum of the energy losses to the sky by the opaque external walls[Wh/m^2]

Lost to the Sky Winter		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-3342,21	-3864,29	-3800,63	-3285,15	-2205,72	-3456,28	-2793,08
	Class 2	-4639,72	-3864,10	-3631,54	-3370,12	-3731,04	-4094,04	-4173,83
	Class 3	---	---	-3641,12	-3701,46	-3501,46	-3682,77	-3909,16
	Class 4	---	---	---	-3834,48	-3633,95	-3383,80	-3511,87
	Class 5	---	---	---	-4157,98	-4108,36	-4091,12	-3621,50
	Exc. Cold	---	---	---	---	---	---	-4014,56

<u>Summer evaluation:</u>Summer time differs with the previous two cases. There are two climatic zones with positive gains through the envelope.(Exc.Heat1 and Exc. Heat2). The collected energy during daytime compensates in every case the night cooling radiated to the sky. For most of the classified clima groups, total energy losses by transmission maintains the prevalence on the energy transportation.

Table 19: Summer energy losses through the envelope[Wh/m²]

Envelope Summer		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	242,43	-253,65	-649,16	-979,07	-847,18	-1586,55	-1691,18
	Class 2	213,64	-335,03	-716,26	-1061,13	-1689,10	-1978,03	-2178,15
	Class 3	---	---	-913,73	-1065,69	-1763,22	-2367,80	-2138,82
	Class 4	---	---	---	-1129,41	-1636,34	-1749,41	-2113,73
	Class 5	---	---	---	-1509,09	-2189,84	-2356,09	-2120,37
	Exc. Cold	---	---	---	---	---	---	-2635,23

Table 20: Summer sum of the solar gains through opaque external walls[Wh/m²]

Solar Delayed Summer		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1570,21	1512,31	1474,87	1416,12	1231,53	1421,89	1209,48
	Class 2	1604,03	1498,96	1382,86	1370,65	1239,99	1275,45	1217,01
	Class 3	---	---	1478,46	1397,01	1157,82	1040,35	1177,30
	Class 4	---	---	---	1322,31	1207,12	1164,43	1113,18
	Class 5	---	---	---	1533,27	1140,41	1098,29	1129,42
	Exc. Cold	---	---	---	---	---	---	1092,55

Table 21: Summer sum of the energy losses to the sky by the opaque external walls[Wh/m²]

Lost to the Sky Summer		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-668,32	-1349,10	-1486,07	-1486,81	-992,47	-1792,15	-1547,65
	Class 2	-603,74	-1112,37	-1260,24	-1193,30	-1470,05	-1543,26	-1611,63
	Class 3	---	---	-1410,73	-1478,88	-1207,32	-1331,74	-1449,41
	Class 4	---	---	---	-1274,74	-1275,59	-1075,55	-1263,93
	Class 5	---	---	---	-1692,35	-1437,55	-1434,73	-1319,03
	Exc. Cold	---	---	---	---	---	---	-1260,81

4.2.2 Energy transmitted through glazed elements.

The effective solar collecting area of a glazed envelope element (e.g. a window), α_{sol}, expressed in square metres, is given by Equation 19

Equation 19: Effective solar collecting area of glazed elements[m^2] [57]

$$\alpha_{Sol} = F_{sh,gl} * g_{gl} * (1 - F_F) * A_{w,p}$$

Where:

$F_{sh,gl}$ Shading reduction factor for movable shading positions

g_{gl} Total solar energy transmittance of the transparent part of the element

F_F Frame area fraction, ratio projected frame area vs. overall projected area of the glazed element

$A_{W,p}$ Overall projected area of the glazed element [m^2]

In this work, in order to have a general evaluation method for a determinate building, it has not being considered a shading reduction factor that mostly is associated to the personal use of them or the control implemented as a function on the existence radiation for the determinate Latitude/longitude. Also it has not been considered the radiation reduction due to the shadows created by other neighbour buildings/volumes.

In the following Table 22, Table 23 and Table 24 it is described the energy amounts passing through the glazed elements to the occupied zones. This input is considered a positive load delivered to the building without any delay effect due to the irradiative nature of the sun rays.

Table 22: Total solar energy transmitted through glazed elements[Wh/m^2]

Solar Total load		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	7886,74	7720,77	7612,17	7155,23	6604,92	7277,04	6449,26
	Class 2	7997,00	7430,27	6977,25	6899,27	6336,20	6338,84	6062,88
	Class 3	---	---	7295,28	7020,61	5960,40	5219,66	5762,79
	Class 4	---	---	---	6792,21	6271,76	5907,76	5589,18
	Class 5	---	---	---	7267,10	6124,31	5612,41	5838,84
	Exc. Cold	---	---	---	---	---	---	5484,28

Table 23: Winter solar energy transmitted through glazed elements[Wh/m^2]

SunTotLoad Winter		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	4678,68	4587,06	4474,24	4079,72	3777,19	4162,01	3638,89
	Class 2	4706,06	4258,60	3935,26	3835,16	3520,06	3462,09	3286,68
	Class 3	---	---	4077,86	3897,28	3252,97	2722,78	3049,05
	Class 4	---	---	---	3807,24	3450,50	3153,23	2980,25
	Class 5	---	---	---	3958,06	3401,39	2941,22	3143,84
	Exc. Cold	---	---	---	---	---	---	2686,70

Table 24: Summer solar energy transmitted through glazed elements[Wh/m^2]

SunTotLoad Summer		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	3208,07	3133,71	3137,94	3075,51	2827,73	3115,03	2810,37
	Class 2	3290,94	3171,67	3041,99	3064,10	2816,14	2876,75	2776,20
	Class 3	---	---	3217,42	3123,33	2707,43	2496,87	2713,74
	Class 4	---	---	---	2984,97	2821,25	2754,54	2608,93
	Class 5	---	---	---	3309,03	2722,92	2671,20	2695,00
	Exc. Cold	---	---	---	---	---	---	2797,59

4.2.3 Ventilation and infiltration heat transfer

Air flows introduced into the occupied zones caused by voluntary (ventilation) or involuntary causes (infiltration) leads to an increased amount of energy needed to adequate the incoming air to the pre-set comfort parameters. In winter case, those effects mostly increase the heating demands because the air returned to the environment was previously heated to reach the demanded 21ºC ($\theta_{int,set,H}$).

It is supposed that the ambient temperatures during the winter season stays most of the time under 21ºC while during summer, the temperature asymmetries between day and night causes overheating during the sunny hours and cooling during the rest of the day. 26ºC is the settled temperature for summer($\theta_{int,set,C}$).

In order to simplify the problem, it was not included in the calculation air ventilation proceeding from air exchangers or Air Handling Units (AHU's) that would introduce in the formulas further exchange efficiency parameters. This simplification is easily justifiable on the practically inexistence of treated air systems in the domestic market out of the Passive building topology, that is not the studied case.

Infiltration gains depend on the tightness of the installed windows and it was considered constant along the study independently of the location.

Equation 20: Ventilation formula for heating periods[57]

$$Q_{ven,H} = H_{ve,adj} * \left(\theta_{int,set,H} - \theta_0\right)$$

Equation 21: Ventilation formula for cooling periods [57]

$$Q_{ven,C} = H_{ve,adj} * \left(\theta_{int,set,C} - \theta_0\right)$$

Where:

$H_{ve,adj}$ is the overall heat transfer coefficient by Ventilation [W/K]

$\theta_{int,set,C}$ Internal temperature set point programed for the cooling season. [ºC]

$\theta_{int,set,H}$ Internal temperature set point programed for the heating season. [ºC]

The ventilation heat transfer coefficient is calculated as follows [57]:

Equation 22: Overall heat transfer coefficient by Ventilation

$$H_{ve,adj} = \rho_a * c_a * \sum_k b_{ve,k} * q_{ve,k}$$

Where:

$\rho_a * c_a$ is the heat capacity of the air per volume, expressed in joules per cubic meters per kelvin =1200 [J/m3K]

$q_{ve,k}$ is the time average airflow rate of air flow element k, [m^3/s]

$b_{ve,k}$ is the temperature adjustment factor for air flow element k, with value not 1 if the temperature supply is not equal to the external environment one, such in the case of pre-heating and pre-cooling or heat recovery

Table 25 represents the different ventilation and infiltration loads along the year for the building case of study when placed in the different climatic zones. As can be seen the load increases, as expected when the summer severity decreases and the winter severity increases being more representative winter severity increases that a decrease for the summer one.

Table 26, representing the ventilation loads along the winter period follows the same structure as the yearly ones, being representative in Table 27, summer ventilation loads, that only for the two severe summer climatic classes, the load entering as ventilation load increases the internal temperatures while in all other cases, although in summer, ventilation loads are negatives (Energy loses to the ambient with internal summer set point temperature of 26ºC)

Table 25: Ventilation gains along the year[Wh/m^2]

Ventilation Gains		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-1848,72	-2141,15	-2489,03	-2805,39	-2836,48	-3000,96	-3226,29
	Class 2	-2645,15	-2810,76	-2995,50	-3377,96	-3604,48	-3690,15	-3794,82
	Class 3	---	---	-3676,86	-3785,36	-4132,21	-4372,26	-4121,18
	Class 4	---	---	---	-4066,70	-4355,82	-4402,54	-4533,60
	Class 5	---	---	---	-4565,70	-5249,08	-5230,23	-5017,40
	Exc. Cold	---	---	---	---	---	---	-6127,46

Table 26: Ventilation gains during the winter season[Wh/m²]

Ventilations Winter		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-1959,35	-2025,71	-2193,51	-2401,19	-2450,82	-2278,84	-2455,93
	Class 2	-2742,55	-2657,25	-2683,91	-2907,96	-2879,08	-2888,50	-2962,64
	Class 3	---	---	-3259,04	-3298,14	-3339,40	-3345,10	-3289,92
	Class 4	---	---	---	-3550,06	-3608,38	-3603,26	-3637,46
	Class 5	---	---	---	-3875,56	-4250,04	-4175,16	-4049,50
	Exc. Cold	---	---	---	---	---	---	-4925,00

Table 27: Ventilation gains during the summer season[Wh/m²]

Ventilations Summer		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	110,62	-115,44	-295,52	-404,20	-385,66	-722,12	-770,37
	Class 2	97,40	-153,52	-311,58	-470,00	-725,40	-801,65	-832,17
	Class 3	---	---	-417,82	-487,22	-792,81	-1027,17	-831,26
	Class 4	---	---	---	-516,64	-747,44	-799,27	-896,14
	Class 5	---	---	---	-690,15	-999,05	-1055,06	-967,90
	Exc. Cold	---	---	---	---	---	---	-1202,46

4.2.4 Internal heat gains

The internal gains to be considered for the calculation of building thermal demands are the following ones, all of them expressed in Wh:

a. The internal heat flow rate from lighting, φint,L
b. The internal heat flow rate from appliances, φint,A,
c. The internal heat flow rate from occupants, φint,Oc.
d. The internal heat flow rate from hot and mains water and sewage, φint,WA,
e. The internal heat flow rate from heating, cooling,ventilation systems, φ int,HVAC,
f. The internal heat flow rate from processes and goods, φint,Proc

For the study developed in this work, the gains produced inside the building, directly dependent on its occupancy and the way the users behave in their homes, were considered identical for every case and it was only divided into two different categories, one related to the occupant heat production and a second one related to all the appliances and lighting simulated into the building. (Labeled before with a, b and c. Labels d, e and f have not been scheduled nor calculated under the consideration of enough representativeness of the problem with the three related ones.)

The internal load profile was defined in an hourly base for a day that will be repeated the 365 days of the year. This profile fits a normal working day and not weekends or holiday periods, but it was defined identical for all the cases, allowing comparison of the results without increasing the programming difficulties.

- The number of people considered in the building is 4 with a determinate hourly profile defined in the first columns of Table 28 as percentages of 4 people with a sedentary movement that corresponds to a sensible heat production of 50 W and a latent one of 25W.

- The heat sources calculated in our conditioned space cover lighting and appliances following the profile defined in the second columns of Table 28

Table 28: Diary internal load profiles

	% People	**Elect (W)**		**% People**	**Elect (W)**
0-1am	100	0	12-13pm	0	0
1-2 am	100	0	13-14pm	100	2000
2-3am	100	0	14-15pm	100	2000
3-4am	100	0	15-16pm	0	0
4-5am	100	0	16-17pm	0	0
5-6am	100	0	17-18pm	0	0
6-7am	100	0	18-19pm	50	1000
7-8am	50	2000	19-20pm	100	1000
8-9am	50	1000	20-21pm	100	1000
9-10am	0	0	21-22pm	100	500
10-11am	0	0	22-23pm	100	500
11-12am	0	0	23-24pm	100	0

4.2.5 Domestic Hot Water demand

Hot water demands inside the residential zones has been calculated in base to specifically formulated profiles, widely use inside the solar thermal community following the Jordan 2001 works.

With the help of the application provided by the profile authors, it has been defined an hourly domestic hot water profile demand for the number of occupants described in 4.1.

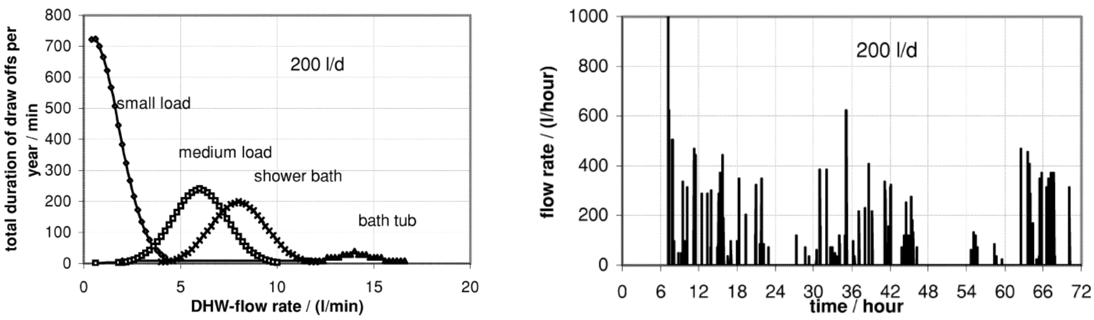


Figure 26: DHW demand profiles (Source: Jordan, 2001)

4.3 Evaluation of the heat demands for a predefined building

The total heat demand for the studied building was calculated as that sum of all demands acting over the zone in the hourly base time interval used in this work.

For this study it has been considered, as it was previously explained:

- Total solar radiation entering through the roofs(0)
- Total solar radiation entering through the opaque vertical elements (0)
- Energy radiation to the sky(4.2.1.2)
- Energy transmission through vertical walls based on temperature differences(4.2.1.3)
- Energy transmission through floors to the ground (4.2.1.4)
- Total solar radiation entering through the transparent vertical elements(4.2.2)
- Latent internal loads in summer time (4.2.3)
- Total gains associated to ventilation and infiltration(4.2.3)
- Sensible internal loads (4.2.4)

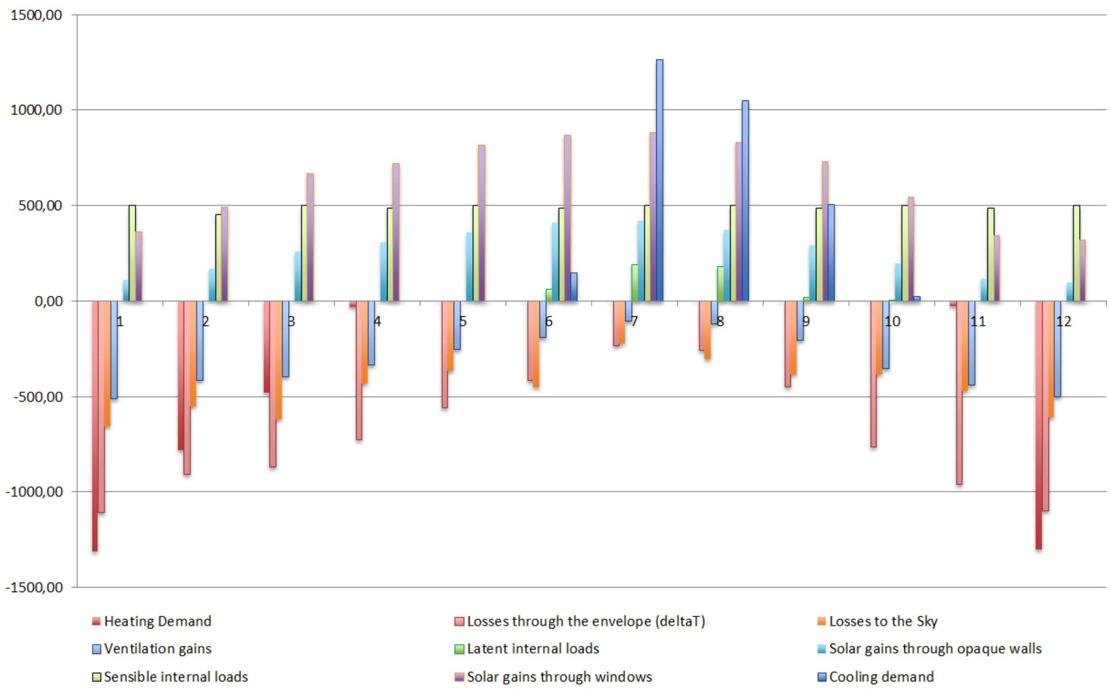


Figure 27: Energy monthly distribution calculated for the studied house in Valladolid (SP)[kWh]

As an example, Figure 27 presents the heating and cooling demands, divided in each one of the calculated loads for the city of Valladolid (SP). In this case, heating demands are mainly related to the losses through the envelope with conduction and convection effects, while the cooling demand relates to the solar gains collected through the building windows. For each month the sum of the loads are done on the left of the interval for heating (-) and on the right for cooling (+).

4.3.1 Yearly evolution of demands for all studied climatic conditions

The previously defined building has been virtually moved around Europe, obtaining the heating and cooling demands represented under these lines in Table 27 and Table 28. Latent demand was not evaluated during the heating system because it is no usual to find dehumidification facilities inside residential buildings for winter use)

As expected, heating demands increment as we move into the matrixes to the bottom right and cooling demands keep a contrary behaviour. (It should be realized that the climatic zones were created in base to the zone climatic severities.). The logical progression of the demands inside the matrix is not "continuous" in some positions, what can be explained from the methodology applied. Values presented are arithmetical averages of the obtained ones for each of the cities contained in the categories.

Table 29: Averaged cooling demand for the simulated building in all the defined climatic zones [Wh/m^2]

Summer Demand		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	7828,08	5508,43	4415,19	3486,02	3694,74	2253,39	1516,80
	Class 2	7092,17	5262,62	4076,71	3502,19	1680,44	1221,00	774,18
	Class 3	---	---	3867,36	3220,29	1728,43	211,51	939,77
	Class 4	---	---	---	3149,89	2142,42	1958,77	949,90
	Class 5	---	---	---	2614,64	1266,09	634,77	1009,36
	Exc. Cold	---	---	---	---	---	---	547,48

Table 30: Averaged heating demand for the simulated building in all the defined climatic zones [Wh/m^2]

Winter Demand		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-766,80	-846,95	-1013,17	-1832,62	-1187,26	-864,68	-1264,50
	Class 2	-3432,84	-2692,13	-3017,71	-3406,26	-4174,97	-4986,34	-5909,33
	Class 3	---	---	-4400,33	-4673,05	-5584,44	-6648,65	-7058,82
	Class 4	---	---	---	-5788,87	-6311,17	-6337,10	-7241,78
	Class 5	---	---	---	-6808,50	-9210,28	-9430,59	-7953,35
	Exc. Cold	---	---	---	---	---	---	-11989,83

4.3.2 *Monthly evolution of the building demands*

Figure 28 represents heating and cooling demands for the studied building along the year in all the Summer Climatic Severities discussed in Chapter 3: Climatic Distribution. Previous

Table 29 and Table 30 represent the integral demand of the buildings but it doesn't show the distributions in short periods as could be the monthly base (Figure 27). The 49 climatic categories in which was divided the European climates didn't allow to clearly recognizing the evolution of the demands what pushed the author to use 7 summer supra classes to plot the amount of heating/cooling needed by the building under the previously defined conditions.

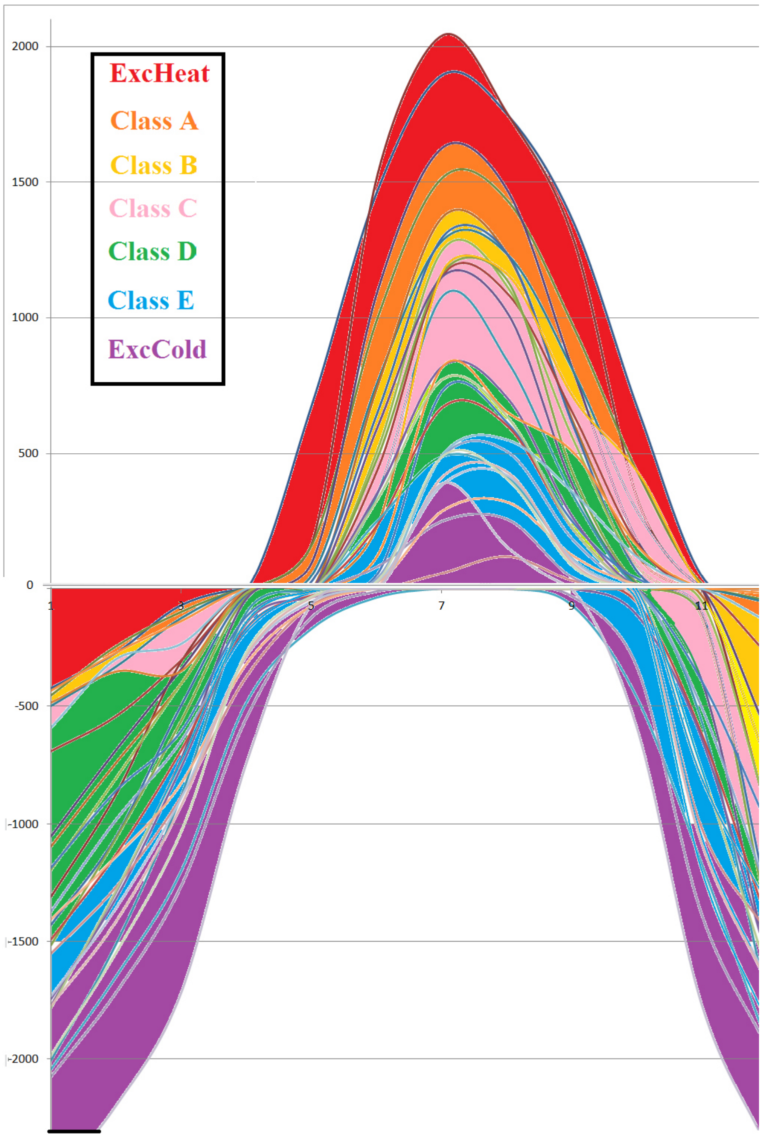


Figure 28: Interpolated monthly distribution of building demands along the year, classified by Summer Climatic Severity classes. (Cooling (+), Heating (-)) [Wh/m²]

Massive colours represent the heating and cooling demands in which each of the components of a determinate Summer Climatic class is contained. (Climatic classes with lower absolute demand values are always placed forward).

Cooling Demand January

Winter Climatic Severities's	Summer Climatic Severities's: Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	0	0	0	0	0	0	0
Class 2	0	0	0	0	0	0	0
Class 3	---	---	0	0	0	0	0
Class 4	---	---	---	0	0	0	0
Class 5	---	---	---	0	0	0	0
Exc. Cold	---	---	---	---	---	---	0

Cooling Demand February

Winter Climatic Severities's	Summer Climatic Severities's: Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	0	0	0	0	0	0	0
Class 2	0	0	0	0	0	0	0
Class 3	---	---	0	0	0	0	0
Class 4	---	---	---	0	0	0	0
Class 5	---	---	---	0	0	0	0
Exc. Cold	---	---	---	---	---	---	0

Cooling Demand March

Winter Climatic Severities's	Summer Climatic Severities's: Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	0	0	0	0	0	0	0
Class 2	0	0	0	0	0	0	0
Class 3	---	---	0	0	0	0	0
Class 4	---	---	---	0	0	0	0
Class 5	---	---	---	0	0	0	0
Exc. Cold	---	---	---	---	---	---	0

Heating demand January

Winter Climatic Severities's	Summer Climatic Severities's: Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	-423	-454	-498	-691	-484	-434	-590
Class 2	-1309	-1053	-1096	-1195	-1186	-1372	-1406
Class 3	---	---	-1429	-1515	-1491	-1551	-1732
Class 4	---	---	---	-1772	-1744	-1781	-1773
Class 5	---	---	---	-2006	-2043	-2074	-1984
Exc. Cold	---	---	---	---	---	---	-2534

Heating demand February

Winter Climatic Severities's	Summer Climatic Severities's: Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	-273	-245	-331	-542	-352	-272	-300
Class 2	-874	-686	-740	-805	-859	-982	-1139
Class 3	---	---	-1053	-1060	-1130	-1268	-1358
Class 4	---	---	---	-1289	-1316	-1283	-1414
Class 5	---	---	---	-1510	-1648	-1717	-1547
Exc. Cold	---	---	---	---	---	---	-2198

Heating demand March

Winter Climatic Severities's	Summer Climatic Severities's: Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	-71	-99	-126	-305	-351	-138	-235
Class 2	-310	-342	-404	-403	-606	-647	-828
Class 3	---	---	-497	-563	-688	-884	-890
Class 4	---	---	---	-724	-760	-736	-923
Class 5	---	---	---	-880	-1201	-1265	-1033
Exc. Cold	---	---	---	---	---	---	-1719

Figure 29: Monthly evolution of the heating and cooling demand Wh/m^2 (January to March)

Cooling Demand April	Summer Climatic Severities's						
Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	0	0	0	0	0	0	0
Class 2	0	0	0	0	0	0	0
Class 3	---	---	0	0	0	0	0
Class 4	---	---	---	0	0	0	0
Class 5	---	---	---	0	0	0	0
Exc. Cold	---	---	---	---	---	---	0

Cooling Demand May	Summer Climatic Severities's						
Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	687	169	55	0	0	0	0
Class 2	177	104	0	0	0	0	0
Class 3	---	---	32	0	0	0	0
Class 4	---	---	---	0	0	0	0
Class 5	---	---	---	0	0	0	0
Exc. Cold	---	---	---	---	---	---	0

Cooling Demand June	Summer Climatic Severities's						
Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	1472	1003	768	444	238	127	0
Class 2	1532	1103	752	518	59	43	26
Class 3	---	---	655	489	240	0	28
Class 4	---	---	---	601	360	334	10
Class 5	---	---	---	357	255	85	32
Exc. Cold	---	---	---	---	---	---	0

Heating demand April	Summer Climatic Severities's						
Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	0	0	0	-20	0	0	-1
Class 2	0	-8	-19	-19	-119	-184	-321
Class 3	---	---	-26	-38	-168	-375	-288
Class 4	---	---	---	-45	-148	-141	-283
Class 5	---	---	---	-102	-486	-551	-271
Exc. Cold	---	---	---	---	---	---	-745

Heating demand May	Summer Climatic Severities's						
Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	0	0	0	0	0	0	-1
Class 2	0	0	0	-1	-13	-17	-75
Class 3	---	---	0	0	-30	-72	-55
Class 4	---	---	---	0	-37	-13	-39
Class 5	---	---	---	-9	-171	-124	-34
Exc. Cold	---	---	---	---	---	---	-69

Heating demand June	Summer Climatic Severities's						
Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	0	0	0	0	0	0	0
Class 2	0	0	0	0	0	0	0
Class 3	---	---	0	0	0	0	0
Class 4	---	---	---	0	0	0	0
Class 5	---	---	---	0	-38	-12	0
Exc. Cold	---	---	---	---	---	---	0

Figure 30 Monthly evolution of the heating and cooling demand Wh/m^2 (April to June)

Cooling Demand July		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1897	1519	1288	1159	1175	823	500
	Class 2	2042	1630	1374	1254	736	495	292
	Class 3	---	---	1301	1169	673	61	389
	Class 4	---	---	---	1155	824	776	418
	Class 5	---	---	---	1083	491	253	493
	Exc. Cold	---	---	---	---	---	---	392

Cooling Demand August		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1744	1427	1230	1085	1156	649	550
	Class 2	1745	1462	1226	1108	608	504	320
	Class 3	---	---	1229	1131	598	121	417
	Class 4	---	---	---	1012	700	630	429
	Class 5	---	---	---	834	412	257	403
	Exc. Cold	---	---	---	---	---	---	151

Cooling Demand September		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1348	963	799	640	703	502	354
	Class 2	1284	798	610	546	243	178	121
	Class 3	---	---	595	417	217	30	105
	Class 4	---	---	---	373	258	218	93
	Class 5	---	---	---	340	108	40	82
	Exc. Cold	---	---	---	---	---	---	4

Heating demand July		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	0	0	0	0	0	0	0
	Class 2	0	0	0	0	0	0	0
	Class 3	---	---	0	0	0	0	0
	Class 4	---	---	---	0	0	0	0
	Class 5	---	---	---	0	0	0	0
	Exc. Cold	---	---	---	---	---	---	0

Heating demand August		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	0	0	0	0	0	0	0
	Class 2	0	0	0	0	0	0	0
	Class 3	---	---	0	0	0	0	0
	Class 4	---	---	---	0	0	0	0
	Class 5	---	---	---	0	0	0	0
	Exc. Cold	---	---	---	---	---	---	0

Heating demand September		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	0	0	0	0	0	0	0
	Class 2	0	0	0	0	0	0	0
	Class 3	---	---	0	0	0	0	0
	Class 4	---	---	---	0	0	0	0
	Class 5	---	---	---	0	-69	-31	0
	Exc. Cold	---	---	---	---	---	---	0

Figure 31 Monthly evolution of the heating and cooling demand Wh/m^2 (July to September)

Cooling Demand October — Winter Climatic Severities's \ Summer Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	648	417	274	157	423	152	113
Class 2	313	167	114	76	34	0	15
Class 3	---	---	55	14	0	0	0
Class 4	---	---	---	9	0	0	0
Class 5	---	---	---	1	0	0	0
Exc. Cold	---	---	---	---	---	---	0

Cooling Demand November — Winter Climatic Severities's \ Summer Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	32	10	1	0	0	0	0
Class 2	0	0	0	0	0	0	0
Class 3	---	---	0	0	0	0	0
Class 4	---	---	---	0	0	0	0
Class 5	---	---	---	0	0	0	0
Exc. Cold	---	---	---	---	---	---	0

Cooling Demand December — Winter Climatic Severities's \ Summer Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	0	0	0	0	0	0	0
Class 2	0	0	0	0	0	0	0
Class 3	---	---	0	0	0	0	0
Class 4	---	---	---	0	0	0	0
Class 5	---	---	---	0	0	0	0
Exc. Cold	---	---	---	---	---	---	0

Heating demand October — Winter Climatic Severities's \ Summer Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	0	0	0	0	0	0	0
Class 2	0	0	0	0	-5	0	-3
Class 3	---	---	0	0	-57	-27	-22
Class 4	---	---	---	0	-110	0	-55
Class 5	---	---	---	0	-460	-328	-48
Exc. Cold	---	---	---	---	---	---	-587

Heating demand November — Winter Climatic Severities's \ Summer Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	0	0	0	0	0	0	0
Class 2	0	0	-29	-53	-391	-503	-805
Class 3	---	---	-99	-118	-615	-1015	-1053
Class 4	---	---	---	-389	-636	-765	-1081
Class 5	---	---	---	-562	-1167	-1383	-1195
Exc. Cold	---	---	---	---	---	---	-1766

Heating demand December — Winter Climatic Severities's \ Summer Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	0	-49	-58	-274	0	-20	-138
Class 2	-940	-604	-730	-930	-995	-1281	-1334
Class 3	---	---	-1296	-1380	-1406	-1457	-1661
Class 4	---	---	---	-1571	-1560	-1617	-1672
Class 5	---	---	---	-1740	-1926	-1946	-1842
Exc. Cold	---	---	---	---	---	---	-2372

Figure 32: Monthly evolution of the heating and cooling demand Wh/m^2 (October to December

4.3.3 Evaluation of the Summer Latent demand

Latent demand inside the building proceeding from the load specified in Table 12 has been calculated for the complete year but it is only effectively used along the summer season under boundaries explained in 4.1. (Cooling production during the summer season allows dehumidification processes that usually doesn't occur in residential buildings without air treatment units during heating periods)

Table 31: Yearly latent demand for all the studied climates [Wh/m^2]

Latent Demand		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	5101,32	5831,72	4705,06	3638,07	4950,25	1794,53	1708,86
	Class 2	3797,47	2995,04	3661,29	2671,16	1677,79	935,68	777,72
	Class 3	---	---	2360,19	2824,32	1494,73	113,36	743,35
	Class 4	---	---	---	2399,86	1429,33	1296,87	495,90
	Class 5	---	---	---	1417,88	926,81	341,84	573,68
	Exc. Cold	---	---	---	---	---	---	215,20

Table 31 and Table 32relate the latent loads calculated in the building for the complete year as well as the demand that would be seen by dehumidification systems in case of existence during cold periods. As seen when both matrices are compared, winter latent demand is only significant (around a 12% of the yearly demand) for Climate zones with low winter severities and high summer ones A1 and B1, while there is no demand out of the summer period for zones C, D and lower. Figure 33 show a time profile for latent loads from May to October. In these two months, it exist a relative high latent demand for warm climatic zones that is not appreciated for the other climatic classifications.

Table 32 : Latent demand occurring during winter months [Wh/m^2]

Latent Winter		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	577,11	425,33	214,12	76,12	288,35	85,83	77,82
	Class 2	146,99	79,73	47,49	20,28	16,15	0,00	2,92
	Class 3	---	---	59,24	0,47	0,00	0,00	0,00
	Class 4	---	---	---	1,69	0,00	0,00	0,00
	Class 5	---	---	---	0,00	0,00	0,00	0,00
	Exc. Cold	---	---	---	---	---	---	0,00

Latent demand May		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	331,84	67,36	3,31	0,00	0,00	0,00	0,00
	Class 2	52,95	24,63	0,00	0,07	0,00	0,00	0,00
	Class 3	---	---	44,02	0,00	0,00	0,00	0,00
	Class 4	---	---	---	0,00	0,00	0,00	0,00
	Class 5	---	---	---	0,00	0,00	0,00	0,00
	Exc. Cold	---	---	---	---	---	---	0,00

Latent demand June		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	794,13	824,29	647,27	362,44	343,04	64,05	0,00
	Class 2	480,31	556,24	631,79	412,14	54,36	10,28	25,09
	Class 3	---	---	469,63	529,44	206,33	0,00	10,35
	Class 4	---	---	---	495,90	288,18	271,04	4,04
	Class 5	---	---	---	284,69	205,20	54,21	15,01
	Exc. Cold	---	---	---	---	---	---	0,00

Latent demand July		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1380,73	1611,50	1440,03	1262,11	1697,29	660,11	584,26
	Class 2	1225,42	894,02	1232,02	960,59	702,47	361,61	285,02
	Class 3	---	---	820,02	1042,15	597,01	46,38	232,37
	Class 4	---	---	---	873,46	523,36	471,07	191,48
	Class 5	---	---	---	537,71	385,59	116,14	267,75
	Exc. Cold	---	---	---	---	---	---	132,44

Latent demand August		Summer Climtic Severities's						
		Exc. Heat	Class A	Class B	Cass C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1544,89	1868,64	1555,47	1367,44	1827,31	542,18	682,80
	Class 2	1365,33	1032,12	1249,04	910,27	668,64	445,40	337,62
	Class 3	---	---	736,44	917,60	529,08	57,40	350,53
	Class 4	---	---	---	761,45	497,15	444,13	255,83
	Class 5	---	---	---	449,43	288,57	152,01	248,83
	Exc. Cold	---	---	---	---	---	---	81,38

Latent demand September		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	804,46	1101,36	848,18	569,35	793,76	442,35	363,98
	Class 2	579,42	432,93	500,94	367,89	236,17	118,38	127,08
	Class 3	---	---	274,85	334,67	162,30	9,58	90,10
	Class 4	---	---	---	264,36	120,64	110,63	44,55
	Class 5	---	---	---	146,05	47,45	19,48	42,10
	Exc. Cold	---	---	---	---	---	---	1,38

Latent demand October		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	243,80	354,82	204,21	76,12	288,35	85,83	77,82
	Class 2	94,04	55,09	47,49	20,21	16,15	0,00	2,92
	Class 3	---	---	15,22	0,47	0,00	0,00	0,00
	Class 4	---	---	---	1,69	0,00	0,00	0,00
	Class 5	---	---	---	0,00	0,00	0,00	0,00
	Exc. Cold	---	---	---	---	---	---	0,00

Figure 33: Latent loads calculated for the studied building during the central months of the year

5. Solar System Definition

The second part of this work is based on the integration and evaluation of different solar based technologies working under a determinate number of boundary conditions. After evaluating the climatic conditions able to lately classify this work results, and define and calculate loads and demands for the studied building, it is time to have a clear view of the potential solar energy to be collected by different technologies. Solar radiation is to be collected to introduce the produced thermal energy into a determinate heating facility that in the case of this work, delivers energy in both heating and cooling mode into an occupied zone of a residential building.

5.1 Radiation parameters

As a first step, a reduced number of solar indicators and definitions related to each climatic zone defined must be exploded to limit the studied problem

5.1.1 Total radiation

As a first approximation to the problem, the amount of energy that the sun can provide along the year to the European earth surface, represented by total radiation on an horizontal surface, (Table 33), and the percentage of the radiation arrived in summer compared with the total. (Table 34). The calculations were done on the base of direct normal and diffuse radiation contained inside the of the meteorological data files following [Duffie 1983] methodology

Table 33: Yearly total radiation on horizontal classified by climatic severities [Wh/m^{2}y]

Total Horizontal Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1764,06	1705,87	1633,86	1474,66	1332,62	1523,01	1281,90
	Class 2	1770,38	1610,91	1447,92	1409,60	1270,16	1269,64	1193,82
	Class 3	---	---	1536,71	1445,72	1169,88	997,08	1128,79
	Class 4	---	---	---	1378,56	1230,71	1149,25	1088,44
	Class 5	---	---	---	1531,52	1167,28	1053,88	1124,87
	Exc. Cold	---	---	---	---	---	---	963,38

Table 34 represents in a comparative way the amount of energy received from the sun during the four previously defined summer months against the complete year. This parameter is important when the solar systems are potentially used as driving energy to heat and cool occupied spaces. Down-right positions of Table 33 and Table 34 remark quantitatively that in colder places (D3, D4,E3, E4…) radiation resources are around 30% lower than in the other classifications and what it is more important, the radiation is mostly available during four summer months.

Along winter periods the potential available radiation is low and heating demands are high, needing of higher collector surfaces to cover the demands. In summer time that zones receive the most of their solar radiation, but due to the relatively cold summers, the cooling demand is not critical. That would make difficult the economical return of investment of the facilities as it would be seen lately in this work.

Table 34: Ratio (Summer/yearly)total radiation on horizontal [%]

Summer / Yearly Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	47%	47%	47%	49%	47%	48%	48%
	Class 2	48%	49%	49%	50%	49%	50%	50%
	Class 3	---	---	50%	50%	50%	52%	52%
	Class 4	---	---	---	49%	50%	51%	51%
	Class 5	---	---	---	52%	49%	52%	51%
	Exc. Cold	---	---	---	---	---	---	56%

To fix the last ideas, it was prepared a table to represent the number of hours from the total 8760 of a year from which the radiation can be a useful resource. Table 35 denotes that the number of daylight hours is not so different from one to other climatic zone. Combining Table 33, Table 34 and Table 35 it is easy to understand that climates located bottom right in the tables, do have not only lower total radiation but also the daily winter average potential radiation is also smaller,making difficult its use as “free” energy source with economical return of investment problems when the technologies would be compared with other existing in the market.

Table 35: Daylight hours along the year classified by climatic severities[h]

Day time hours		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	4578,80	4493,50	4521,14	4490,60	4546,00	4533,50	4517,67
	Class 2	4586,33	4484,53	4521,14	4511,17	4474,00	4434,00	4424,55
	Class 3	---	---	4521,14	4570,17	4446,94	4371,85	4440,63
	Class 4	---	---	---	4473,00	4466,50	4478,29	4383,93
	Class 5	---	---	---	4455,00	4452,17	4418,64	4407,39
	Exc. Cold	---	---	---	---	---	---	4423,30

The confirmation of all the previously exposed concepts is completely cleared with the help of Weibull distributions. The hourly total radiation for each of the studied weather points, and the averages when studying the climate zone classified by severities, were adjusted using Weibull distributions. For every one of the studied cases, the Weibull distribution fits total solar radiation on the horizontal with R^2 values over 98%, assuring the viability of the adjustment. Figure 34 represents the Weibull probability distribution for some climatic zones to denote how the movement along similar summer climatic severities towards coldest places goes hand in hand with a clear concentration of sunny days only around the central positions of the distribution while hottest climates have a more equitable solar distribution (Same coloured lines correspond to a determinate summer climatic severity while solid lines represent the warmest zone of the summer class and dotted line to the last zone of the summer class)

For a determinate colour (summer classification) the dotted line is always moved to the right with respect to the solid one and the central point of the distribution is higher.

The same effect is clearly seen when comparing summer zones for the same winter class. Comparison between solid or dotted lines always represent lower and displaced to the left the warmest climates.

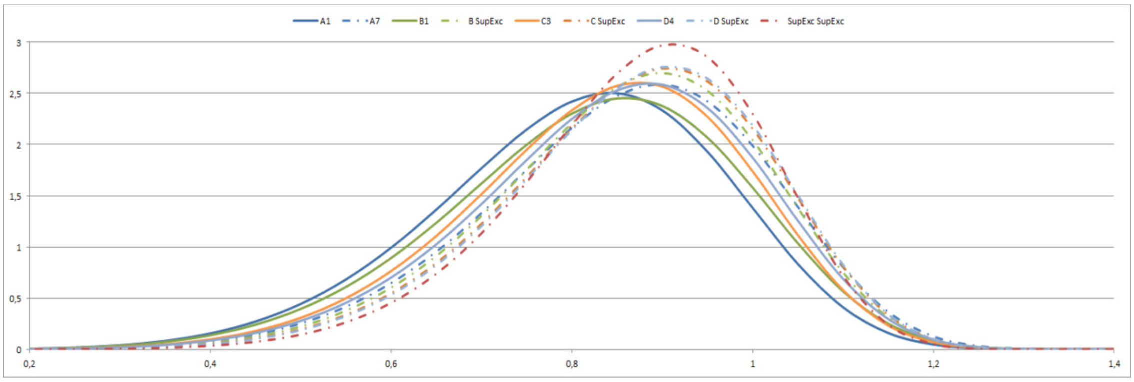


Figure 34: Weibull probability distribution for some of the studied climates.

In order to evaluate more accurately the suitable solar energy that could be collected, a delimitation of these data was done, calculating the potential arriving energy on a tilted surface oriented to the south. This orientation is considered optimal for solar collectors if the designer scope was collecting radiation during all day hours and not only during mornings or afternoons. For comparison purposes, the tilt angle of the collectors chosen for all Europe was 40º, even though the best value varies with the latitude and the use periods of the radiation collected.

Moreover, two different maps were created, one for the heating season and one for the cooling season, Figure 35 and Figure 36, respectively. Cooling season has been defined from 15th May to 15th September and heating season is the remaining part of the year.

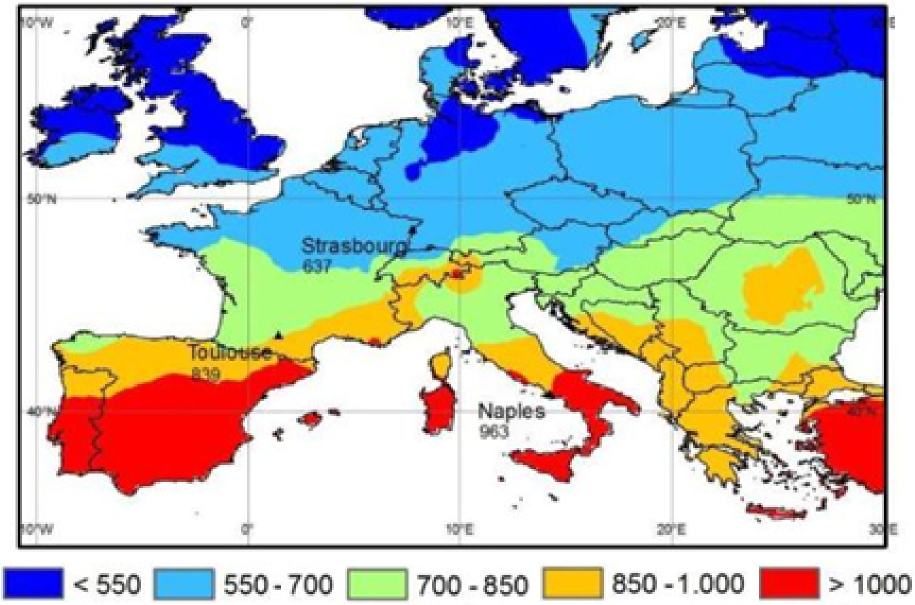


Figure 35: Total radiation on 40 ºtilted surface for the heating season [kWh/m^{2}y] (8 months).

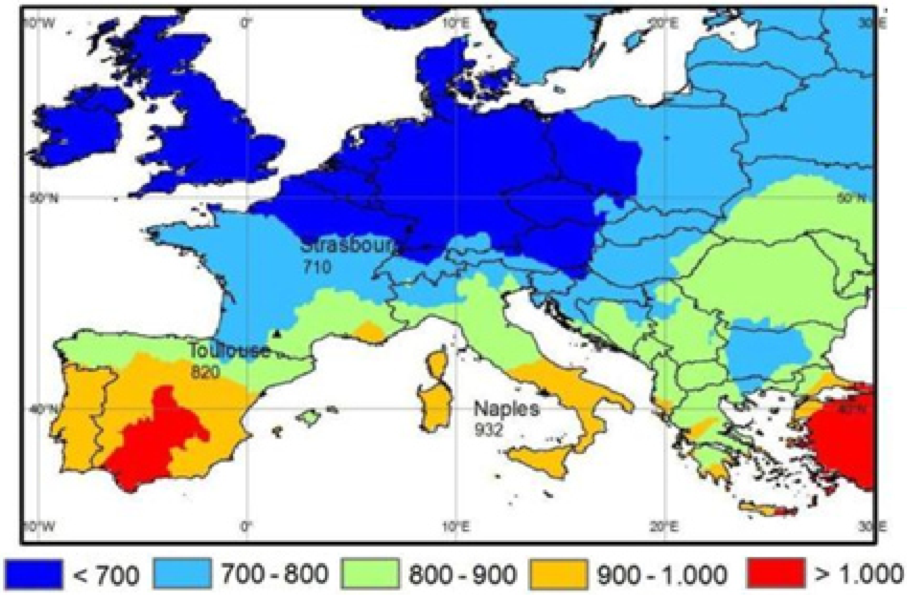


Figure 36: Total radiation on 40º tilted surface for the cooling season [kWh/m^{2}y] (4 months).

The last two figures above represent the maximum amount of energy able to be collected from the sun independently of the type of collector and the temperature needed in the processes, so these graphs correspond to the upper limits in terms of potential energy to be collected.

5.1.2 Critical and useful radiation

Along the last chapter 5.1.1, it was calculated the maximal solar availability for two different seasons, but solar collectors convert the energy collected from the sun with a *determinate efficiency* into thermal or electrical energy with the purpose of using it in different processes, decreasing fossil fuel demands. New potentialities for the solar radiation, divided by technologies and processes, and as a consequence by seasons, are going to be defined to adjust better the expected results when each one of them would be applied. Definitions as critical and useful radiations become the tool that reduces the first solar potential to those that adjust the different studied processes.

To introduce the utilizability concept it will be used the Hottel-Whillier equation, which relates the rate of useful energy collection, q_u, to the design parameters of the collector and its operating conditions.

Equation 23: Energy collected by a solar collector [Hottel-Whillier]

$$q_u = A \cdot [F_R \cdot (\tau \cdot \alpha) \cdot I_T - F_R \cdot U_L . (T_i - T_{amb})]^+$$

Where:

q_u	is the rate of useful energy collection.[W]
F_R	is the collector heat removal factor
$(\tau\alpha)$	is the effective transmittance-absorptance product
I_T	is the instantaneous solar radiation per unit area on a tilted plane [W/m^2]
U_L	is the collector overall energy loss coefficient [W/m^{2}K]
T_i	is the collector fluid inlet temperature [K]
T_{amb}	is the ambient temperature[K]

Collector parameters, $F_R(\tau\alpha)$ and$F_R U_L$., can be determined form standardized collector tests or obtained from the technical brochure of the manufacturer. The superscript + is used to indicate that only positive values of the quantity in brackets are considered. In practice, a controller is employed to prevent fluid circulation whenever the solar radiation is not sufficient to overcome thermal losses from the collector.

Equation 23 can be rearranged into:

Equation 24: Hottel-Whillier equation written as a function of Critical radiation (I_C)

$$\boldsymbol{q_u = A \cdot F_R \cdot (\tau \cdot \alpha) \cdot [I_T - I_C]^+}$$

Where:

I_c is the critical solar radiation [W/m^2]

The critical radiation I_C is defined as the radiation level needed to maintain the collector plate at the fluid inlet temperature. In other words, critical radiation can be defined as the level of radiation that creates the equilibrium between the energy loses and the energy collected for a collector working at a predetermined temperature.

Equation 25: Critical radiation

$$I_C = \frac{F_R \cdot U_{L\cdot}}{F_R \cdot (\tau \cdot \alpha)} \cdot (T_i - T_{amb})$$

From the definition of critical radiation derives the concept of utilizability. Klein et al 1984, define it as the fraction of solar radiation incident on a surface that exceeds a specified threshold or critical level. Mathematically the useable radiations defined as the difference between total and critical radiation received by a determinate collector to be used by an application defined by its driven temperature. (Utilizability concept is a radiation statistic analogous to degree-days replacing the temperature data by solar incident radiation)

Equation 26: Useful radiation

$$I_{Useful}^{temp,coll} = I_{total} - I_{Critical}^{temp,coll}$$

Where:

$\boldsymbol{I_{Useful}^{temp,coll}}$ is the useful solar radiation for a determinate temperature and collector.[W/m^2]

$\boldsymbol{I_{Critical}^{temp,coll}}$ is the critical solar radiation for a determinate temperature and collector[W/m^2]

5.2 Application of the utilizability concept for the studied cases

The utilizability concept exploded in the first part of the chapter is being crossed with the equipment integrated into the solar facility, defined mainly by a representative temperature of the process and the type of collector that heats the fluids.

In order to reach the scope of this work, two different solar thermal collector technologies were decided to be studied to evaluate their potential alone, or in combination with other components, to cover the heating and/or cooling loads of a determinate building around Europe.

The first stage was the election of two collectors that will be used in this work to test the potentialities of different technologies that differ in efficiencies and prices. Taking a look on the solar thermal collector state of the art, it was clear a first division of the technologies, flat plate (FPC's) and Evacuated Tube (ETC's) collectors, which main differences are the efficiencies when working at relatively high thermal levels and the installed price by squared meter that increases in the Evacuated Tube case around a 30% the installation. (Although the number of square meters needed to produce the same energy than the flat plate ones is smaller).

The second decision for the election of the collectors was the choice of one representative collector for each technology with enough quality to reach 60ºC needed for Domestic Hot Water production (DHW) without abrupt efficiency decreases. It was decided to control the thermal collector data base existing in SPF Institut where the collectors are certified for all Europe and the internet data base is public, including the efficiency parameters and schematic designs of the collectors and their absorber plates.Solar thermal collectors are defined by its efficiency. It evaluates performance as the ability of collecting solar radiation,decreased with the thermal losses to the environment (see Equation 27):

Equation 27: Solar thermal collector efficiency

$$\eta = IAM \times k_0 \; - k_1 * \frac{(T_{avg} - T_{amb})}{G_\perp} - k_2 \frac{(T_{avg} - T_{amb})^2}{G_\perp}$$

Where:

k_0 optical efficiency

k_1 =linear loss coefficient [W/m^2K]

k_2 = quadratic loss coefficient (not used in this case)[W/m^2K^2]

T_{avg} = average temperature [K]

T_{amb} = ambient temperature [K]

$G_\perp$ = Total solar irradiance on the collector plane [W/m^2]

IAM = Incident Angle Modifier, evaluates in percentages the amount of energy that arrives to the collector depending on the two angles (transversal and longitudinal) that the sun forms hourly with the tilted collector.

After a statistical analyses of the existing collectors and their parameters, it was decided to use a flat plate collector with 0.823 optical efficiency parameter (k_0) and 3.02 W/m^{2}K as linear loss coefficient (k_1). The k_2 quadratic loss coefficient was decided to be neglected to simplify calculations (second order losses are comparatively much lower than first order ones represented by the second term of Equation 27). The IAM values that modify the radiation collected as a function of the incident transversal and longitudinal angle are described in Figure 37.

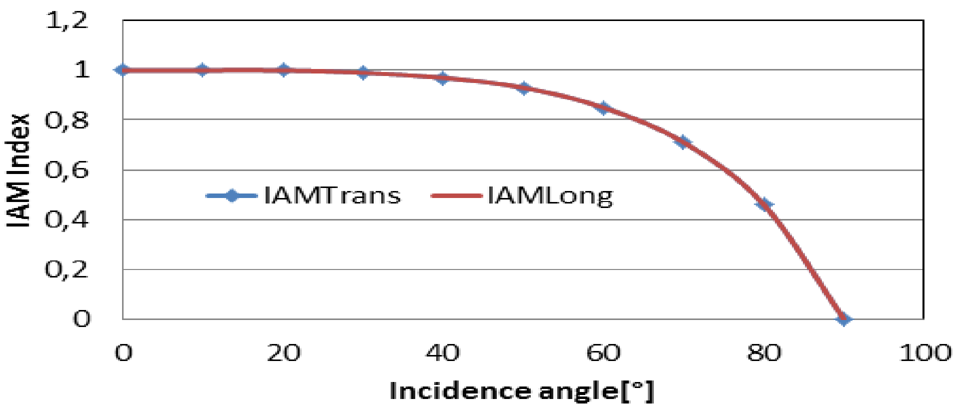


Figure 37: IAM angles for Flat Plate Collector

The Evacuated Tube collector was chosen firstly based on the more often constructive design represented in the European market when this part of the work began in 2007. The two constructive types on the left of Figure 38 were used in the 75% of the Evacuated Tubes sold in the European market. Both of them have similar k0, k1coeffiecients and their IAM angles differ only a little, an standardized collector of those typologies with k0= 0.601 and k1= 0.767 W/m2K was chosen as the Evacuated Tube to be simulated. IAM values are represented in Figure 39.

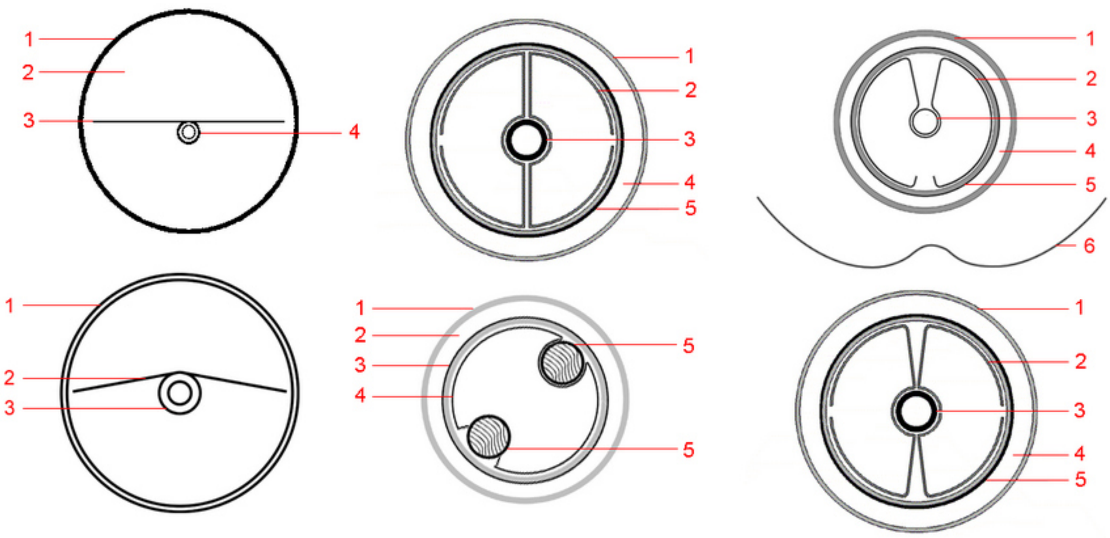


Figure 38: Six different constructive typologies for Evacuated Tube solar collectors

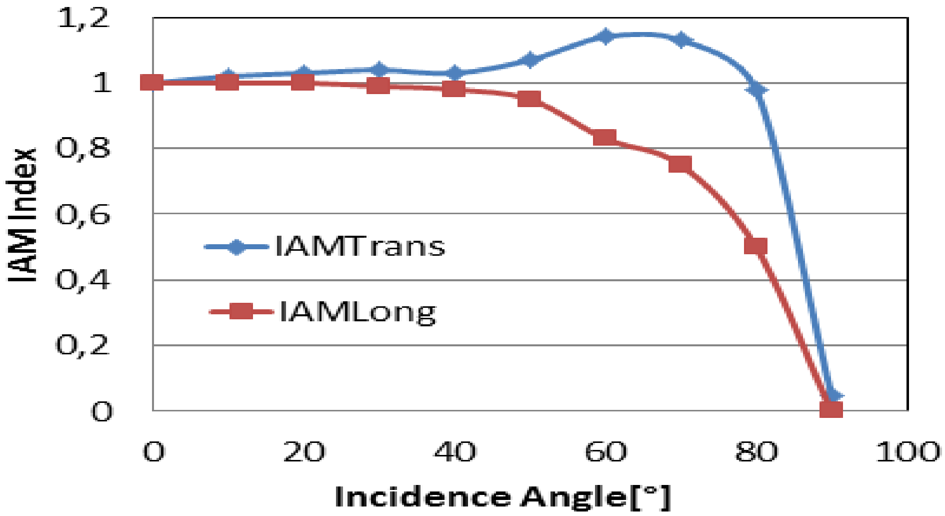


Figure 39: IAM angles for the Evacuated Tube collector studied

Critical radiation can be reformulated from Equation 25 andEquation 27 into

Equation 28

Equation 28: Critical radiation for a determinate collector and process

$$I_{Critical}^{temp,coll} = \frac{k_1}{IAM \times k_0} * \left(T_{procces} - T_{amb}\right)$$

As can be seen, to define the Critical Radiation it should be previously defined, the type of collector, the IAM angles and the temperatures needed for the considered processes.

Within this work, the process temperatures considered were dependent on the technologies of the sorption chillers used for the cold water production and on the needs to distribute domestic hot water and heating. Therefore, the temperatures considered for the computation of the Critical Radiation were:

- 20ºC for heating increasing the temperature level with the use of a heat pump.
- 40ºC for heating with direct feeding of radiant floors or low temperature fan coils.
- 60ºC for Domestic Hot Water production all along the year.
- 70ºC for Adsorption chillers (summer time)
- 90ºC for Absorption chillers (summer time)

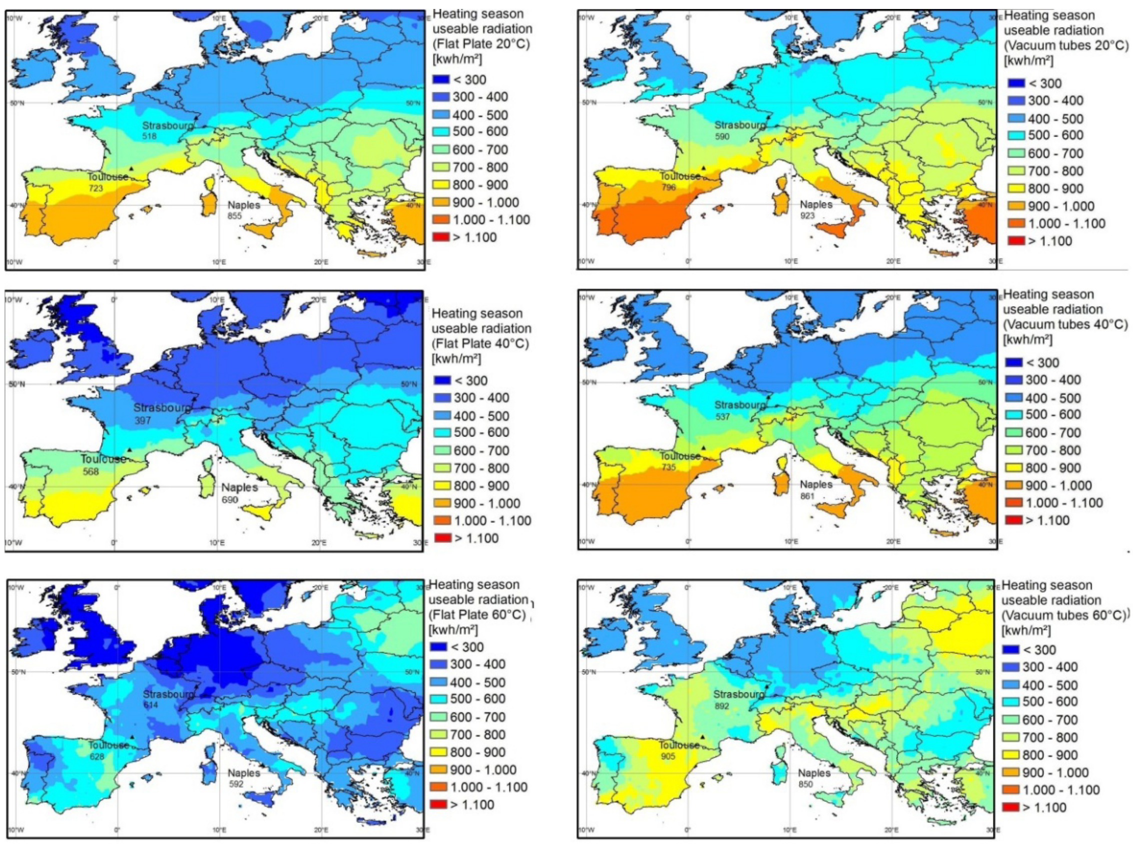


Figure 40: Heating season useable radiation for FP and ETC collectors working at 20ºC, 40ºC and 60ºC

Previous and following maps represent in a common scaled graphical way the usable radiation for each of the two thermal collectors chosen in different seasons. Heating season radiations are represented in Figure 40: Heating season useable radiation for FP and ETC collectors working at 20ºC, 40ºC and 60ºC. Figure 40 while summer radiations are described in Figure 41. Flat Plate collectors are positioned on the left part of the figure and the process temperatures are increasing from top to bottom.(For each of the locations the collectors are south oriented and the tilted angle over the horizontal is the one that optimize the amount of radiation by them received along the year)

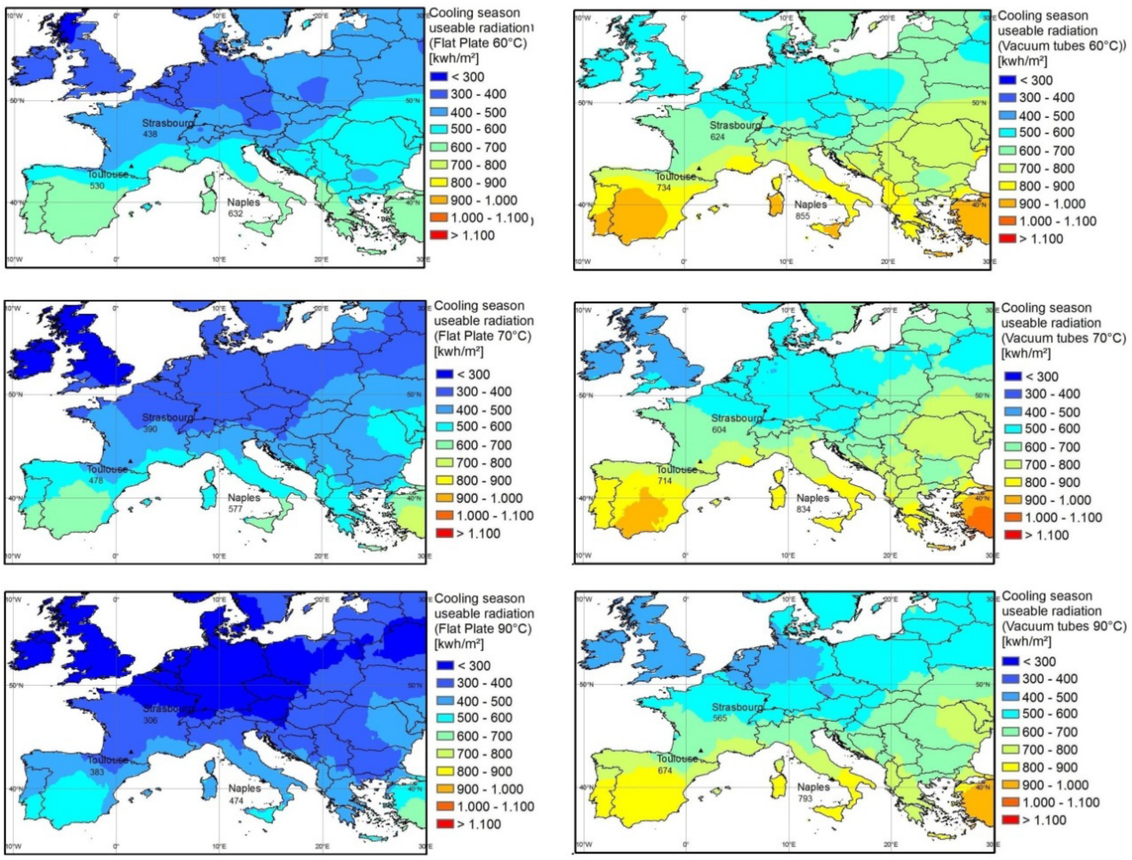


Figure 41: Cooling season useable radiation for FP and ETC collectors working at 20ºC, 40ºC and 60ºC

It should be remembered that the useable radiation results are related to the maximum amount of collected energy, for defined processes and ambient temperatures; therefore, in the case of the chillers, the temperature evaluated is the minimum one that can drive the system. Moreover, the characteristic parameters of the collectors (k_0 and k_1) are taken constant for the calculations, which is only achievable if their inlet temperature is also retained constant. This is only possible if the demand and the Useable radiation always overlap, which is not the case. As a result, the model used introduces some simplifications that result in somehow overestimated figures, when compared with actual energies available for heating, cooling and domestic hot water production. Nevertheless the model is well suited for the purpose of the most promising markets analysis, since it allows an easy comparison of the European regions in terms of offered solar energy at different year times.

Comparing vertical rows it can be noticed how the potentially useable radiation increases with evacuated tube collector for all temperatures. ETC's behave better as colder the winter or the summer season is.

1. Table 36 represents the potential increase in the energy to be collected when ETC are used instead the FP ones for a determinate temperature level that determines a process. The six tables are divided in two columns, representing winter and summer potential increases while the temperatures levels were chosen to drive different processes. The results obtained determine only the potential energy collected from at a determinate temperature. In this chapter is not still considered the building demands that will adjust the results to the energy collected at one determinate temperature and delivered to the building. This last consideration avoids accounting energy that is collected but not used to satisfy the building demands. i.e: Spring periods where the heating demand is nearly zero are being accounted as solar collected energy.

    a. There are two different maps and tables representing the increases at useful temperatures for DHW systems (60º) explained by the continuity of the DHW demand along the year. The division in two different plots allow lately the comparison between energies collected between 40 and 60 ºC during the heating season (direct feeding of radiant floors vs DHW)and the differences between 60 and 70 in the summer season (DHW vs. adsorption machine driving temperature.)

    b. Table 36 denotes different increases in winter and summer season explained by the highest ambient temperatures registered during the central months of the year against the lower winter temperatures

    c. The use of heat pumps at 20ºC as evaporator temperature doesn't increase drastically the collected energies. Price differences bigger than 10% in warm climates and 16% in cold ones would not recommend the use of ETC in combination with a solar thermal facility.

    d. In winter time, the increased efficiency of the ETC against the FP's keep a logical increase of energy collected with the temperature. ETC behaves in most of the cases collecting between 0.70 to 1.1% more energy for each degree over 20ºC that defines the operating temperature of the studied process. .In summer time, the ETC efficiencies are still higher than for FP collectors, but the energy collecting ratio increase is lower than in winter time because of the lower thermal losses of the collector envelopes (Lower ambient temperatures)

Table 36: Difference in the collected solar energy when used ETC vs FP for 3 different winter (left) and summer cases (right)

ETC/FP20 Useable Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	4%	5%	6%	7%	8%	6%	8%
	Class 2	6%	7%	7%	8%	9%	9%	10%
	Class 3	---	---	8%	8%	11%	14%	12%
	Class 4	---	---	---	9%	10%	12%	13%
	Class 5	---	---	---	10%	13%	14%	13%
	Exc. Cold	---	---	---	---	---	---	16%

ETC/FP40 Useable Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	14%	15%	16%	19%	21%	17%	21%
	Class 2	16%	18%	19%	20%	22%	22%	25%
	Class 3	---	---	19%	20%	25%	32%	27%
	Class 4	---	---	---	22%	24%	26%	29%
	Class 5	---	---	---	22%	27%	31%	28%
	Exc. Cold	---	---	---	---	---	---	34%

ETC/FP60 winter Useable Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	31%	34%	36%	38%	48%	41%	51%
	Class 2	28%	32%	36%	37%	43%	46%	49%
	Class 3	---	---	32%	36%	47%	55%	49%
	Class 4	---	---	---	39%	43%	46%	50%
	Class 5	---	---	---	31%	48%	51%	48%
	Exc. Cold	---	---	---	---	---	---	46%

ETC/FP60Summer Useable Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	16%	17%	19%	21%	25%	22%	27%
	Class 2	15%	17%	20%	21%	25%	26%	28%
	Class 3	---	---	18%	20%	28%	35%	29%
	Class 4	---	---	---	22%	25%	28%	30%
	Class 5	---	---	---	19%	29%	32%	29%
	Exc. Cold	---	---	---	---	---	---	32%

ETC/FP70 Useable Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	21%	23%	25%	27%	33%	28%	36%
	Class 2	20%	23%	26%	27%	32%	34%	37%
	Class 3	---	---	24%	27%	36%	44%	37%
	Class 4	---	---	---	29%	33%	36%	39%
	Class 5	---	---	---	24%	37%	41%	38%
	Exc. Cold	---	---	---	---	---	---	40%

ETC/FP90 Useable Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	33%	36%	38%	42%	51%	43%	55%
	Class 2	31%	36%	41%	43%	50%	52%	57%
	Class 3	---	---	37%	41%	55%	68%	58%
	Class 4	---	---	---	45%	51%	56%	60%
	Class 5	---	---	---	37%	55%	63%	58%
	Exc. Cold	---	---	---	---	---	---	61%

2. Comparing horizontal rows it can be seen how lower process temperatures maximize the useable radiation for each one of the collectors.(Figure 40, Figure 41 and Table 37)
   1. The eight tables represent the potential collected energy increases for a determinate technology when a heat pump is driven against direct floor heating feeding or floor heating vs DHW for heating seasons (20ºC vs40ºC and 40ºC vs 60ºC). During cooling seasons, DHW is compared to the energies related to adsorption systems and those last against absorption chillers (60ºC vs 70ºC and 70ºC vs 90ºC). Every value represented inside the tables is negative revealing that the efficiency of the collectors decreases with a temperature increase.

- The results obtained determine the potential decrease for a determinate technology when increasing from one temperature level to the next one in terms of heating, DHW and cooling feasibility studied in this work. Left columns in Table 37 relate to Flat plate collectors while on the right side of the figure, the evacuated tube collectors are studied. Only the potential energy collected from at a determinate temperature. In this chapter is not still considered the building demands that will adjust the results to the energy collected at one determinate temperature and delivered to the building. This last consideration avoids accounting energy that is collected but not used to satisfy the building demands. i.e: Spring periods where the heating demand is nearly zero are being accounted as solar collected energy.

  - Temperatures related to heat pump processing with the use of flat plate collectors obtain as minimum a 15% more solar energy that when a direct driven heat floor is studied, although heat pump processes need of a fuel/electricity to be driven. The importance of heat pumping with the use of ETC's isn't completely clear. The energy collected is not much higher and the investment costs would surely eliminate the advantages.

  - During the winter season the energy losses when working at 60ºC instead 40ºC are important for the flat plate collectors, but prevalence on DHW over heating loads will lead to assume the losses or create a differentiate heating generation protocol that feeds DHW from backups sources and heating from renewable ones. The effect as happened before is not so important for ETC's, accepting these last ones an increase on the working set point temperature without nearly affecting the efficiencies.

  - Along the summer season the differences are much smaller between DHW and adsorption driven temperatures for the FP case. Nearly imperceptible is the difference for the ETC cases.

  - Results obtained when comparing adsorption and absorption driven temperatures, show the potentiality of the set ETC and absorption machine while results for the FP collectors cases should be deeply studied.(Increased efficiency of absorption machine technologies is lowered by the smaller amounts of energy collected by the solar field)

Table 37: Difference in the collected solar energy when used FP (left) and ETC (right) for 5 different temperature levels.

FP40/20 Useable Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-15%	-16%	-16%	-18%	-19%	-16%	-19%
	Class 2	-15%	-16%	-18%	-18%	-18%	-19%	-20%
	Class 3	---	---	-16%	-17%	-19%	-23%	-21%
	Class 4	---	---	---	-18%	-18%	-20%	-21%
	Class 5	---	---	---	-16%	-18%	-20%	-20%
	Exc. Cold	---	---	---	---	---	---	-20%

ETC40/20 Useable Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-7%	-8%	-8%	-9%	-10%	-8%	-9%
	Class 2	-7%	-8%	-9%	-8%	-9%	-9%	-9%
	Class 3	---	---	-7%	-8%	-9%	-11%	-10%
	Class 4	---	---	---	-8%	-8%	-9%	-10%
	Class 5	---	---	---	-7%	-8%	-9%	-9%
	Exc. Cold	---	---	---	---	---	---	-8%

FP60/40 Useable Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-27%	-30%	-29%	-22%	-36%	-30%	-33%
	Class 2	-21%	-18%	-19%	-17%	-20%	-22%	-21%
	Class 3	---	---	-15%	-16%	-21%	-8%	-13%
	Class 4	---	---	---	-21%	-21%	-15%	-13%
	Class 5	---	---	---	-22%	-21%	-10%	-15%
	Exc. Cold	---	---	---	---	---	---	-15%

ETC60/40 Useable Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-17%	-18%	-17%	-9%	-22%	-16%	-17%
	Class 2	-12%	-8%	-7%	-5%	-7%	-8%	-6%
	Class 3	---	---	-5%	-6%	-7%	8%	1%
	Class 4	---	---	---	-11%	-9%	-1%	1%
	Class 5	---	---	---	-8%	-8%	4%	-2%
	Exc. Cold	---	---	---	---	---	---	-2%

FP70/60 Useable Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-6%	-6%	-7%	-7%	-8%	-7%	-9%
	Class 2	-6%	-6%	-7%	-7%	-8%	-8%	-9%
	Class 3	---	---	-6%	-7%	-9%	-10%	-9%
	Class 4	---	---	---	-8%	-8%	-9%	-9%
	Class 5	---	---	---	-6%	-8%	-9%	-9%
	Exc. Cold	---	---	---	---	---	---	-9%

ETC70/60 Useable Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-2%	-2%	-2%	-2%	-3%	-2%	-3%
	Class 2	-2%	-2%	-2%	-2%	-2%	-3%	-3%
	Class 3	---	---	-2%	-2%	-3%	-3%	-3%
	Class 4	---	---	---	-2%	-3%	-3%	-3%
	Class 5	---	---	---	-2%	-3%	-3%	-3%
	Exc. Cold	---	---	---	---	---	---	-3%

FP90/70 Useable Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-12%	-13%	-14%	-15%	-17%	-14%	-17%
	Class 2	-12%	-13%	-15%	-15%	-16%	-16%	-17%
	Class 3	---	---	-13%	-14%	-17%	-19%	-18%
	Class 4	---	---	---	-15%	-16%	-18%	-18%
	Class 5	---	---	---	-13%	-17%	-18%	-18%
	Exc. Cold	---	---	---	---	---	---	-18%

ETC90/70 Useable Radiation		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	-4%	-4%	-4%	-4%	-5%	-4%	-5%
	Class 2	-3%	-4%	-4%	-4%	-5%	-5%	-5%
	Class 3	---	---	-4%	-4%	-6%	-6%	-6%
	Class 4	---	---	---	-5%	-5%	-6%	-6%
	Class 5	---	---	---	-4%	-5%	-6%	-6%
	Exc. Cold	---	---	---	---	---	---	-6%

6. Combination between building and solar system

In the three previous chapters it has being created a European climatic division to facilitate the classification of building demands and solar energy collected by different solar collectors. Along this chapter the intersection between building demands and solar energy potentials is going to be settled, ordering the results in the climatic severity matrix.

The intersection between building demands and solar energy production delivered, has been evaluated with 16 different parameters for each one of the two collectors studied in this work. As can be further seen, once that the collecting technology has been chosen, the parameters differentiate results obtained by the facilities developed in 6.1 with and without Heat Pump during heating and cooling season.

1. Square meters of solar thermal collector installed
2. Gas saved [kW] by the solar thermal plant
3. Gas saved [kW] by the solar thermal plant with HP
4. Electricity saved [kW] by the solar thermal plant with HP
5. Energy saved by the solar plant for heating production and CO2 not emitted
6. Energy saved by the solar plant with HP for heating and cooling production and CO2 not emitted
7. % coverage of heating and DHW demands by the solar plant
8. % coverage of heating, DHW and cooling demands by the solar plant with HP
9. Primary energy saved by the solar thermal plant
10. Primary energy saved by the solar thermal plant with HP

11. Yearly monetary savings by the solar thermal plant
12. Yearly monetary savings by the solar thermal plant with HP
13. Investment costs of the solar plant for heating production
14. Investment costs of the solar plant for heating and cooling production
15. Return of investment for the solar plant for heating production
16. Return of investment for the solar plant for heating and cooling production

From those 16 evaluated parameters, the first four could be considered as principals to determine the viability of the systems when combined with the fossil fuel prices and the investment costs. From them, it could be evaluated all the other 12 indicators relating to primary energy and CO_2 factors, building energy demand by seasons or the substitution of gas in heating processes and electricity for cooling ones. The first indicator relates to installation sizes while the comparison between the second and the third indicator describe the relative importance of the thermal heat pump during demand heating periods. The fourth indicator explains the electricity savings for cooling production.

An accurate description of each parameter for the two collectors evaluated around Europe, would lead to a wide chapter. Because of that, only a reduced group of parameters will be investigated in a first step, to eliminate the locations where the feasibility of solar driven technologies installed in island mode for heating and cooling, doesn't meet a number of predetermined requirements. By definition, a system connected in island mode consumes its own energy in the building and the energy exceeds are not sold or distributed to other users.The requirements critical to exclude a climatic condition from the study are, for example, the number of years to make the facility economically profitable or a maximum solar collector area needed to climate 100m^2 of occupied space.

The studied parameters are divided in two categories related to economy and efficiency, both of them used to compare the savings obtained when the solar system is driven the building against a typical heating and cooling installation.

The amount of variables needed to be taken into account, and the intervals in which each of the variables should be evaluated, creates a pretty high number of combinations to be applied on the weather data points studied. That kind of work would deliver a high amount of rough data difficult to evaluate and in some of the cases, not useful because some of the studied zones will be lately found as not recommended to have installed solar technologies for heating and cooling. The solution adopted goes through the initial evaluation of the problem, determining a “real value” for each one of the studied parameters, and later on, it is studied the variation of every single parameter to obtain better energetic and economical results for the set building-solar facility.

Economical parameters:

- Initial costs of equipment where it is included the installation, commissioning and adjacent equipment needed to properly work.
    - Flat plate collectors. (Price 700€/m2)
    - Evacuated tube collectors (Price 1000€/m2)
    - Electrical heat pump (chiller) (Price 700€/kWCold)
    - Thermal heat pumps (chillers) (Price 900€/kWCold)
- Operational costs:
    - Gas Price: 0.1€/kWh
    - Electricity prices: 0.15€/kWh

Efficiency based parameters:

- Boiler efficiency: 0.95%
- CO2 gas factor= 0.202 tCO_2/MWh_t [IPCC2006]
- CO2 electricity factor= 0.44t CO_2/MWh_e[IPCC2006]

In a first step, the energy saved by the different installations is described independently of the characteristics of the energy replaced (gas or electricity in the case studied here).

Table 38 compares the energy delivered from the two different solar thermal facilities and used by the building (Energies represented by square meter of solar collector installed). In this case the compared facilities are both of them based on Flat plate collectors, being the second one combined with a sorption heat pump, taking advantage of the higher collector efficiencies and benefiting the positive COP of the machine when combining the energy delivered by a boiler with the one proceeding from the solar field working with low temperature levels.

Table 38: Saved Energy by a FP's solar field, alone and in combination with HP along the heating season [kWh/m²]

Flat Plate Heat saved [kWh/m2]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	412,44	440,57	385,44	244,76	292,67	382,05	230,03
	Class 2	289,52	253,78	216,40	187,78	110,82	133,73	123,12
	Class 3	---	---	187,61	188,48	75,25	56,73	83,26
	Class 4	---	---	---	201,17	79,63	71,61	69,38
	Class 5	---	---	---	161,80	104,53	57,05	65,02
	Exc. Cold	---	---	---	---	---	---	21,34

Flat Plate + HP Heat saved [kWh/m2]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	430,20	463,79	409,39	267,81	314,71	406,34	250,96
	Class 2	325,34	281,78	240,12	211,65	128,84	156,41	144,93
	Class 3	---	---	215,41	215,56	89,38	67,65	99,83
	Class 4	---	---	---	235,78	93,46	83,90	83,15
	Class 5	---	---	---	190,75	123,43	67,34	77,32
	Exc. Cold	---	---	---	---	---	---	24,81

-

Exccold zone.

Table 39remarks the extra energy obtained in kWh/m² terms or percentage when a heat pump is installed in a Flat Plate installation. Although there are relative high energy increases related to the use of heat pumps inside the dotted zones (right matrix), the absolute values of the extra energy produced are lowest ones (left matrix). This behaviour is directly related to the low solar irradiation available during the heating season in places comprised between D3 and Exccold-Exccold zone.

Table 39: Compared energy savings. FP vs. FP+HP in absolute and relative numbers

Increases due to HP + FP's [kWh/m2]		SummerClimatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	17,76	23,22	23,96	23,05	22,03	24,30	20,92
	Class 2	35,82	28,00	23,72	23,87	18,01	22,68	21,81
	Class 3	---	---	27,79	27,08	14,13	10,93	16,57
	Class 4	---	---		34,60	13,83	12,29	13,78
	Class 5	---	---		28,95	18,90	10,29	12,30
	Exc. Cold	---	---					3,47

Increases due to HP + FP's [%]		Summer Clinatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	4,3%	5,3%	6,2%	9,4%	7,5%	6,4%	9,1%
	Class 2	12,4%	11,0%	11,0%	12,7%	16,3%	17,0%	17,7%
	Class 3	---	---	14,8%	14,4%	18,8%	19,3%	19,9%
	Class 4	---	---		17,2%	17,4%	17,2%	19,9%
	Class 5	---	---		17,9%	18,1%	18,0%	18,9%
	Exc. Cold	---	---					16,3%

Table 40 represents the amount of energy delivered to the building during the cooling season related to the number of square meters installed (left matrix) and the ratio between the energy delivered in summer time vs total amount of energy delivered. This last matrix demonstrate in relative values how the system delivers a little bit more energy in Exc. Heat Summer zones during the four summer months than in rest of the year, underlining the prevalence of cooling needs against heating ones. Right-down movements in the table leads to more focalized heating facilities compared to the previous cooling ones.

Table 40: Saved Energy by an FP+HP facility along the cooling season and its ratio against yearly savings

Flat Plate + HP Summer Saves [kWh/m2]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	475,46	370,70	330,41	226,75	200,91	237,36	123,66
	Class 2	440,91	319,02	234,36	188,36	52,65	44,18	25,32
	Class 3	---	---	203,00	174,62	36,10	2,80	20,35
	Class 4	---	---	---	164,05	42,45	37,11	15,22
	Class 5	---	---	---	105,24	27,69	6,99	14,66
	Exc. Cold	---	---	---	---	---	---	1,72

Flat Plates + HP Summer vs Total [%]		Summer Climatic Severities's						
			Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	52,5%	44,4%	44,7%	45,8%	39,0%	36,9%	33,0%
	Class 2	57,5%	53,1%	49,4%	47,1%	29,0%	22,0%	14,9%
	Class 3	---	---	48,5%	44,8%	28,8%	4,0%	16,9%
	Class 4	---	---	---	41,0%	31,2%	30,7%	15,5%
	Class 5	---	---	---	35,5%	18,3%	9,4%	15,9%
	Exc. Cold	---	---	---	---	---	---	6,5%

Similar tables are obtained for the Evacuated tube cases, Table 41, with the logical increase of energy produced during the heating season by square meter of collector installed and with lower production differences between the two proposed facility layouts. In this case, the utilization of heat pumps does not produce great advantages along the here studied season, but it will allow more efficient cold water production during summer time.

Table 41: Saved Energy by an ETC field, alone and in combination with HP along the heating season

ETC's Heat saved [kWh/m2]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	541,68	576,06	510,55	367,35	416,86	506,62	342,06
	Class 2	377,30	344,82	304,47	285,14	211,06	255,56	244,60
	Class 3	---	---	299,50	294,03	167,69	134,36	185,70
	Class 4	---	---	---	322,05	194,12	160,85	159,69
	Class 5	---	---	---	300,80	236,21	150,52	159,94
	Exc. Cold	---	---	---	---	---	---	81,93

ETC's + HP Heat saved [kWh/m2]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	551,16	588,01	523,26	380,70	428,41	520,30	355,03
	Class 2	398,09	360,70	319,15	300,38	226,18	275,01	264,45
	Class 3	---	---	319,37	312,89	182,77	148,45	204,34
	Class 4	---	---	---	345,60	210,56	175,52	176,56
	Class 5	---	---	---	324,97	256,52	165,34	175,94
	Exc. Cold	---	---	---	---	---	---	89,30

Table 42: Compared energy savings. ETC vs. ETC+HP in absolute and relative numbers

Increases due to HP + ETC's [kWh/m2]		SummerClimatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	9,48	11,95	12,71	13,35	11,54	13,67	12,97
	Class 2	20,79	15,88	14,68	15,24	15,13	19,45	19,85
	Class 3	---	---	19,88	18,86	15,08	14,09	18,65
	Class 4	---	---	---	23,55	16,44	14,67	15,88
	Class 5	---	---	---	24,17	20,30	14,82	15,00
	Exc. Cold	---	---	---	---	---	---	7,37

Increases due to HP + ETC's [%]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1,7%	2,1%	2,5%	3,6%	2,8%	2,7%	3,3%
	Class 2	5,5%	4,6%	4,8%	5,3%	7,2%	7,6%	8,1%
	Class 3	---	---	6,6%	6,4%	9,0%	10,5%	10,0%
	Class 4	---	---	---	7,3%	8,5%	9,1%	10,6%
	Class 5	---	---	---	8,0%	8,6%	9,8%	10,0%
	Exc. Cold	---	---	---	---	---	---	9,0%

As it happened with the flat plate collectors, the single dotted zone correspondent with ETC's deliver much less energy to the building in both seasons than the worst zone of the other 25 climatic categories. (Around a 50% lower that eliminates the zone potentialities for ETC facilities)

Table 43: Saved Energy by an ETC+HP facility along the cooling season and its ratio against yearly savings

ETC's + HP Summer Saves [kWh/m2]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	634,91	505,45	457,59	338,43	322,49	327,67	187,11
	Class 2	568,77	426,80	328,13	276,14	95,56	79,86	48,48
	Class 3	---	---	305,56	258,29	74,51	6,23	43,27
	Class 4	---	---	---	245,48	96,76	78,73	32,90
	Class 5	---	---	---	185,50	58,64	17,41	34,18
	Exc. Cold	---	---	---	---	---	---	6,29

ETC's + HP Summer vs Total [%]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	53,5%	46,2%	46,7%	47,1%	42,9%	38,6%	34,5%
	Class 2	58,8%	54,2%	50,7%	47,9%	29,7%	22,5%	15,5%
	Class 3	---	---	48,9%	45,2%	29,0%	4,0%	17,5%
	Class 4	---	---	---	41,5%	31,5%	31,0%	15,7%
	Class 5	---	---	---	36,3%	18,6%	9,5%	16,3%
	Exc. Cold	---	---	---	---	---	---	6,6%

Finishing with the energetic substitution overview, some figures represent the coverage factor for each of the layouts and compared by solar technologies. In a first couple of figures, Table 44, shows the total coverage factor when using simple Flat Plate or Evacuated Tube Collector facilities. Differences between both factors in energetic terms remain small in most of the cases.

Table 45 and Table 46 discriminate the building demand in heating and cooling season respectively, being also obtained similar results in comparative terms, although in following chapters will be evaluated the same values from an economical point of view, to decide which technology is better for each zone. An interesting aspect can be appreciated in Table 46, where zones B3, C5, E2, E4, and ExcCold3 to 5 cover nearly the complete cooling demand with the use of a thermal heat pump, this means that there is nearly no need to use the gas boiler during the heating season to assure internal comfort . It also can be appreciated how the solar system is optimized to cover in winter time the demand of warm zones and summer time demands for coldest places avoiding over-dimensioning and over-heating periods that create damages to the collectors and disturbances to the facility. In case of overheating, solar facilities should be partially covered to avoid stagnation temperatures or some heat evacuators should be installed distributed among the collector lines, increasing the installation costs

Table 44: Coverage from the total building demand delivered by a solar facility without thermal heat pump

Flat Plate Coverage Factor [%]		Summer Climatic Severities's						
			Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	78,7%	76,5%	75,1%	71,2%	71,0%	73,7%	70,5%
	Class 2	64,7%	67,8%	67,6%	64,3%	63,0%	60,5%	61,4%
	Class 3	---	---	59,5%	60,2%	58,3%	59,4%	57,7%
	Class 4	---	---	---	56,4%	56,5%	56,6%	55,1%
	Class 5	---	---	---	53,5%	54,6%	56,3%	54,8%
	Exc. Cold	---	---	---	---	---	---	55,8%

ETC's Coverage Factor [%]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	81,1%	79,2%	78,2%	75,7%	76,1%	77,0%	75,3%
	Class 2	70,0%	73,0%	72,5%	69,0%	67,4%	63,0%	64,0%
	Class 3	---	---	62,6%	64,1%	62,6%	63,2%	60,4%
	Class 4	---	---	---	60,3%	59,7%	59,2%	58,6%
	Class 5	---	---	---	55,6%	57,0%	59,2%	57,5%
	Exc. Cold	---	---	---	---	---	---	58,5%

Table 45: Coverage from the heating building demand delivered by a solar facility with thermal heat pump

Flat Plate + HP Coverage Factor Winter [%]		Summer Climatic Severities's						
			Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	82,0%	80,3%	79,6%	77,8%	76,3%	78,4%	76,8%
	Class 2	72,6%	75,2%	74,9%	72,4%	72,9%	70,4%	72,0%
	Class 3	---	---	68,3%	68,9%	69,1%	70,8%	69,1%
	Class 4	---	---	---	66,1%	66,3%	66,2%	66,1%
	Class 5	---	---	---	63,0%	64,4%	66,4%	65,1%
	Exc. Cold	---	---	---	---	---	---	64,9%

ETC's + HP Coverage Factor Winter [%]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	82,5%	80,8%	80,1%	78,4%	78,2%	79,1%	78,1%
	Class 2	73,9%	76,4%	76,0%	72,6%	72,0%	67,6%	69,1%
	Class 3	---	---	66,7%	68,2%	68,1%	69,8%	66,4%
	Class 4	---	---	---	64,7%	64,7%	64,5%	64,7%
	Class 5	---	---	---	60,1%	61,8%	65,0%	63,3%
	Exc. Cold	---	---	---	---	---	---	63,8%

Table 46: Coverage from the summer building demand delivered by a solar facility with thermal HP

Flat Plate + HP Coverage Factor Summer [%]		Summer Climatic Severities's						
			Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	32,9%	29,0%	36,1%	55,2%	29,1%	55,5%	64,8%
	Class 2	67,4%	70,9%	69,6%	81,9%	55,4%	88,9%	75,2%
	Class 3	---	---	91,9%	85,2%	54,5%	69,2%	98,1%
	Class 4	---	---	---	85,2%	72,6%	98,1%	92,4%
	Class 5	---	---	---	98,4%	46,2%	64,3%	93,0%
	Exc. Cold	---	---	---	---	---	---	100,0%

ETC's + HP Coverage Factor Summer [%]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	34,6%	31,4%	39,4%	58,8%	35,1%	60,4%	70,1%
	Class 2	72,3%	75,3%	73,9%	84,2%	55,7%	87,7%	75,2%
	Class 3	---	---	90,7%	85,7%	54,0%	69,2%	97,8%
	Class 4	---	---	---	84,7%	71,8%	97,3%	92,3%
	Class 5	---	---	---	97,4%	45,3%	64,0%	92,6%
	Exc. Cold	---	---	---	---	---	---	100,0%

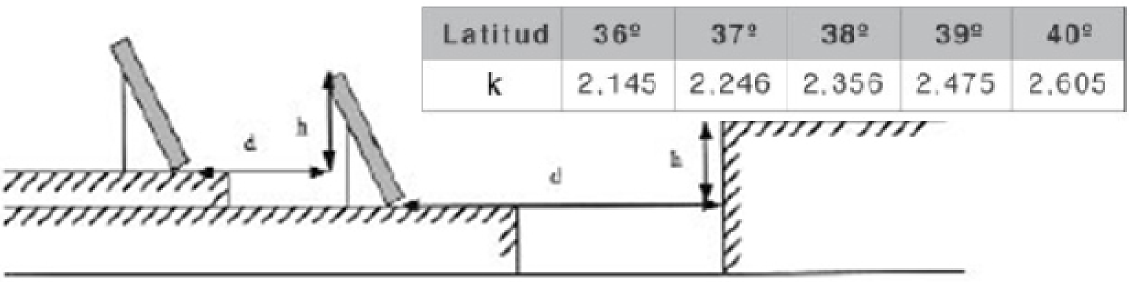
6.1 Number of square meters needed to cover partially building demands.

As it was explained in the chapter dedicated to introduce the methodology followed in this work, heating demands (where space heating and DHW are included) and cooling ones (where DHW and cooling are included) for each location have been evaluated as well as the potential energy to be collected from the sun. All the three curves has been compared in a monthly base to determine for which season was the solar facility optimized (number of collectors and tilted angle over the horizontal), covering the maximum demand in that period, without overheating the solar plant along the year. In this way, it is clear that the solar plant will not be able to deliver 100% of the energy demanded but it is assured that the facility will not be over dimensioned. By obviating over-dimensioning problems, it will be avoided long return of investment periods caused by larger investment costs.

As a limiting factor, it will be settled the maximum area covered by collectors. Supposing a nearly flat roof, south faced collectors and Equation 29, it is determined the maximum collector area that can be installed on the roof. Values overpassing that number will be considered not acceptable for solar based systems. Table 47 represents the maximum accepted surface of solar collectors for each climatic condition.

Equation 29: Distance between collector rows for determinate latitude and collector tilted angles (h= f(α))

$$d = \frac{h}{tg(61 - k)}$$



Latitud	36º	37º	38º	39º	40º
k	2,145	2,246	2,356	2,475	2,605

Figure 42: Parameter d is defined to assure the inexistence of internal shadows on the solar plant

Table 47: Maximum accepted solar collector area by climatic zone [m^2]

Maximum m2 to be installed		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	64,32	64,72	63,70	63,52	65,78	64,08	65,64
	Class 2	63,85	64,32	64,62	64,19	64,23	64,46	65,93
	Class 3	---	---	63,42	64,52	64,02	63,84	65,71
	Class 4	---	---	---	64,03	62,85	64,34	65,06
	Class 5	---	---	---	62,78	62,74	61,97	63,55
	Exc. Cold	---	---	---	---	---	---	61,58

Intersecting solar energy production curves and building demands are obtained the following results for the two collector types studied. Table 48 represents the amount of FP collectors needed to cover the demand while Table 49 does it with ETC's for the given methodology.

Table 48: Optimize Flat Plate Collector area classified by climatic zones [m^2]

Flat Plate [m^2]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	8,59	8,08	9,57	16,93	12,51	9,47	16,38
	Class 2	16,62	17,98	22,21	25,94	47,27	41,53	50,66
	Class 3	---	---	27,53	28,69	77,04	116,06	79,45
	Class 4	---	---	---	28,61	76,79	85,44	93,54
	Class 5	---	---	---	37,44	73,14	139,61	106,34
	Exc. Cold	---	---	---	---	---	---	444,03

Table 49: Optimize Evacuated Tubes Collector area classified by climatic zones

Evacuated Tubes [m^2]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	6,75	6,41	7,53	12,01	9,42	7,46	11,78
	Class 2	13,82	14,26	16,94	18,29	26,49	22,56	26,55
	Class 3	---	---	18,12	19,57	37,09	52,13	37,22
	Class 4	---	---	---	19,09	33,27	39,79	43,15
	Class 5	---	---	---	20,96	33,85	55,62	45,39
	Exc. Cold	---	---	---	---	---	---	121,24

The first boundary conditions appear when comparing the limits expressed in Table 47 against the calculated collector area obtained in Table 48 and Table 49. One climatic zone will be clearly eliminated from the study; the correspondent to excessive cold summers and winters is not considered an acceptable place to install solar collectors for heating or cooling purposes under the scope studied in this work. Some other zones are accepted as potential places to install ETC and not for Flat plates. The highest efficiencies of ETC's, caused by their lower thermal losses, allow in a first iteration their installation in cold places (Table 50)

Table 50: Reduced number of zones where the study will be followed filtered by collector area

Flat Plate [m^2]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	8,59	8,08	9,57	16,93	12,51	9,47	16,38
	Class 2	16,62	17,98	22,21	25,94	47,27	41,53	50,66
	Class 3	---	---	27,53	28,69	---	---	---
	Class 4	---	---	---	28,61	---	---	---
	Class 5	---	---	---	37,44	---	---	---
	Exc. Cold	---	---	---	---	---	---	---

Evacuated Tubes [m^2]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	6,75	6,41	7,53	12,01	9,42	7,46	11,78
	Class 2	13,82	14,26	16,94	18,29	26,49	22,56	26,55
	Class 3	---	---	18,12	19,57	37,09	52,13	37,22
	Class 4	---	---	---	19,09	33,27	39,79	43,15
	Class 5	---	---	---	20,96	33,85	55,62	45,39
	Exc. Cold	---	---	---	---	---	---	---

6.2 Economical parameters.Installation costs

In this subchapter it will be evaluated, from an economical point of view, payback periods of the proposed layouts against classical heating and cooling systems widely installed in the residential market. It is remarked by the authors, the wrong logic that remains behind the cost evaluation of environmental improvements. Although, Return of Investment (ROI) is a widely spread variable used to decide the installation of energy systems, this cost parametrization doesn't consider the benefits of ambient pollution decreases or life quality increases, associated to the use of substitutive,and nowadays available energy generation methods based in renewable energies.

Further evaluations have being done treating all the defined climatic zones, although there were previously accepted zones which assure the unfeasibility of the technologies when the classification is done in base to the maximum allowable collector area to be installed on the 100m^2 building roof. The corresponding zones previously eliminated are represented with dotted cells in the following figures.Investments costs related to collectors and heat pumps, as well as operating costs have been considered with the intention of evaluate the facilities from an economical point of view.

6.2.1 Collectors Market: Results based on collector price variation.

The first economical parameter to be evaluated in this work has been collector prices and the potential decreases within the following years.

Solar thermal sector in the EU, presents a semi-steady growth rate the last decades, increasing with the additional features and type of use that the newmore advanced systems provide, numbering about 3.05 million square meters area of installed collectors in 2013 as relates ESTIF 2014

Figure 43 represents the evolution of the capacity installed in the last 10 years, being clearly differentiable the maximum installation peak before 2008 where the last economic crises hit hardly the installation of new solar thermal plants.

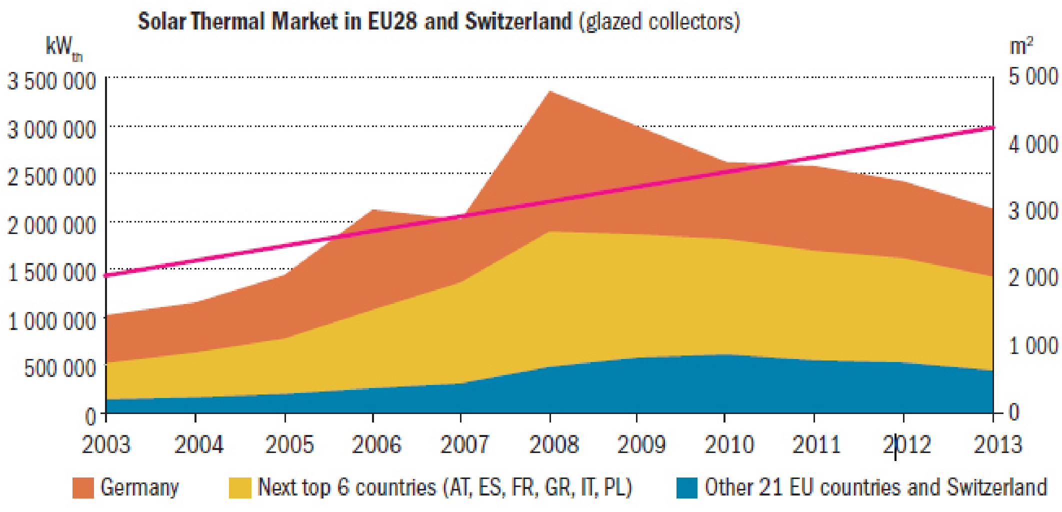


Figure 43: EU+27 Solar Thermal market evolution [ESTIF]

The majority of solar-thermal systems, which accounts for 90% of the installed capacity in Europe, is designated for the supply of domestic hot water at single family house units, while the remaining is equally split between systems of domestic hot water at multi-family house units, and combi-systems for single family houses that provide both hot water and space heating. The market portion of the abovementioned type of systems however varies among the various countries.

In addition, a number of large scale solar thermal installations based in countries like Denmark, Sweden, Germany and Austria are committed for supplying heat to district heating networks. Some of them are also coupled with seasonal heat storage. In this work, the two layouts considered for each one of the solar collectors doesn't take into consideration any kind of governmental economical measurement based on efficiency nor energy savings, being the prices studied the ones that a final user should pay to get the facility working in their places.

Figure 44 represents monetary cost for the two considered thermal collectors, avoiding the installation costs, as a function of the solar plant size. [Henning,2012]

- Initial prices for FP collectors are around 550 €/m^2. while the most economical price ends in 200€/m^2
- Initial prices for ETC's are closed to 700€/m^2 while the cheapest one is near to 350€/m^2.
- The ETC prices are decreasing drastically due to the massive production in Asiatic countries. Previous prices correspond to the year 2012 when nowadays, 2014 it is possible to find in Germany ETC systems with prices around 200€/m^2. Flat plate collectors haven't had this drastically price fall down because they aren't an object of interest to be manufactured in Asia.
- It is assumed by the author that installation costs of the solar plant represent a quantity closed to 200€/m^2 that includes, piping, heat exchangers, pumps, and all the needed components to let the facility run properly

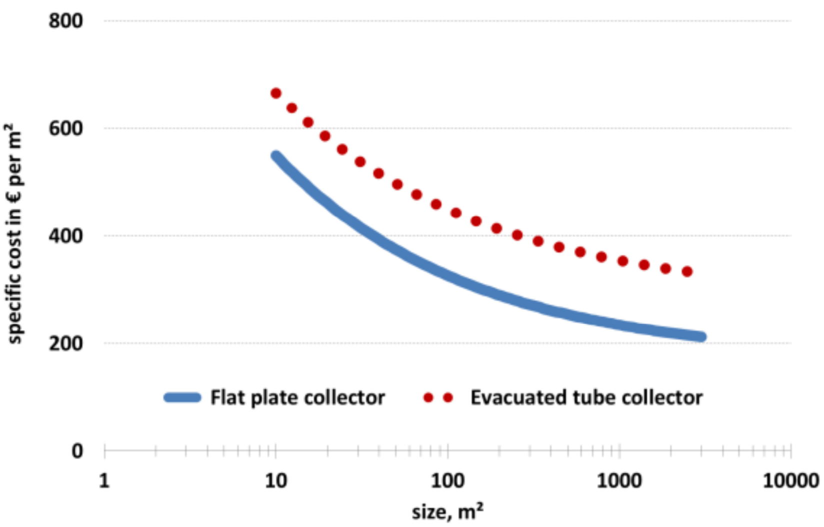


Figure 44: Cost figures of solar thermal collectors (without installation cost) (source Delphi)

Different prices were evaluated inside this work to test the variation of simple ROI for each facility layout. The large amount of variables studied led the author to fix all prices and magnitudes previously exposed and change only the studied ones to understand the implication of those in the final economic viability of the system.

The climatic zones that would not have simple return of investment periods under the limit of 20 years will be marked as places where the solar collector price doesn't play any economic saving role for the studied solar facilities.

From the previously visited data, installation prices under 400€/m^2 for flat plate collectors will be considered, at least nowadays, unfeasible (200€/m^2 for the collector and other 200€m/^{2} needed for installation and needed components) and the corresponding zones will be marked as not accepted for savings based in decreasing installation prices. For the ETC cases, the limit will be fixed in 530€/m^2 (ETC costs ratio is considered 330/200 for collectors and installation).

Table 51: FP collector prices (€/m^2) installed that assure simpleROI=20 years (facilities with and without HP)

Flat Plate Preis for ROI=20		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	829,87	858,36	793,65	492,61	543,48	666,66	462,96
	Class 2	578,03	480,77	401,61	384,62	235,29	213,21	221,24
	Class 3	---	---	394,47	323,62	148,92	120,00	163,80
	Class 4	---	---	---	351,49			
	Class 5	---	---	---	621,12			
	Exc. Cold	---	---	---	---	---	---	

Flat Plate + HP Preis for ROI=20		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1534,14	1151,35	1134,74	882,45	801,28	920,61	575,00
	Class 2	1598,07	1170,70	917,15	863,89	280,23	235,09	267,41
	Class 3	---	---	912,91	683,92	181,60	136,26	195,79
	Class 4	---	---	---	800,98			
	Class 5	---	---	---	959,52			
	Exc. Cold	---	---	---	---	---	---	

Table 51 represents the FP's collector prices that assure a 20 years simple ROI. It is clear in this case, how the warmest winter zones have always values over 400€/m^2.

It should be noticed:

- There are seven climate zones which doesn't contain any data. D4, D5, E4, E5, ExcCold4, ExcCold5 and ExcColdExcCold deliver negative price numbers as potential prices to be economically profitable, so the results have been zeroed.
- The potential savings based on FP collector prices are higher as we moved to the top left part of both tables.
- Only 10 zones from 28 are under the limit of 400€/m2. The 7 class1 winter zones, the two warmest summer zones of winter class 2 and C5.
- The combination of the solar plant with a thermal heat pump add to the potential saving zones B3, C2, C3 and C4.
- The combination of the solar plant with a thermal heat pump increases the savings potentials for every climatic zone, although it still remain not accepted as potential saving zones the ones comprised into the matrix defined by D2 and ExcColdExcCold.

Table 52: ETC's prices (€/m²) installed that assure simpleROI=20 years (facilities with and without HP)

ETC Preis for ROI=20		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1092,90	1129,94	1052,63	740,74	763,36	913,24	687,29
	Class 2	751,88	664,45	586,51	573,37	464,04	424,62	446,43
	Class 3	---	---	641,03	542,01	331,67	280,11	371,05
	Class 4	---	---	---	586,51	365,63	325,20	
	Class 5	---	---	---	985,22			
	Exc. Cold	---	---	---	---	---	---	

ETC + HP Preis for ROI=20		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	2032,86	1556,83	1556,74	1281,97	1195,30	1266,47	861,99
	Class 2	2042,45	1554,42	1217,72	1150,78	527,92	439,43	503,69
	Class 3	---	---	1344,15	1041,41	396,52	299,21	410,76
	Class 4	---	---		1050,97	436,74	364,97	
	Class 5	---	---		1374,63			
	Exc. Cold	---	---					

Table 52 show the potential saving zones when ETC's with (right matrix) and without (left matrix) heat pumps are used. In this case the limits are placed in 530€/m².

- As It happened for the FPcase, there are some zones which negative results are not plotted, but for ETC cases, appear two new zones D4 and E4, not existing in FP case.
- Both plots reveal feasible economic savings for the same zones that FP+HP facility did.
- As it happened for the FP, the ETC cases also increases the saving potentials with the use of heat pumps.
- Both studied ETC layouts habilitate the same "collector price" based potential saving zones.

Table 53: Potential monetary saving zones based on collector installation prices for both FP's and ETC's

Potential zones Collector price based ROI=20yr		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1							
	Class 2							
	Class 3	---	---					
	Class 4	---	---	---				
	Class 5	---	---	---				
	Exc. Cold	---	---	---	---	---	---	

As a conclusion of the subchapter, Table 53 shows the zones where the decrease of collector costs could be a tool to obtain acceptable simple ROI results. For the both studied solar collector technologies there are coincident zones where scales economies would not affect the ROI. (Matrix D2 to ExcColdExcCold). It is also a certain number of zones, where flat collectors without being combined with heat pumps would not be chosen as feasible (green coloured crossed zones B3, C2, C3 and C4).

6.2.2 *Heat Pump Market: Results based on HP price variation.*

The second parameter to be studied is the Heat Pump installation costs for the two cases where the solar facility collects energy to produce cooling.

Henning 2012, presents the specific costs [€/kW] for some cooling components, Figure 45.

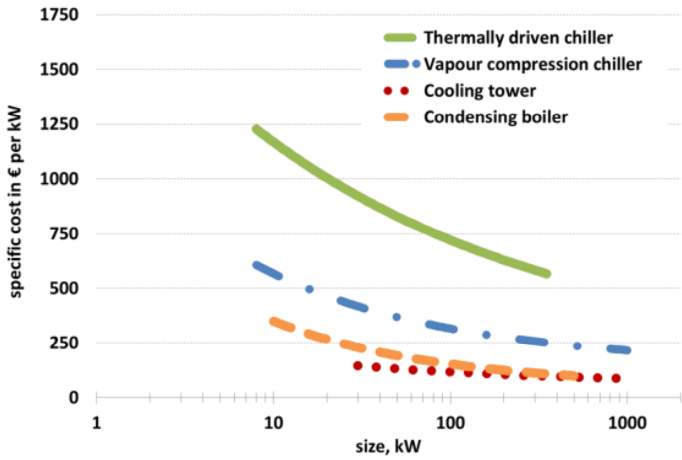


Figure 45: Cost figures for other components used in the evaluation study

The need of a chiller and a cooling tower to evacuate the condensing energy along the summer season, made necessary the sum of both cost by chilling kW installed. In this case the limit will be placed in 900€/kW chiller installed.

The evaluation results are represented in Table 54 where Flat Plate and ETC facilities are compared:

- In both cases there are a number of zones where the HP costs plays no role to obtain quicker return of investment cost, because the resulting values became negative.
- In both cases ExcCold1 class needs of HP prices under 900 €/kW to reach simpleROI=20 years.
- There are two zones where FP facilities nearly doesn't get influenced by HP installation prices.
- For every considered zones inside Table 54, it is easily to obtain better simple ROI's in combination with Flat Plates than with Evacuated Tube Collectors. The logic behind these numbers resides in the system total efficiency increase, that is much more important with the use of flat plate collectors for winter production. (ETC's efficiencies doesn't vary much with the temperature changes while PF's does)

Table 54: Heat Pump prices (€/kWcooling) installed that assure simpleROI=20 years (FP and ETC's)

Flat Plate HP price ROI=20		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1837.4	1387.5	1449.9	1321.3	1106.3	1356.7	526.5
	Class 2	3001.1	2193.9	1417.3	1320.6	---	---	---
	Class 3	---	---	1820.7	832.0	---	---	---
	Class 4	---	---	---	804.3	---	---	---
	Class 5	---	---	---	2143.3	---	---	---
	Exc. Cold	---	---	---	---	---	---	---

ETC HP price ROI=20		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1841.6	1343.3	1455.9	1356.2	1211.0	1312.7	597.7
	Class 2	2928.8	2123.7	1421.7	1338.9	---	---	---
	Class 3	---	---	1891.9	1021.0	---	---	---
	Class 4	---	---	---	1065.1	---	---	---
	Class 5	---	---	---	2143.3	---	---	---
	Exc. Cold	---	---	---	---	---	---	---

To conclude the HP price subject, Table 55 , represent the zones where independently of the solar technology, HP prices can help reducing the investment cost to get lower simpleROI's.

- Plane green zones: Zones where there is economic saving potential on the HP installation to get Lower simpleROI's.
- Crossed green zones: C3 and C4 play only an economic role based on HP prices when combined with ETC's
- Plane red zones: Places where a decrease in the HP installation costs would not allow a simpleROI period lower as 20 years.

Table 55: Potential monetary saving zones based on HP installation prices for both FP's and ETC's

Potential zones HP price based ROI=20yr		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1							
	Class 2							
	Class 3	---	---					
	Class 4	---	---	---				
	Class 5	---	---	---				
	Exc. Cold	---	---	---	---	---	---	---

6.3 Economical parameters.Operational costs

Once that the facilities were studied from two different points of view, acceptable solar areas and installation costs, the operational costs will be pointed, evaluating the savings as opportunity costs. The kind of solar facilities proposed save gas and electricity when compared to typical layout facilities.

6.3.1 Fossil fuel savings: Results based on gas price variation

For the studied solar facilities, gas is the fuel that 100% drives the comparative system during the heating season, and acts as backup from the solar system to cover the building heating and cooling demands when there is not enough solar radiation.

As it has been described previously, in the building description chapter, for most of the studied climates, there is a prevalence of the heating demands over the cooling ones, what makes gas savings particularly important to give viability to the proposed installations.

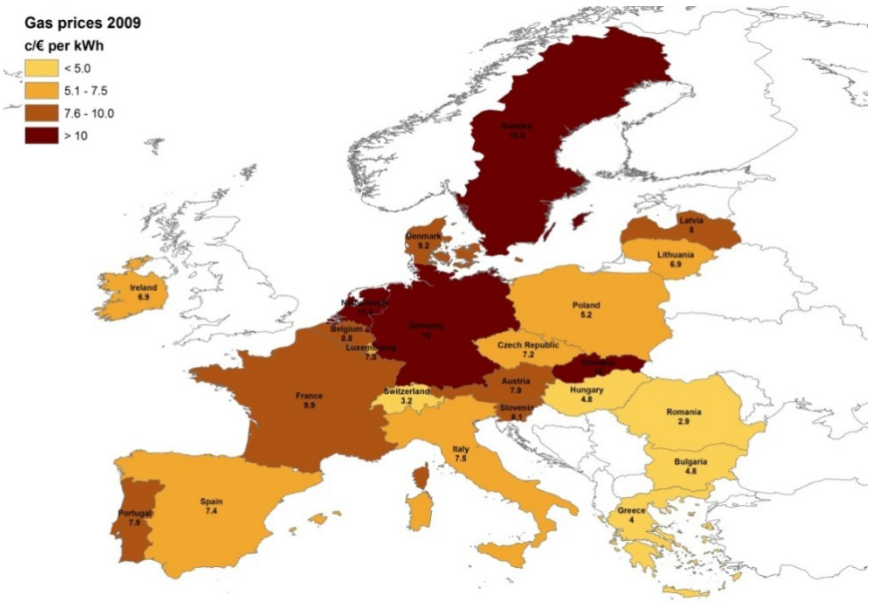
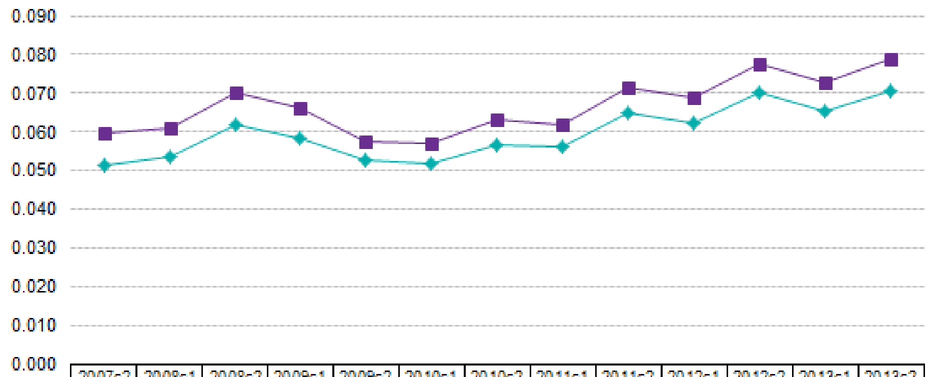


Figure 46: Gas prices around Europe 2009 [SC+ project]

Gas prices are constantly rising, and since the publication of Figure 46. The last available data from Eurostat before finishing this work, year 2013 denotes a yearly price increase of 4.6% since 2009. Figure 47 represents the actual European averaged natural gas prices with taxes and their evolution while Figure 48 represents in a graphical way the share of taxes and levies in the final gas price organized by countries. Table 56 contains the numerical values [93].



	2007s2	2008s1	2008s2	2009s1	2009s2	2010s1	2010s2	2011s1	2011s2	2012s1	2012s2	2013s1	2013s2
EU-28	0.051	0.054	0.062	0.058	0.053	0.052	0.057	0.056	0.065	0.063	0.070	0.065	0.071
EA	0.060	0.061	0.070	0.066	0.058	0.057	0.063	0.062	0.071	0.069	0.078	0.073	0.079

Figure 47: EU-28 & EA natural gas prices evolution (household consumers, 2013s2 [EUR/kWh]

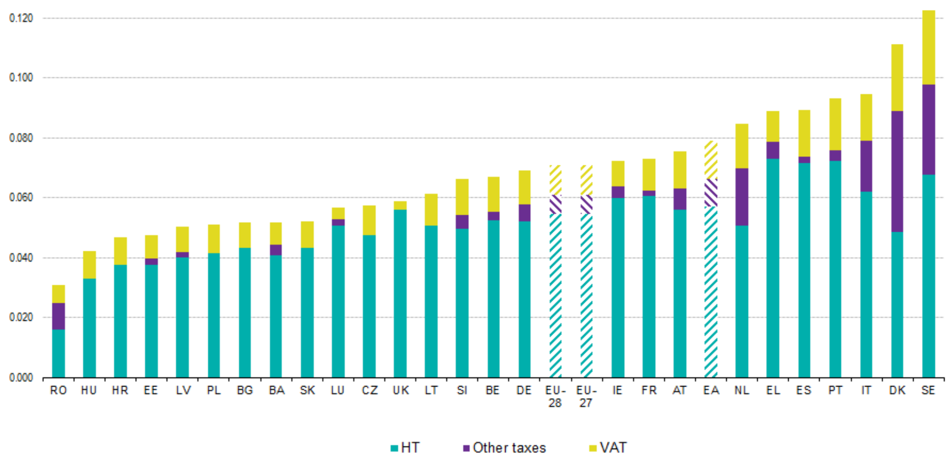


Figure 48: Average gas price for households per 100kWh in 2nd half of 2013, in euro

The last available gas prices published by Eurostat, 0.079€/kWh_{gas}, serves us as limit to compare if each classified zone are in a “potential” saving situation and the role of the gas prices in the potential savings. Table 57 and Table 58 contain the gas prices, ordered by climatic zones, which assure a simple ROI of 20 years. In both cases the results for the HP based system are placed on the right matrix.

Table 56: Natural gas - share of taxes and levies paid by household consumers, 2013s2 (%)

	Basic price	Other taxes and levies (excl. VAT)	VAT	All taxes and levies
		in EUR per kWh		
BE	0.052	0.003	0.012	21.71%
BG	0.043	0.000	0.009	16.60%
CZ	0.048	0.000	0.010	17.39%
DK	0.049	0.040	0.022	56.38%
DE	0.052	0.006	0.011	24.67%
EE	0.037	0.002	0.008	21.43%
IE	0.060	0.004	0.009	17.04%
EL	0.073	0.006	0.010	18.02%
ES	0.071	0.002	0.016	19.96%
FR	0.061	0.002	0.011	16.87%
HR	0.037	0.000	0.009	20.09%
IT	0.062	0.017	0.016	34.36%
LV	0.040	0.002	0.009	20.83%
LT	0.051	0.000	0.011	17.43%
LU	0.051	0.002	0.004	10.25%
HU	0.033	0.000	0.009	21.19%
NL	0.051	0.019	0.015	40.19%
AT	0.056	0.007	0.013	25.73%
PL	0.041	0.000	0.010	18.66%
PT	0.072	0.004	0.017	22.51%
RO	0.016	0.009	0.006	47.56%
SI	0.050	0.005	0.012	25.23%
SK	0.043	0.000	0.009	16.57%
FI	:	:	:	:
SE	0.068	0.030	0.025	44.69%
UK	0.056	0.000	0.003	4.76%
MK	:	:	:	:
TR	:	:	:	:
BA	0.041	0.004	0.008	21.62%

From the comparison of the four matrixes, it can be realized:

- Climates positioned on the bottom right part of the matrixes give prevalence to the ETC's against FP's, although the resulting gas comparative prices are so elevated that in practice does not give allowable economical potentials. (It should be noticed that the gas prices increased an average of 3.44% yearly in the last 7 years, what means a round price about 0.098€/kWh natural gas in 2020)
- Flat collector systems, in both configurations, are more sensible to a decrease of the gas prices in zones where cooling is the load with priority. (Summer classifications ExcHeat 1 and 2, A1, A2 and B1)(left position of the red line plotted over Table 56 and Table 58)
- Evacuated tube collector systems, (with and without HP) are in all the other climates, easily to be an economical investment (right position of the red line, Table 56 and Table 58)
- No facility without Heat Pump reaches the 20 years simpleROI limit when gas prices are the unique controlled element. Only Exc.Heat1, A1 and B1 zones would be profitable in 2020 from the gas price point of view.
- As it has happened in previous studies along this work, the matrix defined by D2 as inferior limit and ExcCold, ExcCold is not affected in terms of gas price decrease to obtain acceptable simple ROI's. (Gas prices needed in that zones duplicate the price forecast for 2020, what means with a linear extrapolation of the prices, that until 2040 will not be a configuration able to do it profitable zone D1 with ETC's & HP when only the gas price is considered as studied variable)
- Heat pump facilities are in the economical profitable zones since now for locations placed on the left side of the blue line plotted over HP matrixes of Table 56 and Table 58 plus C5 locations
- Heat pump facilities combined with ETC have more possibilities of being profitable than the FP ones in every case where heating is the prevalent demand.

Table 57: Gas Prices in cent€ that assure a simpleROI of 20 years for facilities installed with FP collectors

Flat Plate gas prices ROI=20	Summer Climatic Severities's						
Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	8.42	8.14	8.83	14.21	14.89	10.51	15.12
Class 2	12.12	14.55	17.45	18.19	29.77	32.84	31.65
Class 3	---	---	17.76	21.64	42.75	58.78	43.24
Class 4	---	---	---	19.91	46.39	41.01	49.07
Class 5	---	---	---	11.26	47.80	54.14	70.26
Exc. Cold	---	---	---	---	---	---	82.00

Flat Plate + HP gas prices ROI=20	Summer Climatic Severities's						
Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	4.50	6.88	6.61	7.56	9.03	7.89	12.43
Class 2	2.88	5.04	7.84	8.65	25.00	28.83	26.70
Class 3	---	---	7.16	10.71	39.37	50.21	36.04
Class 4	---	---	---	10.74	40.77	33.27	41.64
Class 5	---	---	---	7.33	43.21	46.49	62.24
Exc. Cold	---	---	---	---	---	---	67.25

Table 58: Gas Prices in cent€ that assure a simpleROI of 20 years for facilities installed with ET collectors

ETC gas prices ROI=20		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	9.13	8.83	9.50	10.15	13.11	10.94	14.53
	Class 2	13.31	15.06	17.06	17.35	21.55	23.55	22.41
	Class 3	---	---	15.62	18.44	30.13	35.72	26.95
	Class 4	---	---	---	17.07	27.36	27.26	30.76
	Class 5	---	---	---	13.52	32.25	30.75	35.51
	Exc. Cold	---	---	---	---	---	---	39.42

ETC + HP gas prices ROI=20		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	4.63	6.98	6.66	7.76	8.51	8.13	12.00
	Class 2	3.19	5.40	7.89	8.60	19.20	22.20	20.06
	Class 3	---	---	6.84	9.85	26.19	32.73	24.30
	Class 4	---	---	---	9.71	23.90	22.39	27.27
	Class 5	---	---	---	7.31	25.76	27.66	32.25
	Exc. Cold	---	---	---	---	---	---	35.26

To conclude the study about the influence of natural gas prices on the economic feasibility of the proposed solar thermal facilities, it has been created Table 59, where it is denoted:

- Green cells: Climatic zones where HP based facilities obtain advantage of the natural gas prices to get simpleROI's lower as 20 years.
- Green cells with a single diagonal line: Zones where solar facilities without HP installed is closed to 20 years simpleROI in a next future.(Prices around 0.1€/kWhgas)
- Crossed green cells: zones where HP +FPC's doesn't reach a minimum simpleROI value with the actual gas price increases in at least 10 years.
- Red cells: Places where gas prices does not play any role to quickly reach acceptable payback periods.

Table 59 Potential monetary saving zones based on natural gas prices for all the studied facilities

Potential zones Gas price based ROI=20yr		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1							
	Class 2							
	Class 3	---	---					
	Class 4	---	---	---				
	Class 5	---	---	---				
	Exc. Cold	---	---	---	---	---	---	---

6.3.2 Electrical savings: Results based on electricity price variation

Electricity savings for the studied facilities are due to the driven energy not used by the electrical chillers to cover building cooling demands. It is clearly understandable that will be only considered for the solar facilities installed in combination with thermal heat pumps with the ability of working in dual heat pump/chiller mode.

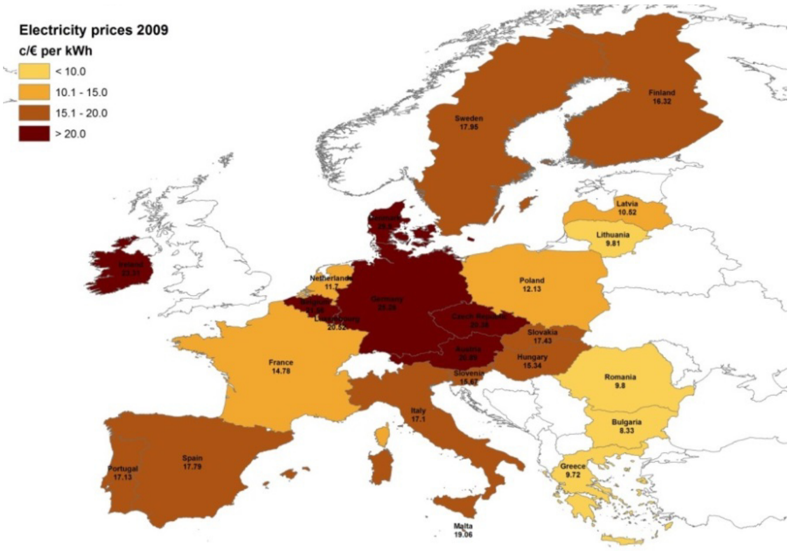
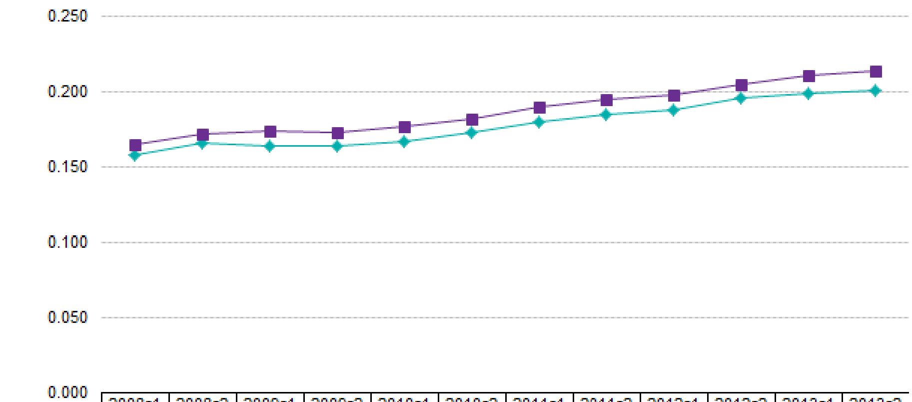


Figure 49: Electricity prices around Europe 2009 [SC+ project]



	2008s1	2008s2	2009s1	2009s2	2010s1	2010s2	2011s1	2011s2	2012s1	2012s2	2013s1	2013s2
EU-28	0.158	0.166	0.164	0.164	0.167	0.173	0.180	0.184	0.188	0.195	0.199	0.201
EA	0.165	0.172	0.174	0.173	0.177	0.182	0.190	0.195	0.198	0.205	0.211	0.213

Figure 50: EU-28 & EA electricity prices evolution (household consumers, 2013s2 [EUR/kWh]

In the same mode, that it has being commented previously for natural gas, electricity prices have been growing constantly around a 4.14% yearly for the last years. Price variations were more stable than for natural gas, there were fewer oscillations. Figure 50 represents the actual European averaged electrical prices with taxes, levies and network costs, while Figure

48 represent in a graphical way the share of the previously mentioned components in the final electrical price organized by countries. Table 61 contains the numerical values [93].

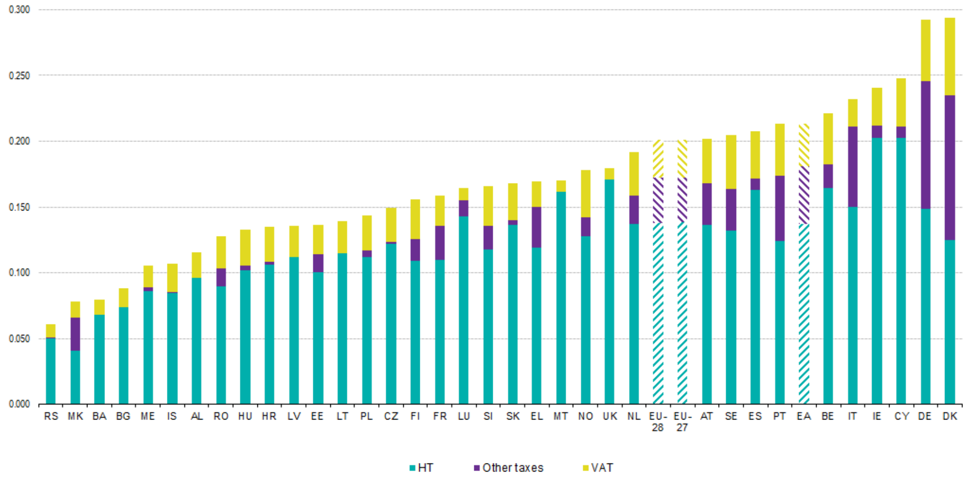


Figure 51: Average electricity price for households per 100kWh in 2nd half of 2013, in euro

The last available electricity prices published by Eurostat, 0.213€/kWh$_{elec}$, serves us as limit to compare if each classified zone are in a "potential" saving situation and the role of the electricity prices in the potential savings. Table 60 contains the electricity prices, ordered by climatic zones, which assure a simple ROI of 20 years.

Table 60: Electricity prices in cent€ that assure a simpleROI of 20 years for HP based solar facilities

Flat Plate + HP elect. prices ROI=20		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	7.94	10.23	9.82	11.96	13.20	11.13	19.80
	Class 2	6.71	8.95	12.13	12.90	---	---	---
	Class 3	---	---	10.93	15.64	---	---	---
	Class 4	---	---	---	15.76	---	---	---
	Class 5	---	---	---	8.39	---	---	---
	Exc. Cold	---	---	---	---	---	---	

ETC + HP elect. prices ROI=20		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	7.68	10.53	10.12	11.74	12.62	11.64	18.55
	Class 2	7.36	9.55	12.20	12.85	---	---	---
	Class 3	---	---	10.47	14.46	---	---	---
	Class 4	---	---	---	14.25	---	---	---
	Class 5	---	---	---	8.60	---	---	---
	Exc. Cold	---	---	---	---	---	---	

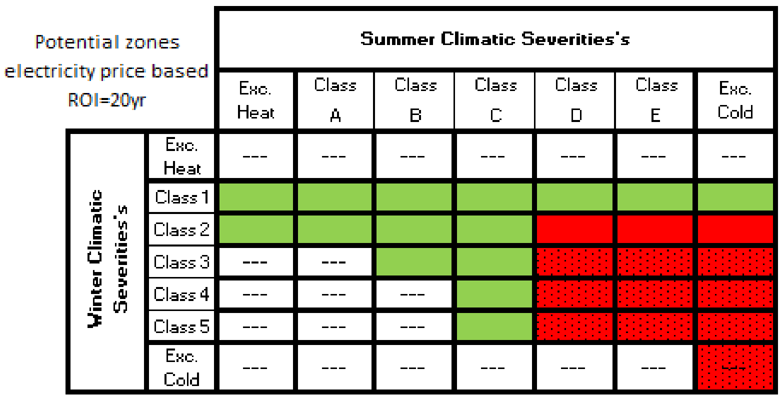
For this particular variable, both matrixes reveals similar results in terms of electricity prices needed to obtain simpleROI of 20 years., with greater savings in zones where summer season is warmer, as it should be logical to think. (This installation is only used from May to September)

It is clearly seen how, again, in zones belonging to the matrix D2 to ExcColdExcCold the variation of electrical prices doesn't play any role in the profit-earning capacity of the facility. That result is understood from the idea of how low is the cooling demand of the building in all that zones. This explanation is represented in Table 62

Table 61: Disaggregated price data for household consumers 2013s2 (EUR/kWh)

	Composition of the electricity prices for household consumers (in € perkWh)				Share in price without taxes and levies (in %)	
	Total price	Energy and supply	Network costs	Taxes and levies	Energy and supply	Network costs
Belgium	0.222	0.071	0.093	0.057	43.21%	56.79%
Bulgaria	0.088	0.044	0.029	0.015	60.00%	40.00%
Czech Republic	0.149	0.044	0.078	0.027	36.14%	63.86%
Denmark	0.294	0.048	0.077	0.169	38.67%	61.33%
Germany	0.292	0.087	0.062	0.143	58.16%	41.84%
Estonia	0.137	0.048	0.053	0.036	47.57%	52.43%
Ireland	0.241	0.125	0.078	0.038	61.52%	38.48%
Greece	0.170	0.093	0.027	0.050	77.79%	22.21%
Spain	0.208	0.130	0.033	0.044	79.72%	20.28%
France	0.159	0.058	0.052	0.049	52.87%	47.13%
Croatia	0.135	0.063	0.043	0.029	59.53%	40.47%
Italy	0.232	0.106	0.044	0.082	70.89%	29.11%
Cyprus	0.248	0.165	0.037	0.045	81.56%	18.44%
Latvia	0.136	0.056	0.056	0.024	49.73%	50.27%
Lithuania	0.139	0.049	0.066	0.024	42.87%	57.13%
Luxembourg	0.165	0.070	0.073	0.022	48.85%	51.15%
Hungary	0.133	0.058	0.044	0.031	56.53%	43.47%
Malta	0.170	0.140	0.022	0.009	86.38%	13.62%
Netherlands	0.192	0.076	0.061	0.054	55.43%	44.57%
Austria	0.202	0.076	0.060	0.066	55.65%	44.35%
Poland	0.144	0.059	0.054	0.032	52.27%	47.73%
Portugal	0.213	0.073	0.051	0.089	58.65%	41.35%
Romania	0.128	0.037	0.053	0.038	40.85%	59.15%
Slovenia	0.166	0.061	0.056	0.048	52.04%	47.96%
Slovakia	0.168	0.063	0.073	0.031	46.34%	53.66%
Finland	0.156	0.060	0.048	0.047	55.47%	44.53%
Sweden	0.205	0.057	0.076	0.073	42.77%	57.23%
United Kingdom	0.180	0.135	0.036	0.009	78.97%	21.03%
Iceland	0.107	0.063	0.022	0.023	74.59%	25.41%
Norway	0.178	0.052	0.076	0.050	40.81%	59.19%
Montenegro	0.105	0.040	0.046	0.020	46.85%	53.15%
FYROM	0.078	:	:	:	:	:
Serbia	0.061	0.018	0.032	0.011	36.18%	63.82%
Turkey	:	:	:	:	:	:
Albania	0.115	:	:	:	:	:
Bosnia and Herzegovina	0.080	0.035	0.033	0.012	51.91%	48.09%

Table 62 Potential monetary saving zones based on electricity prices for HP based facilities



6.4 Feasibility study of each climatic zones based on the facility layout

A combination of all the results obtained after evaluating the maximum allowable solar collector area able to be installed on a 100m^2 house roof, and prices associated to investment and operational cost will represent along this subchapter the feasibility of each one of the four layouts studied. Figure 52 join the conclusions obtained from 6.1, 6.2 and 6.3.

Figure 52: Combined result of Table 53, Table 55,Table 59and Table 62

The use of the same colours facilitates the task of combining all five results (dotted zones are the results from 6.1). The combination mainly show that the climatic zones belonging to the matrix defined from D2 to ExcCol,ExcCold zone represent places where no one of the studied variables separately makes feasible a profitable investment to obtain simpleROI's of 20 years. Moreover, the matrix defined from D3 to ExcColExcCold discard any solar thermal solution due to the physical impossibility of installing the necessary collector surface on the building roof.

Following pages describe the evolution of the studied parameters climate zone by climate zone, creating a resume of the European potentialities by climatic location with the use of similar curves to the ones represented in Figure 53.

As it can be appreciated in the example, Figure 53, both profiles corresponding to investment costs keep a linear behavior (collector and HP prices) while operational costs are perfectly fitted by potential curves.

Collector curves : simpleROI=a*price

HP curves: simpleROI=b*price+c

Gas curves: simple ROI=d*(price)$^{-1}$

Electricity curves: simpleROI=e*(price)$^{-f}$

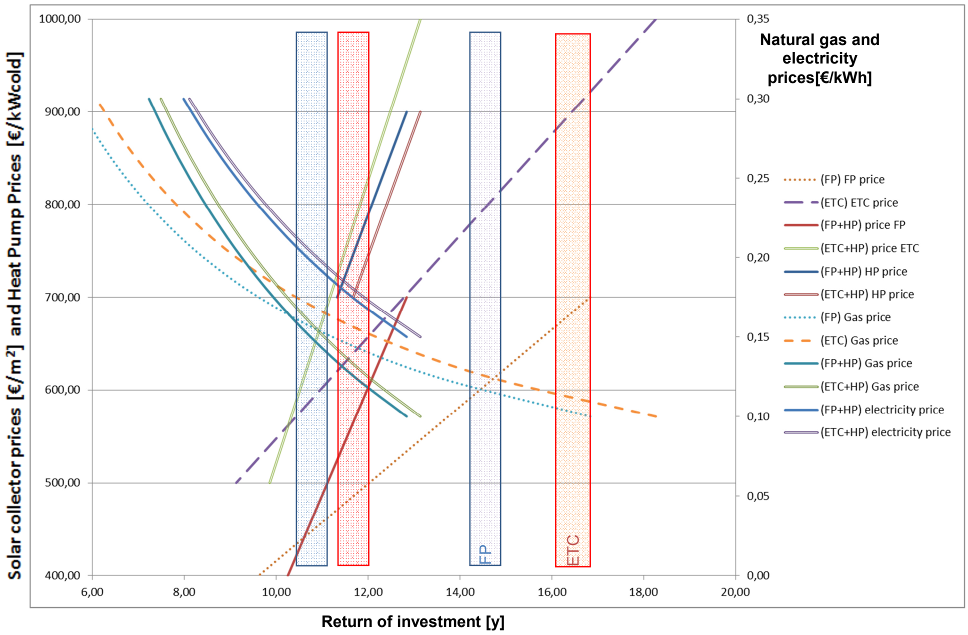


Figure 53: Example of the results obtained for a determinate climatic zone.

For every plot that will appear to the end of the chapter, it has been used identical structure, colours and nomenclature.

Diagram Structure:

- On the left axis are represented the prices for the solar collectors[€/^{m2}] and Heat pumps [€/kWcold]
- On the right axis are the gas and electricity prices [€/kWh].
- Horizontal axis represents the simple return of investment periods [y].

Nomenclature: For every line drawn in the graphics, the name begins with the technological definition among parenthesis, followed by the parameter studied

- (FP) correspond to solar flat collector facilities without HP
- (FP+HP) correspond to solar FP collectors combined with HP
- (ETC) correspond to solar evacuated tube facilities without HP
- (ETC+HP) correspond to solar ETC's combined with HP
- FP price: Flat plate price variation from 700 to a minimum of 400€/m2
- ETC price: ETC price variation from 1000 to a minimum of 500€/m2
- HP price: HP price variation from 900 to a minimum of 700€/m2
- Gas price: Gas price variation from 0.1 to a maximum of 0.3€/kWh
- Electricity price: Gas price variation from 0.15 to a maximum of 0.3€/kWh

Optimal zones:

- Blue vertical rectangle: simpleROI result for FP+HP layouts
- Red vertical rectangle: simpleROI result for ETC+HP layouts
- Violet vertical rectangle: singleROI result for FP layouts
- Orange vertical rectangle: singleROI result for ETC layouts

Furthermore, in order to support the evaluation of future or market evolution and the decision of introducing public helps that promote the potential business opportunities, it is studied for every climatic zone, the effect that produces a price variation on the consumed fossil energies, or for the systems used in the facility, the economic viability of proposed layouts.

To evaluate this potential, it has been derived respect to the price, the ROI/price curves expressed at the beginning of this chapter, and the results were treated to allow a comparison between dimensionless magnitudes that express the influence of each one of the parameters in the final economical return period. The effect of price variations on the final ROI will be constant for the components integrated in the initial facility cost, as the collectors, sorption heat pumps and adjacent components needed for the installation (linear relation between simpleROI and prices) , but time variable when the studied parameters are both electrical and gas prices. For this last case, it has been studied the derivative values in four different time positions correspondent to *simpleROI's twenty, fifteen, ten* and *five years*, as representing values in the interval where a solar TDHP could be potentially installed.

6.4.1 Solar installations without HP:

For the case of solar thermal facilities where there is no heat pump introduced into the generation loop, there are only two variables to compare for each one of the collectors type. The installation costs of the solar platform and the saved gas prices. Table 63 represents the maximum savings that could be done as a function of the decrease on the collector price from 700 to 400 €/m^2 flat plate collector or 1000 to 500 €/m^2 in the Evacuate tube case, while Table 64 represents the same maximum decrease in years for the return of investment, but applied in four different points, 20, 15, 10 and 5 years.

From the combination of both, it can be seen that the importance of the parameters depends on the initial ROI point considered:

- In the coldest European classes, contained into the group limited by D2 and Exc.Cold, Exc.Cold, the price of the collectors is the most important factor to decrease backup period for any ROI initial point.
- As far as the climates are warmer, the importance of the collector price is overpassed by gas prices with initial ROI's:
    - Around 15 years for those climates comprised in zone C2 to C4.
    - Around 10 years for A2, B2 and B2
    - And around to 5 years in the places with the warmest winter periods

Table 63: Number of potential years to be saved in ROI terms when the collector price varies into their interval for solar thermal facilities (Flat Plate and ETC)

Flat Plate price Effect years 400-700 €/m2		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	7,22	6,98	7,57	12,18	11,05	9,01	12,96
	Class 2	10,39	12,47	14,95	15,59	25,51	28,15	27,13
	Class 3	---	---	15,22	18,56	40,28	50,38	36,64
	Class 4	---	---	---	17,06	40,97	35,15	42,06
	Class 5	---	---	---	9,65	---	46,41	60,22
	Exc. Cold	---	---	---	---	---	---	188,68

ETC Price Effect years 500-1000 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	9,13	8,83	9,50	13,52	13,11	10,93	14,53
	Class 2	13,31	15,06	17,06	17,35	21,55	23,55	22,41
	Class 3	---	---	15,63	18,44	30,13	35,72	26,95
	Class 4	---	---	---	17,07	27,36	27,26	30,76
	Class 5	---	---	---	10,15	---	30,75	35,51
	Exc. Cold	---	---	---	---	---	---	79,55

Table 64: Number of potential years to be saved in ROI terms when the gas price varies into its interval for solar thermal facilities (FP and ETC) (Applied when ROI's around 20, 15, 10 and 5 years)

Gas Price FP Effect years 20 0,1-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	47,512	49,137	45,321	28,146	31,027	38,073	26,451
	Class 2	32,992	27,498	22,928	21,991	13,438	12,180	12,637
	Class 3	---	---	22,528	18,480	8,512	6,806	9,356
	Class 4	---	---	---	20,095	8,368	9,753	8,152
	Class 5	---	---	---	35,530	---	7,388	5,510
	Exc. Cold	---	---	---	---	---	---	1,817

Gas Price ETC Effect years 20 0,1-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	43,8020	45,3232	42,1030	29,5770	30,5122	36,5781	27,5387
	Class 2	30,0515	26,5525	23,4432	23,0508	18,5589	16,9866	17,8480
	Class 3	---	---	25,6074	21,6979	13,2747	11,1991	14,8406
	Class 4	---	---	---	23,4267	14,6207	14,6746	13,0050
	Class 5	---	---	---	39,4030	---	13,0066	11,2643
	Exc. Cold	---	---	---	---	---	---	5,0289

Gas Price FP Effect years 15 0,1-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	32,664	33,782	31,158	19,351	21,331	26,175	18,185
	Class 2	22,682	18,905	15,763	15,119	9,239	8,374	8,688
	Class 3	---	---	15,488	12,705	5,852	4,679	6,432
	Class 4	---	---	---	13,816	5,753	6,705	5,604
	Class 5	---	---	---	24,427	---	5,079	3,788
	Exc. Cold	---	---	---	---	---	---	1,249

Gas Price ETC Effect years 15 0,1-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	30,114	31,160	28,946	20,334	20,977	25,147	18,933
	Class 2	20,660	18,255	16,117	15,847	12,759	11,678	12,270
	Class 3	---	---	17,605	14,917	9,126	7,699	10,203
	Class 4	---	---	---	16,106	10,052	10,089	8,941
	Class 5	---	---	---	27,090	---	8,942	7,744
	Exc. Cold	---	---	---	---	---	---	3,457

Gas Price FP Effect years 10 0,1-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	17,817	18,426	16,995	10,555	11,635	14,277	9,919
	Class 2	12,372	10,312	8,598	8,247	5,039	4,567	4,739
	Class 3	---	---	8,448	6,930	3,192	2,552	3,509
	Class 4	---	---	---	7,536	3,138	3,658	3,057
	Class 5	---	---	---	13,324	---	2,771	2,066
	Exc. Cold	---	---	---	---	---	---	0,681

Gas Price ETC Effect years 10 0,1-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	16,426	16,996	15,789	11,091	11,442	13,717	10,327
	Class 2	11,269	9,957	8,791	8,644	6,960	6,370	6,693
	Class 3	---	---	9,603	8,137	4,978	4,200	5,565
	Class 4	---	---	---	8,785	5,483	5,503	4,877
	Class 5	---	---	---	14,776	---	4,877	4,224
	Exc. Cold	---	---	---	---	---	---	1,886

Gas Price FP Effect years 5 0,1-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	2,969	3,071	2,833	1,759	1,939	2,380	1,653
	Class 2	2,062	1,719	1,433	1,374	0,840	0,761	0,790
	Class 3	---	---	1,408	1,155	0,532	0,425	0,585
	Class 4	---	---	---	1,256	0,523	0,610	0,509
	Class 5	---	---	---	2,221	---	0,462	0,344
	Exc. Cold	---	---	---	---	---	---	0,114

Gas Price ETC Effect years 5 0,1-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	2,7376	2,8327	2,6314	1,8486	1,9070	2,2861	1,7212
	Class 2	1,8782	1,6595	1,4652	1,4407	1,1599	1,0617	1,1155
	Class 3	---	---	1,6005	1,3561	0,8297	0,6999	0,9275
	Class 4	---	---	---	1,4642	0,9138	0,9172	0,8128
	Class 5	---	---	---	2,4627	---	0,8129	0,7040
	Exc. Cold	---	---	---	---	---	---	0,3143

6.4.2 Solar installations with HP:

For the Heat Pump layout cases, the number of parameters to be compared is four, relating the initial collector and Heat pump costs, with the substituted energy prices, gas and electricity.

Table 65 and Table 67 correspond to flat plate and evacuate tubes based facilities respectively, while the gas and electricity costs are represented in Table 66 and Table 68.

From a first overview on the flat plate and ETC case, it is seen that, electricity prices are absolutely indifferent for the coldest cases explained in the first point of 0 due to the low cooling demands existing in those places, and in the same way, the second less important factor is the price of the sorption machine, that would be nearly never used as chiller and only in some limited times working in heat pump mode

For both Flat plate and Evacuate tubes Heat pump case, it can be said:

- In the coldest European classes, contained into the group limited by D2 and Exc.Cold, Exc.Cold, the price of the collectors is the most important factor to decrease backup period for any ROI initial point, followed by the gas, sorption heat pump and the electrical prices.

- As far as the climates are warmer, the importance of the collector price is overpassed by gas and electrical prices (in this order), and always being the price of the machine the less important variable.

- In the warmest zones, labeled with winter severity 1, the price of the sorption machine becomes more important than gas and electrical prices when the ROI's are between 5 and 10 years, due to the high cooling demand and machine's size. Gas and electrical price change only the order of importance for the cases: Exc.Heat 1 and 2, and A2.

Table 65: Number of potential years to be saved in ROI terms when the collector price and the sorption price varies into their interval for Flat plate solar thermal facilities with heat pump

Flat Plate Price (HP) Effect years 400-700 €/m2		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	2,59	2,92	3,25	4,72	4,83	4,37	6,83
	Class 2	3,04	4,06	5,23	5,91	17,34	21,08	18,53
	Class 3	---	---	5,37	6,75	28,79	40,52	24,93
	Class 4	---	---	---	6,95	29,37	20,99	27,81
	Class 5	---	---	---	5,26	---	35,94	42,51
	Exc. Cold	---	---	---	---	---	---	149,07

Machine Price (FP) Effect years 700-900 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1,51	1,96	1,72	1,37	1,58	1,46	1,53
	Class 2	0,84	0,96	1,10	0,94	0,84	0,77	0,77
	Class 3	---	---	0,81	1,02	0,57	0,35	0,83
	Class 4	---	---	---	0,94	0,61	0,82	0,76
	Class 5	---	---	---	0,71	---	0,37	0,69
	Exc. Cold	---	---	---	---	---	---	0,52

Table 66: Number of potential years to be saved in ROI terms when the gas and electrical price vary into their interval for FP with Heat pump (Applied when ROI's around 20, 15, 10 and 5 years)

Gas Price FP (HP) Effect years 20 0,1-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	46,711	34,765	36,139	28,876	27,343	31,656	22,540
	Class 2	64,266	40,167	27,324	26,475	13,972	12,752	13,076
	Class 3	---	---	33,133	21,385	9,293	7,766	9,854
	Class 4	---	---	---	22,815	8,886	9,776	8,336
	Class 5	---	---	---	41,875	---	8,156	5,765
	Exc. Cold	---	---	---	---	---	---	1,752

Electricity Pr. FP (HP) Effect years 20 0,15-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	25,919	18,106	18,891	16,051	13,724	15,206	7,762
	Class 2	33,060	23,611	16,780	14,833	0,033	0,002	0,103
	Class 3	---	---	17,600	12,303	0,000	0,000	0,017
	Class 4	---	---	---	11,588	0,000	0,047	0,034
	Class 5	---	---	---	15,207	---	0,000	0,001
	Exc. Cold	---	---	---	---	---	---	0,000

Gas Price FP (HP) Effect years 15 0,1-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	31,423	23,466	24,392	19,469	18,471	21,413	15,287
	Class 2	43,121	26,999	18,389	17,847	9,553	8,736	8,940
	Class 3	---	---	22,329	14,416	6,365	5,333	6,741
	Class 4	---	---	---	15,409	6,084	6,666	5,698
	Class 5	---	---	---	28,490	---	5,595	3,946
	Exc. Cold	---	---	---	---	---	---	1,201

Electricity Pr. FP (HP) Effect years 15 0,15-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	17,567	12,229	12,763	10,853	9,265	10,246	5,218
	Class 2	22,464	16,016	11,368	10,029	0,022	0,002	0,068
	Class 3	---	---	11,901	8,320	0,000	0,000	0,012
	Class 4	---	---	---	7,824	0,000	0,031	0,023
	Class 5	---	---	---	10,188	---	0,000	0,001
	Exc. Cold	---	---	---	---	---	---	0,000

Gas Price FP (HP) Effect years 10 0,1-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	16,135	12,167	12,645	10,062	9,598	11,170	8,034
	Class 2	21,976	13,830	9,454	9,220	5,134	4,721	4,804
	Class 3	---	---	11,526	7,448	3,437	2,901	3,629
	Class 4	---	---	---	8,003	3,283	3,555	3,060
	Class 5	---	---	---	15,106	---	3,033	2,127
	Exc. Cold	---	---	---	---	---	---	0,650

Electricity Pr. FP (HP) Effect years 10 0,15-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	9,214	6,353	6,634	5,656	4,806	5,286	2,674
	Class 2	11,868	8,422	5,956	5,225	0,011	0,001	0,034
	Class 3	---	---	6,203	4,337	0,000	0,000	0,006
	Class 4	---	---	---	4,061	0,000	0,016	0,011
	Class 5	---	---	---	5,168	---	0,000	0,000
	Exc. Cold	---	---	---	---	---	---	0,000

Gas Price FP (HP) Effect years 5 0,1-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	0,848	0,868	0,898	0,655	0,726	0,927	0,782
	Class 2	0,830	0,662	0,519	0,592	0,715	0,705	0,668
	Class 3	---	---	0,722	0,479	0,509	0,468	0,516
	Class 4	---	---	---	0,597	0,481	0,444	0,423
	Class 5	---	---	---	1,722	---	0,472	0,308
	Exc. Cold	---	---	---	---	---	---	0,100

Electricity Pr. FP (HP) Effect years 5 0,15-0,3 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	0,861	0,476	0,505	0,459	0,347	0,325	0,129
	Class 2	1,272	0,828	0,544	0,421	0,000	0,000	0,000
	Class 3	---	---	0,505	0,354	0,000	0,000	0,000
	Class 4	---	---	---	0,297	0,000	0,000	0,000
	Class 5	---	---	---	0,149	---	0,000	0,000
	Exc. Cold	---	---	---	---	---	---	0,000

Table 67: Number of potential years to be saved in ROI terms when the collector price and the sorption price varies into their interval for ETC solar thermal facilities with heat pump

ETC Price (HP) Effect years 500-1000 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	3,28	3,69	4,03	5,52	5,64	5,41	7,82
	Class 2	4,00	5,12	6,23	6,92	15,25	18,61	16,28
	Class 3	---	---	6,03	7,35	21,93	30,68	19,66
	Class 4	---	---	---	7,50	19,71	16,83	21,82
	Class 5	---	---	---	6,07	---	25,04	26,41
	Exc. Cold	---	---	---	---	---	---	66,26

Machine Price (ETC) Effect years 700-900 €/kWh		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	1,46	1,88	1,64	1,31	1,44	1,40	1,46
	Class 2	0,81	0,92	1,06	0,92	0,87	0,81	0,80
	Class 3	---	---	0,83	1,04	0,58	0,36	0,86
	Class 4	---	---	---	0,94	0,62	0,80	0,78
	Class 5	---	---	---	0,75	---	0,38	0,71
	Exc. Cold	---	---	---	---	---	---	0,51

Table 68: Number of potential years to be saved in ROI terms when the gas and electrical price vary into their interval for ETC's with Heat pump (Applied when ROI's around 20, 15, 10 and 5 years)

Gas Price ETC (HP)	Summer Climatic Severities's						
Effect years 20 0,1-0,3 €/kWh — Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	44,4572	33,4680	34,3960	29,1956	27,5465	33,2649	22,9570
Class 2	52,3058	36,7687	26,7306	26,3539	17,5653	16,2955	17,2228
Class 3	---	---	31,6031	23,2983	13,4436	11,8482	14,4574
Class 4	---	---	---	25,1140	14,4566	13,8908	12,6888
Class 5	---	---	---	41,3024	---	13,5228	10,7094
Exc. Cold	---	---	---	---	---	---	4,8681

Electricity Pr. ETC(HP	Summer Climatic Severities's						
Effect years 20 0,15-0,3 €/kWh — Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	25,2292	18,0230	18,8934	16,5462	15,1047	15,6098	8,5482
Class 2	30,5253	22,4593	16,8531	15,0117	0,3319	0,0356	0,3868
Class 3	---	---	18,3002	13,3215	0,0051	0,0000	0,1525
Class 4	---	---	---	12,6545	0,0426	0,8116	0,1683
Class 5	---	---	---	15,4539	---	0,0001	0,0523
Exc. Cold	---	---	---	---	---	---	

Gas Price ETC (HP)	Summer Climatic Severities's						
Effect years 15 0,1-0,3 €/kWh — Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	29,893	22,573	23,198	19,677	18,582	22,514	15,559
Class 2	35,087	24,704	17,983	17,761	11,993	11,157	11,771
Class 3	---	---	21,297	15,707	9,194	8,135	9,887
Class 4	---	---	---	16,961	9,880	9,462	8,672
Class 5	---	---	---	28,083	---	9,272	7,330
Exc. Cold	---	---	---	---	---	---	3,338

Electricity Pr. ETC(HP	Summer Climatic Severities's						
Effect years 15 0,1-0,3 €/kWh — Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	17,107	12,183	12,775	11,194	10,212	10,521	5,751
Class 2	20,752	15,242	11,421	10,153	0,221	0,024	0,258
Class 3	---	---	12,375	9,009	0,003	0,000	0,102
Class 4	---	---	---	8,546	0,028	0,542	0,112
Class 5	---	---	---	10,360	---	0,000	0,035
Exc. Cold	---	---	---	---	---	---	

Gas Price ETC (HP)	Summer Climatic Severities's						
Effect years 10 0,1-0,3 €/kWh — Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	15,328	11,678	11,999	10,159	9,617	11,762	8,161
Class 2	17,868	12,639	9,235	9,168	6,421	6,019	6,318
Class 3	---	---	10,991	8,115	4,944	4,422	5,316
Class 4	---	---	---	8,807	5,303	5,034	4,655
Class 5	---	---	---	14,864	---	5,022	3,952
Exc. Cold	---	---	---	---	---	---	1,808

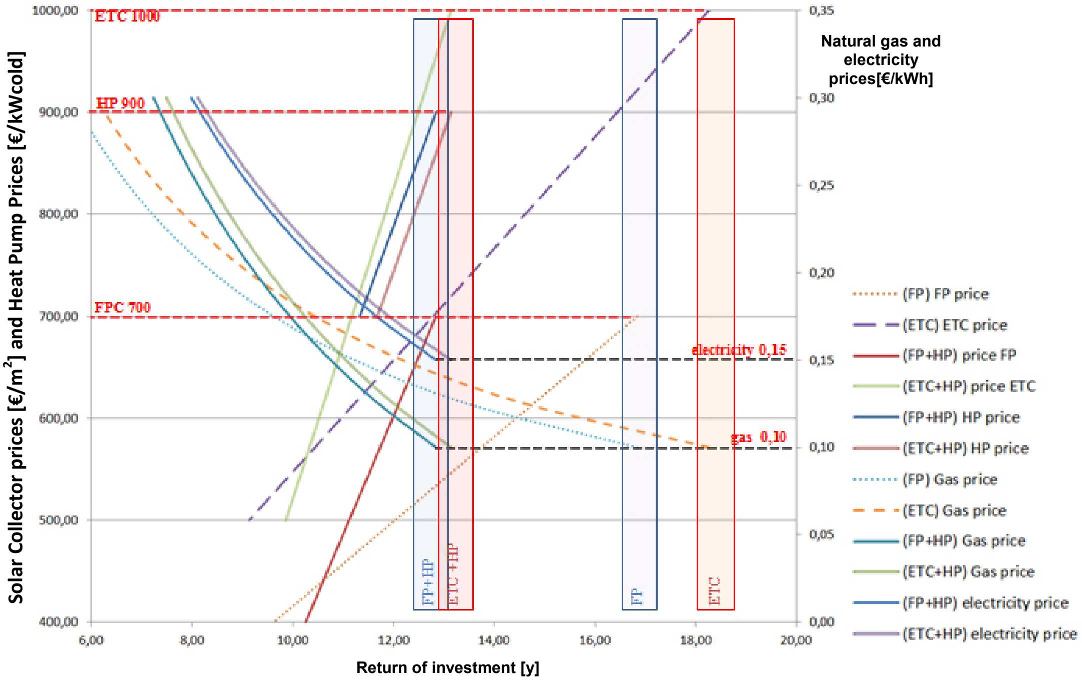
Electricity Pr. ETC(HP	Summer Climatic Severities's						
Effect years 10 0,15-0,3 €/kWh — Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	8,985	6,343	6,656	5,842	5,319	5,432	2,953
Class 2	10,978	8,024	5,990	5,294	0,111	0,012	0,129
Class 3	---	---	6,450	4,696	0,002	0,000	0,051
Class 4	---	---	---	4,438	0,014	0,272	0,056
Class 5	---	---	---	5,266	---	0,000	0,017
Exc. Cold	---	---	---	---	---	---	

Gas Price ETC (HP)	Summer Climatic Severities's						
Effect years 5 0,1-0,3 €/kWh — Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	0,7633	0,7828	0,8012	0,6407	0,6524	1,0111	0,7631
Class 2	0,6484	0,5737	0,4878	0,5743	0,8483	0,8805	0,8659
Class 3	---	---	0,6849	0,5235	0,6949	0,7094	0,7452
Class 4	---	---	---	0,6536	0,7268	0,6054	0,6379
Class 5	---	---	---	1,6451	---	0,7710	0,5726
Exc. Cold	---	---	---	---	---	---	0,2773

Electricity Pr. ETC(HP	Summer Climatic Severities's						
Effect years 5 0,15-0,3 €/kWh — Winter Climatic Severities's	Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Exc. Heat	---	---	---	---	---	---	---
Class 1	0,8628	0,5034	0,5373	0,4892	0,4266	0,3430	0,1558
Class 2	1,2041	0,8062	0,5582	0,4353	0,0001	0,0000	0,0003
Class 3	---	---	0,5248	0,3836	0,0000	0,0000	0,0001
Class 4	---	---	---	0,3302	0,0000	0,0023	0,0002
Class 5	---	---	---	0,1724	---	0,0000	0,0000
Exc. Cold	---	---	---	---	---	---	

6.5 Feasibility study of each climatic zone based on economical parameters

6.5.1 Zone ExcHeat1



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
37.2	44.8	329.19	1725.4	1756.97		-766,81	12929,4		5101,32		8.58	6.74

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	78.71%	81.11%	82.03%	82.49%
Summer Coverage			32.88%	34.57%
SimpleROI	16.84y	18.26y	12.84y	13.13y

<u>5 Studied locations in 2 different countries:</u> Sevilla (SP), Adana, Icel, Iskenderun, Izmir (TR)

The warmest climate zone in Europe has solar potential to obtain economic benefits with the four proposed layouts, maintaining simple ROI values under the limit of 20 years. Moreover, the initial values used to have the first reimbursement period approximations denotes that decreases in the investment costs or increases in the energy costs improve importantly the results.

Flat plate systems are recommendable over the ETC ones. Weather goodness during winter time and high summer temperatures doesn't spoil the FP efficiencies much, prevailing in this case the collector prices over the collecting capacities in terms of simple return of investment periods.

In both cases, with and without HP, the lately denoted importance of the studied variables stay stable until a singleROI between 5 and 10 years is reached, where it is noted higher importance of different variables.

Solar installations without HP: Gas price increases make the return of investment periods shorter than a similar percentage variation between the boundaries of collector prices.

- Flat plate systems: change the variable importance with ROI value around 6.5 years
- ETC collector systems: change the variable importance with ROI value around 9 years

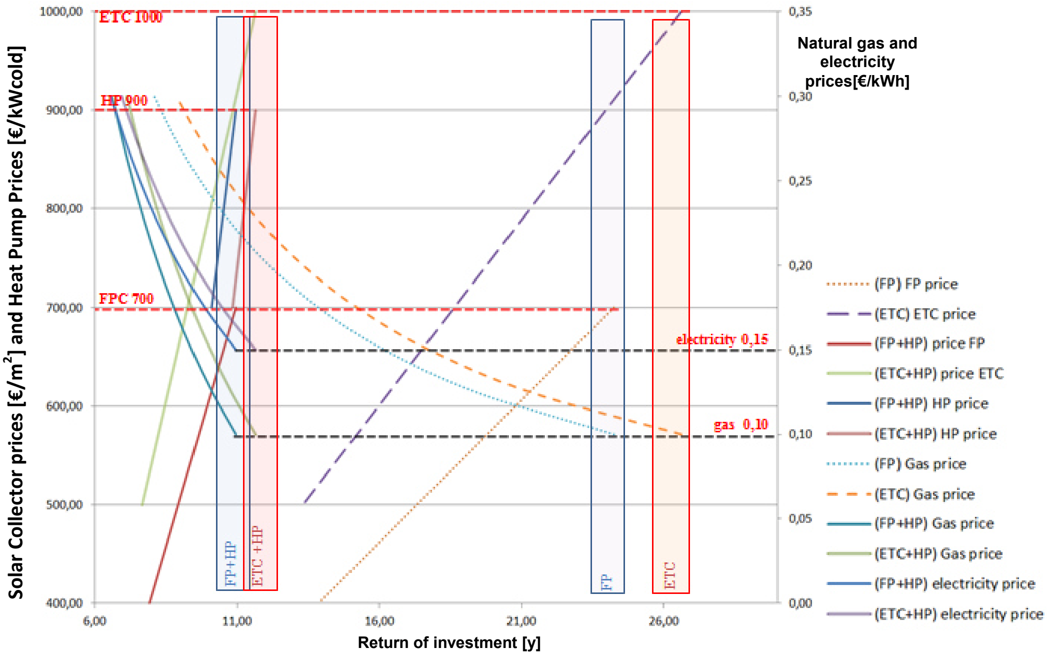
Solar installations with HP: Gas price increases, electricity price increases, collector price decreasing and HP installation price decreases, in this order; make the return of investment periods shorter. For both flat plate and ETC facilities, ROI values between 5 and 6 years, the importance of the variables go in the following order: Collectors, sorption machine, gas, and the less important, the electrical prices

Helping politics proposed:

In these zones, all systems are profitable with the calculated prices, but if it is decided to strength here the solar installations, a good solution would be to help the owners, or in some cases ESCO companies that would make their business on economical savings, to buy the facility, decreasing the initial costs and letting the successive price increasing of the substituted fossil fuels, afford better return of investments. The best solutions is based on prizing the renewable kWh introduced in the building, saving fossil fuel demands, but it is not considered by the authors “ethical” to overpay with public money facilities that without help is able to reach acceptable ROI.

It should be noticed that there is no official gas or electricity price published by the EU in the present date for Turkey, but in the case of Spain electricity prices are rounding 20 cents€/kWh, 5 cents more than the calculated price and gas prices are a little bit lower. The combination can bring the HP based facilities to obtain simpleROI values under 10 years.

6.5.2 Zone ExcHeat2



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]	Winter load [kWh/y]	Summer load [kWh/y]	Latent summer load	FP [m2]	ETC [m2]
39.95	700	339.15	2681.6	1770.39	-3432,84	10889,64	3797,47	16.62	13.82

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	64.65%	69.96%	72.64%	82.89%
Summer Coverage			67.40%	72,27%
SimpleROI	24.25	26.62	10.95	11.65

<u>3 studied locations in one country</u>: *Turkey:* Gaziantep, Kilis, Osmaniye

This zone represents southern locations with pretty high altitude where a combination of very warm summers with not aggressive winters coexists. The mix of heating demands with south latitudes (available winter radiation), facilitates the use of Heat Pumps layouts over the simple heating facilities, achieving simpleROI's closed to ten years when the solar plant works all along the year. It is clearly seen that HP facilities are recommended in this case, increasing the heating demand coverage with renewables methods from a 12 to an 18% when comparing the correspondent solar facilities with and without HP's. Ambient temperatures are warm in summer time and in winter time are high enough to still have prevalence FP collectors over the high efficient ETC's. (It must be remarked that it have being installed a 20% more area of FP than ETC's but the different collector costs make FP collectors prevail in simple ROI terms.

Solar installations without HP: Gas price increases make the return of investment periods shorter than a similar percentage variation of collector prices.

Flat plate case have a change of importance for the variables with simple ROI's of 9 years while the ETC case change the importance with higher ROI's, around 11 years

Solar installations with HP: Gas price increases, electricity price increases, collector price decreasing and HP installation price decreases, in this order; make the simple ROI times shorter.

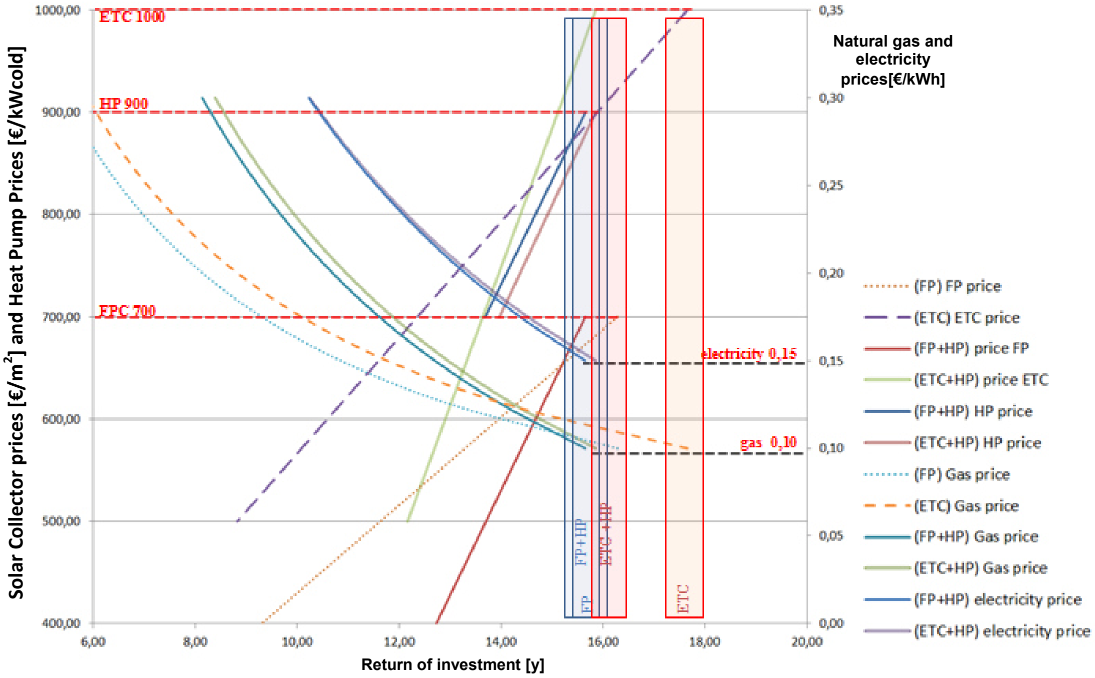
For both flat plate and ETC facilities, ROI values between 5 and 6 years, the importance of the variables go in the following order: Collectors, electricity, sorption machine and gas prices

Helping politics proposed:

In this zone, under the limit of 20 years, only the HP based layouts are profitable although with some decreases for the investment prices or increases on gas and/or electricity the four proposed layouts are profitable. Only for the "no HP" cases a help based on the kWh introduced in the building, combined or not with subsidies to cover the initial costs, is proposed, because causes better backup periods than a single first investment help. For the HP based facilities, it is proposed to help the first investment.

It should be remarked that there is no official gas or electricity price published by the EU in the present date for Turkey.

6.5.3 Zone A1



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load	Summer load		Latent summer load		FP [m2]	ETC [m2]
37,87	127,04	176,88	1823,4	1705,87		-846,95	11340,16		5831,72		8,08	6,41

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	74,48%	79,18%	80,33%	80,76%
Summer Coverage			28,95%	31,38%
SimpleROI	15,77	17,16	15,73	15,93

<u>Studied locations:</u> (28 locations belonging 6 different countries)

Spain: Alicante, Almería, Badajoz, Cáceres, Cádiz, Granada, Huelva, Jaén, Jeréz de la Frontera, Murcia, Valencia

Portugal: Evora

Italy: Cagliari, Catania, Cosenza, Messina, Palermo, Siracusa, Crotone, Olbia,Trapani

Greece: Iraklion, Patrai, Péristéri, Andravida, Athens

*Cyprus:*Cyprus

Malta: Malta

All the localities present in this category are placed in southern Europe, mostly close to the sea. The proximity to water masses soften the temperatures in both summer and winter times, decreasing a little bit the efficiency of the system when compared with similar categories. It is due to the slightly lower demands along the year. Flat plate collectors take advance on the comparison against the evacuated tubes, because the decrease of flat plates collecting efficiency doesn't compensate the higher prices of the evacuate tubes. Heat pump costs are cleared by the savings obtained in cooling mode, but the machine installation doesn't cause greater advantages against a flat plate facility used only for heating for the base considered prices.

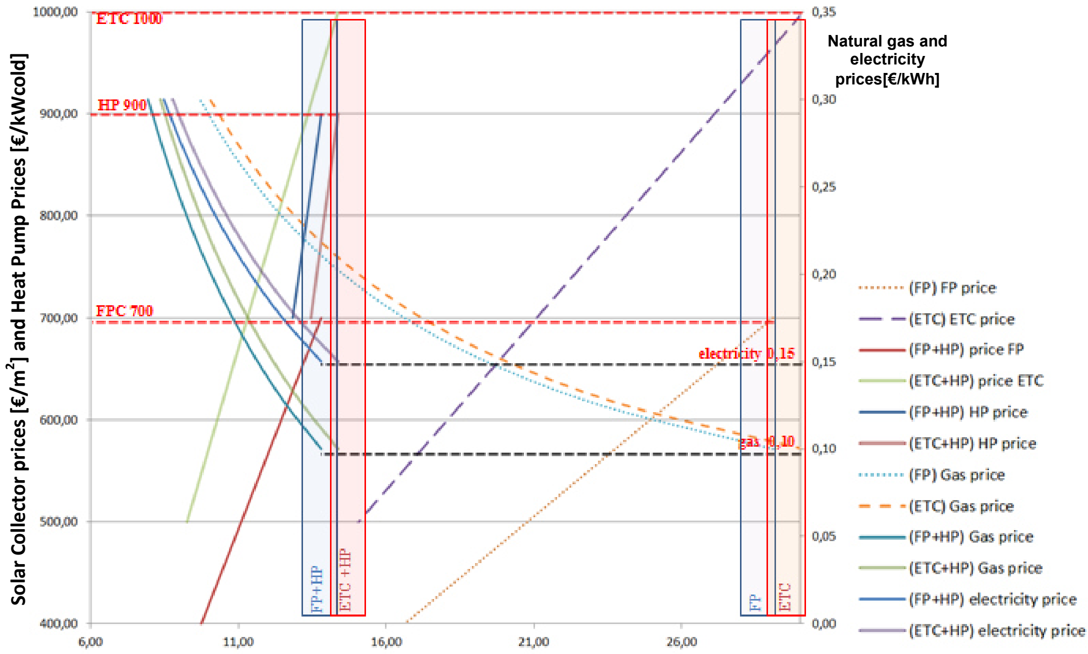
Solar installations without HP: Gas price increases make the return of investment periods shorter than a similar percentage variation of collector prices. Behaviour for Flat plate and ETC facilities change under ROI's of 6 years where the importance is leaded by the collector price.

Solar installations with HP: Gas price increases, electricity price increases, collector price decreasing and HP installation price decreases, in this order; make the simple ROI times shorter. For both flat plate and ETC facilities, ROI values between 5 and 7 years, the importance of the variables go in the following order: Collectors, sorption machine, gas, and the less important, the electrical prices

Helping politics proposed:

In this zone, under the limit of 20 years, all system layouts are profitable; although the ones based on HP's reach shorter ROI's and will get higher advantages when the fossil energies to be substituted, gas and electricity, increase their prices. The most effective way of exploding the technology in this zone is based on prizing every kWh used in the house, although a combination of helping the first investments and prizing the kWh distributed in the house could be combined and varied along the utilization time. The effectiveness of prizing every kWh delivered into the house decreases with the increase of fossil fuel prices, what would make acceptable a first help to by the facilities and a prizing price for the renewable used energies inversely proportional to the fossil prices. In this way, the facility owner is helped in the first steps of the installation and the strength of the economical help would be decreased when the facility increases its economic potential by comparing with the substitutive fossil fuel prices.

6.5.4 Zone A2



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
40,27	228	184,19	2621,2	1610,91		-2692,13	8257,66		2995,03		17,97	14,26

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	67,81%	73,05%	75,22%	76,38%
Summer Coverage			70,91%	75,28%
SimpleROI	28,02	29,26	13,61	14,20

<u>Studied locations:</u> (14 locations belonging to 6 different countries)

Spain: Madrid, Toledo

Italy: Foggia, Amendola

*Greece:*Larissa, Volos, Thessaloniki

Turkey: Balikesir, Bursa, Denizli, Cannakkale, Mugla

Croatia: Split

Serbia: Pogdorica

Once again, every location presented in this classification are placed in southern Europe, with latitudes around 40 degrees for inland places and a little bit smaller for locations closed to the coasts. Ratios between cooling and heating demand are balanced to the cooling needs but the existence of enough heating demand and radiation allows a further use of the sorption machine as heat pump, permitting in those cases to obtain backup periods of around 14 years.

<u>*Solar installations without HP*</u>: Gas price increases make the return of investment periods shorter than a similar percentage variation of collector prices for every ROI calculated over 11 years for FP collectors and 13 for ETC's, where the importance of the variables change.

<u>*Solar installations with HP*</u>: Gas price increases, electricity price increases, collector price decreasing and HP installation price decreases, in this order; make the simple ROI times shorter. The importance of the variables changes for both FP and ETC facilities in the interval between 5 and 7 simple ROI years.

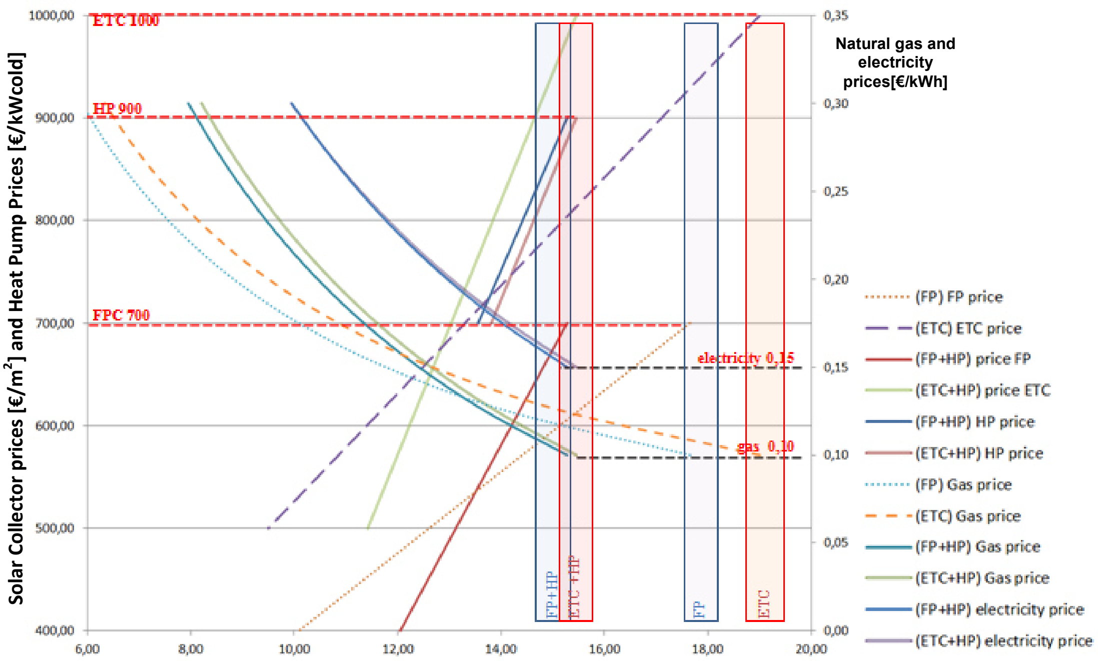
Helping politics proposed:

In this zone, under the limit of 20 years, only the HP based facilities are profitable.

The no-HP in the loop cases, have ROI's over the 25 years, so the unique way of helping the expansion of this technology should be based on subsiding the initial cost of the installation. The number of backup years saved when applying this measurement is 12,5 and 15 when the bought of the systems is helped with the complete price interval studied, 300 €/m^2 FP and 500 €/ m^2 ETC what it would place the installation reimbursements in around 15 years for both cases. Further increases of the substitutive energies would make the systems profitable in less than 10 years.

For both HP cases, the initial ROI calculated is around 14 years, what make of the combination, helping the first investments and prizing the kWh distributed a good way of promoting this kind of facilities. The single use of subsidies to the initial costs will close the ROI's to 10 years and every saving would make the installation profitable, but the combination of both measurements forces the system owner to get the best efficiencies of the system to achieve shorter amortization times

6.5.5 Zone B1



Latitude [º]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
40	54,04	88,46	2051,1	1663,86		-1013,17	9520,25		4705,06		9,56	7,53

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	75,08%	78,21%	79,62%	80,11%
Summer Coverage			36,08%	39,38%
SimpleROI	18,02	19,34	15,31	15,47

<u>Studied locations:</u> (21 locations belonging to 3 different countries)

Spain: Algeciras, Barcelona, Castellón, Lérida, Palma de Mallorca, Tarragona

Portugal: Amadora, Setúbal, Castelo Branco, Faro, Lisboa

Italy: Bari, Latina, Napoli, Pescara, Roma, Salerno, Sassari, Taranto, Brindisi, Gela

Every location of this classification are placed in the three West southern European countries. All of them are closed to the see what contains the maximum and minimum temperatures in summer and winter season respectively. The latitude of all of them corresponds to the central part of the three countries.

Every studied layout maintaining simple ROI values under the limit of 20 years

Flat plate systems are recommendable over the ETC ones. Weather goodness during winter time and high summer temperatures doesn't spoil the FP efficiencies much, prevailing in this case the collector prices over the collecting capacities in terms of simple return of investment periods.

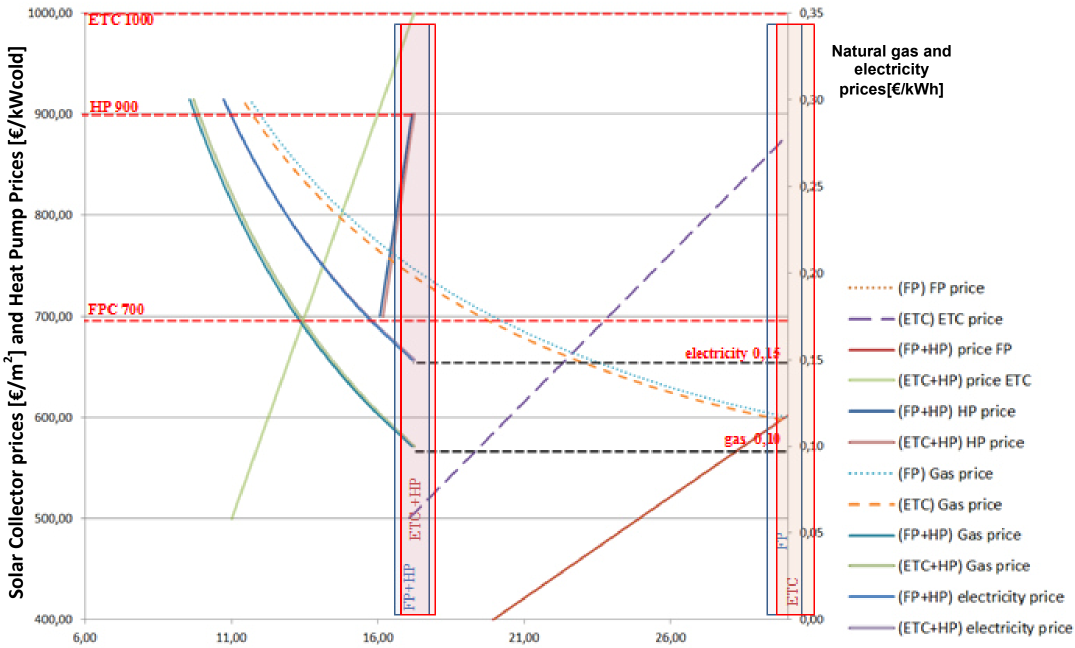
Solar installations without HP: Gas price increases make the return of investment periods shorter than a similar percentage variation between the boundaries of collector prices.Flat plate and ETC based systems change the variable importance with ROI value around 7 years

Solar installations with HP: Gas price increases, electricity price increases, collector price decreasing and HP installation price decreases, in this order; make the return of investment periods shorter. For both flat plate and ETC facilities, for ROI values between 5 and 6 years, the importance of the variables go in the following order: Collectors, sorption machine, gas, and the less important, the electrical prices

Helping politics proposed:

In these zones, all systems are profitable with the calculated prices, but if it is decided to strength here the solar installations, a good solution would be to help the owners in a first step with subsidies to decrease the initial costs and prize every kWh introduced into the demanding building for a determinate number of years that would make the investment interesting from an economic point of view. As it has been previously said, this solution point on the facility optimization and keeps the interest of the owners/managers on collecting as much as possible energy from the sun.

6.5.6 Zone B2



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
42,6	150	115,27	2716,8	1447,92		-3017,71	7737,99		3661,29		22,21	16,94

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	67,57%	72,53%	74,91%	75,99%
Summer Coverage			69,61%	73,86%
SimpleROI	32,36	32,84	16,83	17,09

<u>Studied locations:</u> (12 locations belonging to 6 different countries)

Spain: Zaragoza

Italy: Ancona, Firenze, LA Spezia, Perugia, Terni

*Greece:*Kavala

*Turkey:*Adapazari, Edirne

France: Nimes, Marseille

Bulgaria: Kurdjali

The locations presented in this classification are placed mostly in southern Europe, with latitudes around 43 degrees for inland places and a little bit smaller for locations closed to coasts. Ratios between cooling and heating demand are balanced to the cooling needs but the existence of enough heating demand and radiation allows a further use of the sorption machine as heat pump, permitting in those cases to obtain backup periods of around 17 years.

Solar installations without HP: Gas price increases make the return of investment periods shorter than a similar percentage variation of collector prices. for every ROI calculated over 14 years for FP collectors and 16 for ETC's, where the importance of the variables change.

Solar installations with HP: Gas price increases, electricity price increases, collector price decreasing and HP installation price decreases, in this order; make the simple ROI times shorter. The importance of the variables changes for both FP and ETC facilities in the interval between 5 and 9 simple ROI years.

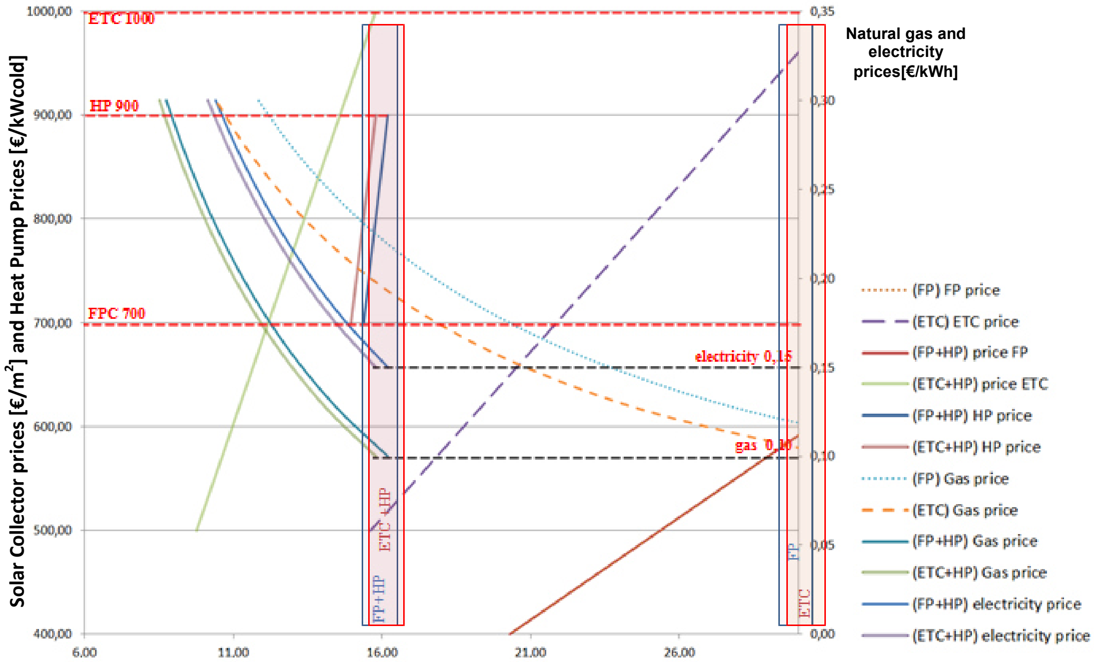
Helping politics proposed:

In this zone, under the limit of 20 years, only the HP based facilities are profitable.

The no-HP in the loop cases, have ROI's over the 30 years, so the unique way of helping the expansion of this technology should be based on subsiding the initial cost of the installation. The number of backup years saved when applying this measurement is 15 and 17 when the bought of the systems is helped with the complete price interval studied, 300 €/m^2 FP and 500 €/ m^2 ETC what it would place the installation reimbursements in around 15 years for both cases. Further increases of the substitutive energies would make the systems profitable in less than 10 years.

For both HP cases, the initial ROI calculated is around 17 years, what make of the combination, helping the first investments and prizing the kWh distributed a good way of promoting this kind of facilities. The single use of subsidies to the initial costs will close the ROI's to 10 years and every saving would make the installation profitable, but the combination of both measurements forces the system owner to get the best efficiencies of the system to achieve shorter amortization times

6.5.7 Zone B3



Latitude [º]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
41,4	575,64	110,96	3329	1536,71		-4400	6227,55		2360,19		27,53	18,12

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	59,50%	62,58%	68,32%	66,74%
Summer Coverage			91,89%	90,68%
SimpleROI	38,33	33,65	16,61	16,15

<u>Studied locations:</u> (11 locations belonging to 3 different countries)

Italy: Bologna, Ferrara, Modena, Parma

*Turkey:*Ankara, Isparta, Kirikkale, Küahya, Usak, Konya

Macedonia: Skopje

The locations presented in this classification are placed in the Southeast Mediterranean countries, for places not directly over the see and a considerable altitude. The heating and cooling demand are nearly balanced along the year and the ETC begin be important due to their low thermal losses coefficient Nevertheless, FP collectors, with wide installed areas reach similar performances. The existence of enough heating demand and radiation allows a further use of the sorption machine as heat pump, permitting in those cases to obtain backup periods of around 16 years.

Solar installations without HP: Gas price increases make the return of investment periods shorter than a similar percentage variation of collector prices. for every ROI calculated over 15 years for FP collectors and 13 for ETC's, where the importance of the variables change.

Solar installations with HP: Gas price increases, electricity price increases, collector price decreasing and HP installation price decreases, in this order; make the simple ROI times shorter. The importance of the variables changes for both FP and ETC facilities in the interval between 5 and 10 simple ROI years.

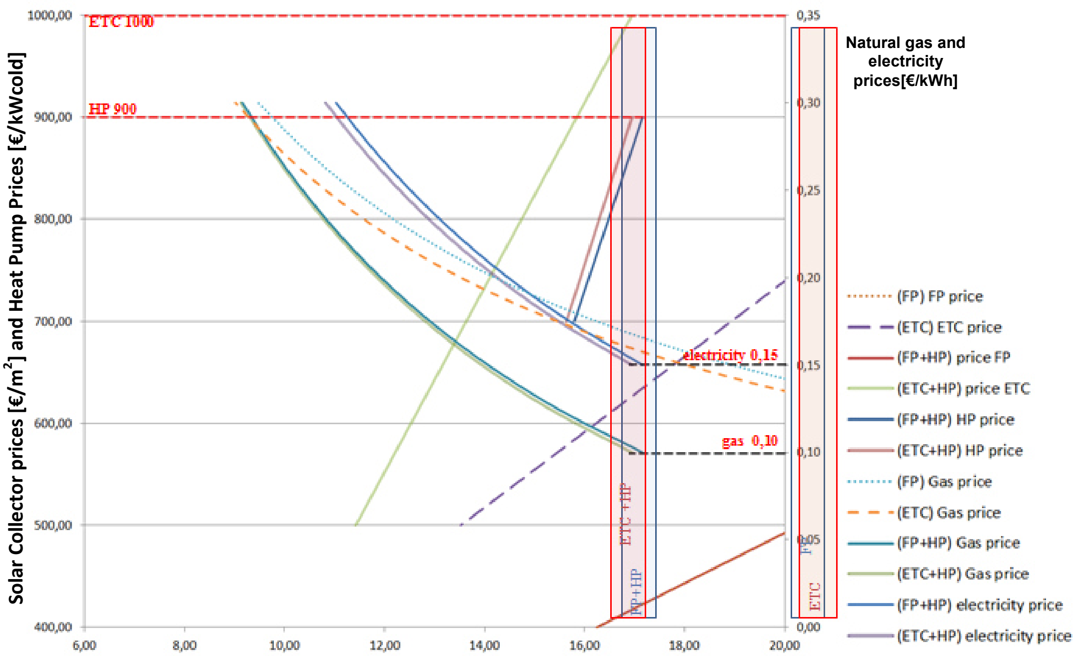
Helping politics proposed:

In this zone, under the limit of 20 years, only the HP based facilities are profitable.

The no-HP in the loop cases, have ROI's over the 36 years, so the unique way of helping the expansion of this technology should be based on subsiding the initial cost of the installation and prizing the introduced kWh in the system. The combination of both monetary helps, would not reach a ROI of 10 years for the two collector technologies. The interest on promoting the technology to fully cover in this case DHW along the year needs of high public efforts.

For both HP cases, the initial ROI calculated is around 16 years, what make of the combination, helping the first investments and prizing the kWh distributed a good way of promoting this kind of facilities. The single use of subsidies to the initial costs will close the ROI's to 10 years and every saving would make the installation profitable, but the combination of both measurements forces the system owner to get the best efficiencies of the system to achieve shorter amortization times.

6.5.8 Zone C1



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
42,85	52	56,56	2386,4	1474,66		-1832,62	7124,08		3638,06		16,93	12,01

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	71,23%	75,68%	77,82%	78,36%
Summer Coverage			55,21%	58,84%
SimpleROI	28,42	27,05	17,16	16,95

<u>Studied locations:</u> (10 locations belonging to 4 different countries)

Portugal: Coimbra

Italy: Genova, Livorno, Pisa, Cape Mele

Turkey: Samsun

France: Nice, Perpignan, Toulon, Ajaccio

The locations presented in this classification are placed in latitudes correspondent to north Mediterranean coasts, near the see.

The existence of enough heating demand and radiation allows a further use of the sorption machine as heat pump, permitting in those cases to obtain backup periods of around 17 years.

<u>Solar installations without HP</u>: Gas price increases make the return of investment periods shorter than a similar percentage variation of collector prices. For every ROI calculated under 11 years for FP and ETC collectors, their prices become more important than the substitutive fuel one.

<u>Solar installations with HP</u>: Gas price increases, electricity price increases, collector price decreasing and HP installation price decreases, in this order; make the simple ROI times shorter. The importance of the variables changes for both FP and ETC facilities in the interval between 5 and 10 simple ROI years.

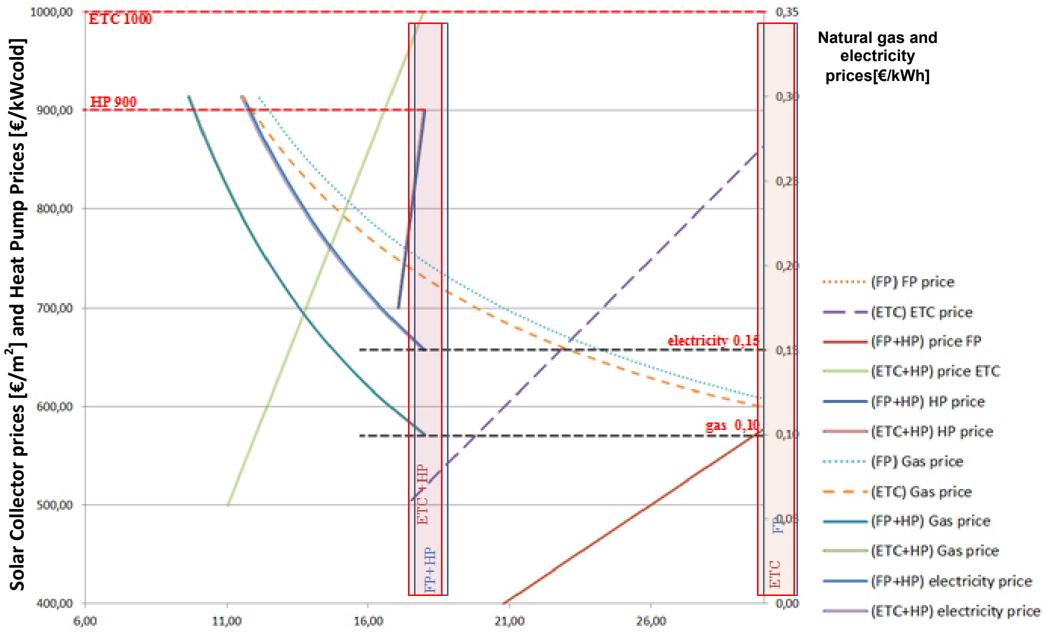
Helping politics proposed:

In this zone, under the limit of 20 years, only the HP based facilities are profitable.

The no-HP in the loop cases, have ROI's around the 28 years, so the unique way of helping the expansion of this technology should be based on subsiding the initial cost of the installation. The number of backup years saved when applying this measurement is 11 when the bought of the systems is helped with the complete price interval studied, for the both solar technologies proposed. Further increases of the substitutive energies would make the systems profitable in less than 10 years. A possible prizing of the saved gas would get the ROIs closer to 10 years, what make possible the decrease of the prizing when the substitutive energy prices rise.

For both HP cases, the initial ROI calculated is around 17 years, what make of the combination, helping the first investments and prizing the kWh distributed a good way of promoting this kind of facilities. The single use of subsidies to the initial costs will close the ROI's to 10 years and every saving would make the installation profitable, but the combination of both measurements forces the system owner to get the best efficiencies of the system to achieve shorter amortization times

6.5.9 Zone C2



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
43,79	249,61	64,79	3039,6	1409,6		-3406,26	6173,35		2671,16		25,93	18,29

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	64.32%	68,98%	72,38%	72,63%
Summer Coverage			81,87%	84,22%
SimpleROI	37,74	35,56	18,06	17,90

Studied locations: (18 locations belonging to 8 different countries)

Spain: Salamanca, **Valladolid**

Portugal: Bragança

*Italy:Alle*sandria, Forli, Rimini, Trieste, Udine, Venezia

*Turkey:*Istanbul

France: Carpentras, Montpellier

Bosnia Herzegovina: Mostar

Croatia: Rijeka

Slovenia: Portoroz

The locations presented in this classification are placed in central locations of the southern European countries or near the coasts in countries whit latitudes close to 45. The heating and cooling demand are nearly balanced along the year and the ETC begin be important due to their low thermal losses coefficient Nevertheless, FP collectors, with wide installed areas reach similar performances. The existence of enough heating demand and radiation allows a further use of the sorption machine as heat pump, permitting in those cases to obtain backup periods of around 18 years.

Solar installations without HP: Gas price increases make the return of investment periods shorter than a similar percentage variation of collector prices. For every ROI calculated under 15 years for FP and ETC's collectors, where the importance of the variables change.

Solar installations with HP: Gas price increases, electricity price increases, collector price decreasing and HP installation price decreases, in this order; make the simple ROI times shorter. The importance of the variables changes for both FP and ETC facilities in the interval between 5 and 10 simple ROI years.

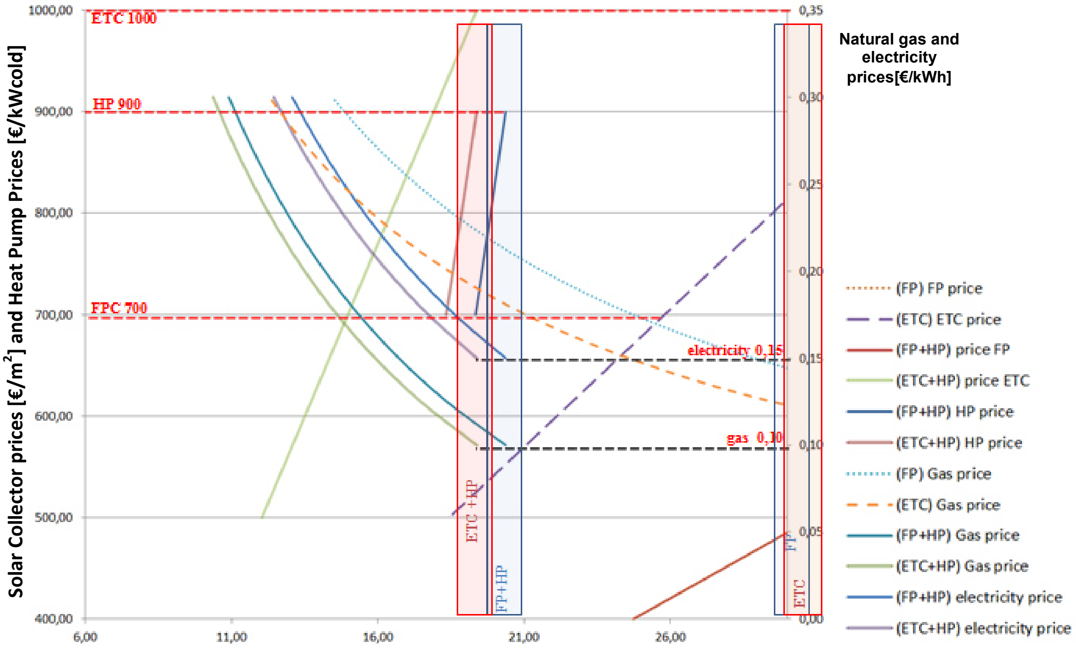
Helping politics proposed:

In this zone, under the limit of 20 years, only the HP based facilities are profitable.

The no-HP in the loop cases, have ROI's over the 36 years, so the unique way of helping the expansion of this technology should be based on subsiding the initial cost of the installation and prizing the introduced kWh in the system. The combination of both monetary helps, would not reach a ROI of 10 years for the two collector technologies. The interest on promoting the technology to fully cover in this case DHW along the year needs of high public efforts.

For both HP cases, the initial ROI calculated is around 18 years, what make of the combination, helping the first investments and prizing the kWh distributed a good way of promoting this kind of facilities. The single use of subsidies to the initial costs will close the ROI's to 11 years and every saving would make the installation profitable, but the combination of both measurements forces the system owner to get the best efficiencies of the system to achieve shorter amortization times.

6.5.10 Zone C3



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
42,84	397	74,12	3507,3	1445,72		-4673,05	6044,61		2824,32		28,69	19,57

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	60,21%	64,09%	68,85%	68,18%
Summer Coverage			85,15%	85,71%
SimpleROI	37,33	33,93	18,55	18,23

<u>Studied locations:</u> (6 locations belonging to 3 different countries)

*Italy:*Padova, Verona, Vicenza

*Turkey:*Afyon, Eskisehir

Bulgaria: Plovdiv

The locations presented in this classification are placed in northern locations of the southern European countries, far from the see. Heating and cooling demand are nearly balanced along the year and the ETC become the important technology to be installed due to their low thermal losses coefficient The existence of enough heating demand and radiation allows a further use of the sorption machine as heat pump, permitting in those cases to obtain backup periods of around 18 years.

<u>Solar installations without HP</u>: Flat plate's costs are the most important variable to make the facility profitable, while for ETC's, substitutive gas prices is the important variable up to a point delimited by ROI equal to 20 years, where the collector price become the most important

<u>Solar installations with HP</u>: Gas price increases, electricity price increases, collector price decreasing and HP installation price decreases, in this order; make the simple ROI times shorter. The importance of the variables changes for both FP and ETC facilities in the interval between 5 and 10 simple ROI years.

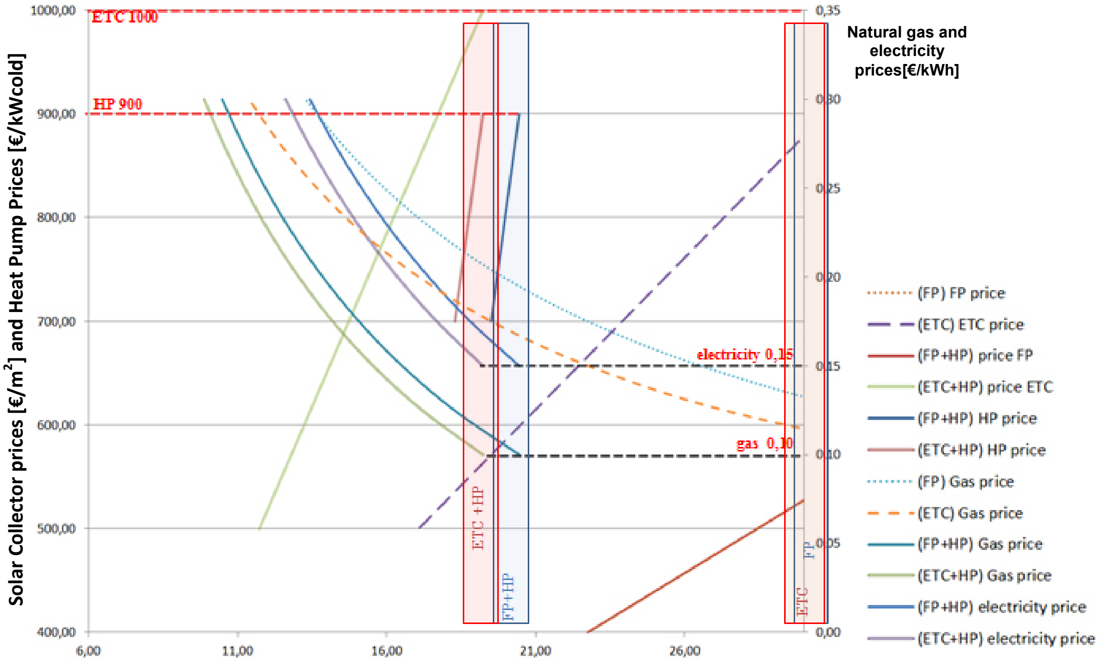
Helping politics proposed:

In this zone, under the limit of 20 years, only the HP based facilities are profitable.

The no-HP in the loop cases, have ROI's around the 35 years, so the unique way of helping the expansion of this technology should be based on subsiding the initial cost of the installation and prizing the introduced kWh in the system. The combination of both monetary helps, would not reach a ROI of 18 years for the two collector technologies. The interest on promoting the technology to fully cover in this case DHW along the year needs of high public efforts.

For both HP cases, the initial ROI calculated is around 18 years, what make of the combination, helping the first investments and prizing the kWh distributed a good way of promoting this kind of facilities. The single use of subsidies to the initial costs, will close the ROI's to 11 years and every saving would make the installation profitable, but the combination of both measurements forces the system owner to get the best efficiencies of the system to achieve shorter amortization times.

6.5.11 Zone C4



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
43,37	198	85,285	3822,5	1378,56		-5788,87	5549,75		2399,86		28,61	19,09

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	56,42%	60,32%	66,14%	64,73%
Summer Coverage			85,17%	84,75%
SimpleROI	35,12	31,13	18,59	18,11

<u>Studied locations:</u> (7 locations belonging to 4 different countries)

Serbia: Negotin, Nis

Macedonia: Bitola

Romania: Braila

Bulgaria: Plévène, Roussé, Stara Zagora

The locations presented in this classification are placed in northern locations of the southern east European countries, far from the see. Heating and cooling demand are balanced along the year and the ETC become the important technology to be installed due to their low thermal losses coefficient The existence of enough heating demand and radiation allows a further use of the sorption machine as heat pump, permitting in those cases to obtain backup periods of around 18 years.

Solar installations without HP: Flat plate's costs are the most important variable to make the facility profitable, while for ETC's, substitutive gas prices is the important variable up to a point delimited by ROI equal to 16 years, where the collector price become the most important

Solar installations with HP: Gas price increases, electricity price increases, collector price decreasing and HP installation price decreases, in this order; make the simple ROI times shorter. The importance of the variables changes for both FP and ETC facilities in the interval between 5 and 10 simple ROI years.

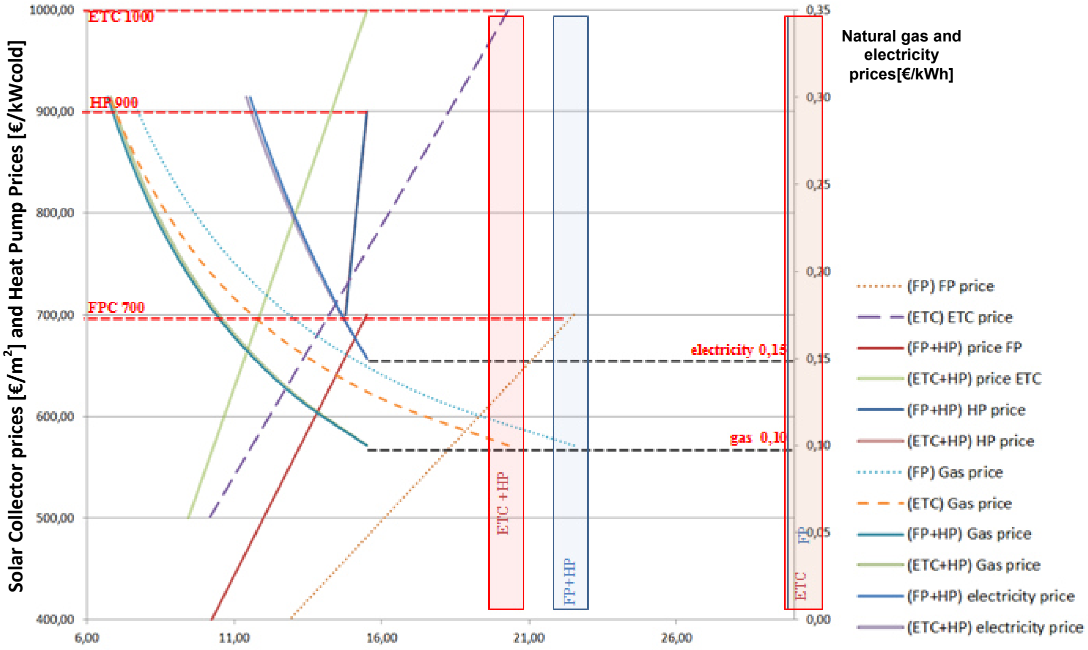
Helping politics proposed:

In this zone, under the limit of 20 years, only the HP based facilities are profitable.

The no-HP in the loop cases, have ROI's around the 33 years, so the unique way of helping the expansion of this technology should be based on subsiding the initial cost of the installation and prizing the introduced kWh in the system. The combination of both monetary helps, would not reach a ROI of 18 years for the two collector technologies. The interest on promoting the technology to fully cover in this case DHW along the year needs of high public efforts.

For both HP cases, the initial ROI calculated is around 18 years, what make of the combination, helping the first investments and prizing the kWh distributed a good way of promoting this kind of facilities. The single use of subsidies to the initial costs, will close the ROI's to 10 years and every saving would make the installation profitable, but the combination of both measurements forces the system owner to get the best efficiencies of the system to achieve shorter amortization times.

6.5.12 Zone C5



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
42,12	713,5	59,46	4316,4	1531,52		-6808,5	4032,52		1417,88		37,44	20,96

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	53,47%	55,65%	62,98%	60,14%
Summer Coverage			98,35%	97,42%
SimpleROI	42,76	32,97	22,34	19,4

<u>Studied locations:</u> (2 locations belonging to 2 different countries)

Turkey: Sivas

Romania: Bucarest

The two locations presented in this classification are placed in Romania and Turkey, with a pretty high altitude. Heating demand becomes more important than cooling and the ETC collectors are recommended for every case, although, Flat plates with heat pump initial saves are not far away for the 20 year ROI limit.

Solar installations without HP: Flat plate installations without heat pump are not recommended due to the need of large collector surfaces that it will not provide acceptable ROI's. For the ETC case, the gas prices are more important than the collector prices when the returning periods are over 16 years

Solar installations with HP: Gas price increases, collector price decreasing, electricity price increases and HP installation price decreases, in this order; make the simple ROI times shorter. The importance of the variables changes for both FP and ETC facilities in the interval between 5 and 10 simple ROI years. The variables associated to cooling as the heat pump price and the electrical costs nearly doesn't influence the ROI

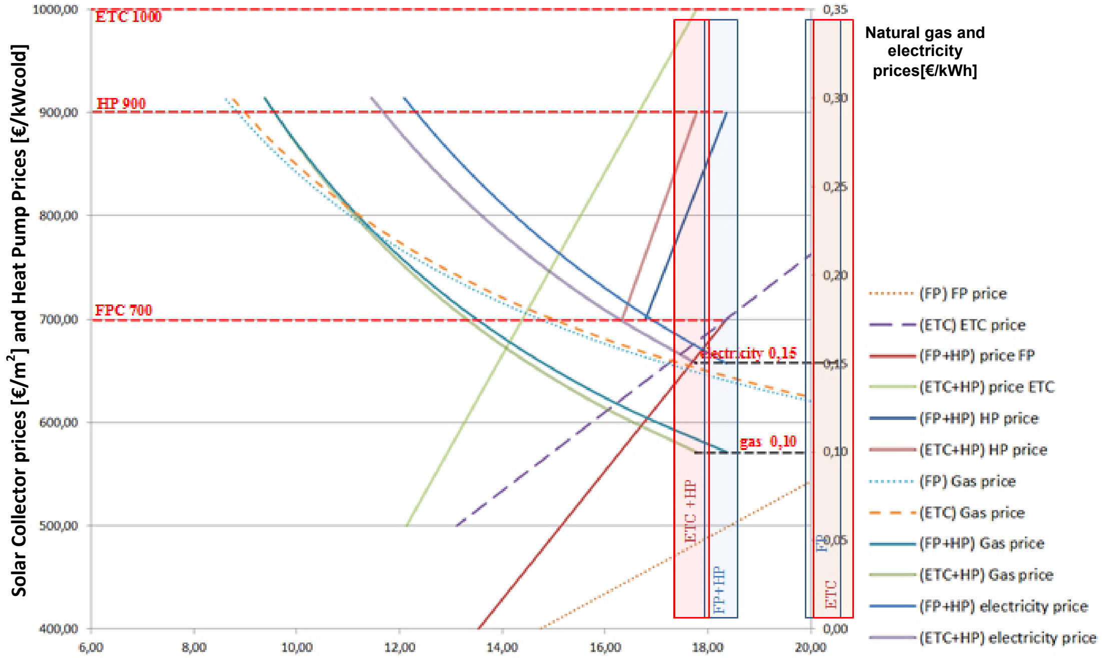
Helping politics proposed:

In this zone, under the limit of 20 years, only the ETC+HP based facilities are profitable.

The no-HP in the loop cases, based on flat plates are nor recommended and the ETC's have ROI's around the 33 years, so the unique way of helping the expansion of this technology should be based on subsiding the initial cost of the installation and prizing the introduced kWh in the system. The combination of both monetary helps, would not reach a ROI of 15 years for the two collector technologies. The interest on promoting the technology to fully cover in this case DHW along the year needs of high public efforts.

For both HP cases, the initial ROI calculated is around 20 years, what make of the combination, helping the first investments and prizing the kWh distributed a good way of promoting this kind of facilities. The single use of subsidies to the initial costs, will close the ROI's to 12 years and every saving would make the installation profitable, but the combination of both measurements forces the system owner to get the best efficiencies of the system to achieve shorter amortization times.

6.5.13 Zone D1



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
40,98	0	17,41	2330,8	1332,624		-1187,26	8644,99		4950,25		12,51	9,42

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	70,98%	76,11%	76,32%	78,21%
Summer Coverage			29,08%	35,14%
SimpleROI	23,92	23,99	19,55	18,30

<u>Studied locations:</u> (1 locations belonging to 1 country)

Turkey: Trabzon

In the studied location, cooling demand is much more important than cooling one.

All four layouts get similar ROI times.

Solar installations without HP: Gas price increases make the return of investment periods shorter than a similar percentage variation of collector prices. For every ROI calculated under 11 years for FP and ETC collectors, their prices become more important than the substitutive fuel one.

Solar installations with HP: Gas price increases, electricity price increases, collector price decreasing and HP installation price decreases, in this order; make the simple ROI times shorter. The importance of the variables changes for both FP and ETC facilities in the interval between 5 and 10 simple ROI years.

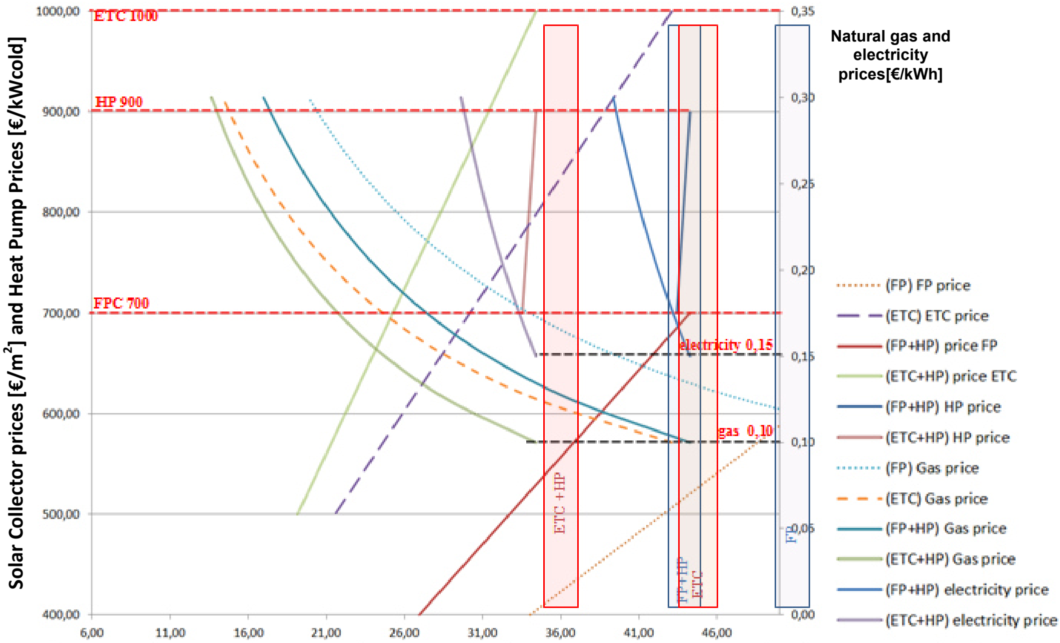
Helping politics proposed:

In this zone, under the limit of 20 years, only the HP based facilities are profitable.

The no-HP in the loop cases, have ROI's around the 24 years, so the unique way of helping the expansion of this technology should be based on subsiding the initial cost of the installation. The number of backup years saved when applying this measurement is 15 when the bought of the systems is helped with the complete price interval studied, for the both solar technologies proposed. Further increases of the substitutive energies would make the systems profitable in less than 10 years. A possible prizing of the saved gas would get the ROIs closer to 10 years, what make possible the decrease of the prizing when the substitutive energy prices rise.

For both HP cases, the initial ROI calculated is around 19 years, what make of the combination, helping the first investments and prizing the kWh distributed a good way of promoting this kind of facilities. The single use of subsidies to the initial costs, will close the ROI's to 12 years and every saving would make the installation profitable, but the combination of both measurements forces the system owner to get the best efficiencies of the system to achieve shorter amortization times

6.5.14 Zone D2



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
45,86	206,43	32,576	3317,7	1270,16		-4174,97	3358,23		1677,79		47,27	26,49

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	63,01%	67,35%	72.86%	71,97%
Summer Coverage			55,40%	55,75%
SimpleROI	60,87	45,93	45,52	36,15

<u>Studied locations:</u> (4 locations belonging to 2 different countries)

France: Valence, Carcassonne

Ireland: Belmullet, Valentia

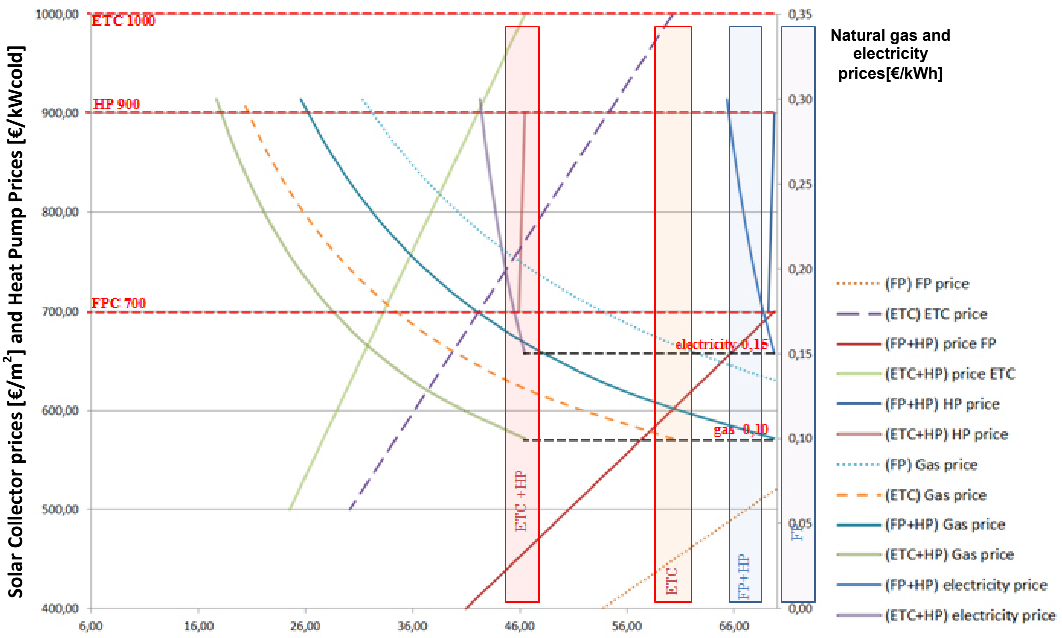
Four locations are studied in this chapter, where heating loads are a little bit higher than the cooling ones, but the low temperatures and radiation along the winter season doesn't allow to install flat plate systems without large areas and as a consequence, with a need of high political support to expand the technology.

In the studied locations, no flat plate facility would be studied because the needed collectors to achieve the studied objectives occupy an area larger than the available roof surface.

ETC base facilities have an opportunity when combined with heat pumps, where the collector prices are the predominant variable to make the systems profitable. The second variable in order of importance are the gas prices, while electricity and overall the sorption machine prices and don't play any important role in the financial problem.

Helping politics proposed: The way to make viable ETC+HP facilities come from a first monetary help to by the facility that would bring the ROi's to 20 years and lately prize every kWh introduced into the building that would make interesting the installation of a system with a minimum ROI of around 12 to 15 years.

6.5.15 Zone D3



Latitude [º]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
48,24	204,6	31,126	3886,7	1169,88		-5584,44	3223,15		1494,73		77,04	37,09

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	58,31%	62,55%	69,14%	68,06%
Summer Coverage			54,49%	54,03%
SimpleROI	90,43	58,23	66,72	44,8

<u>Studied locations:</u> (16 locations belonging to 7 different countries)

Spain: Burgos; *Italy:* Brescia, Milano, Torino, Bolzano

France: Embrun*Great Britain:* Belfast, Dunstaffnage, Oban

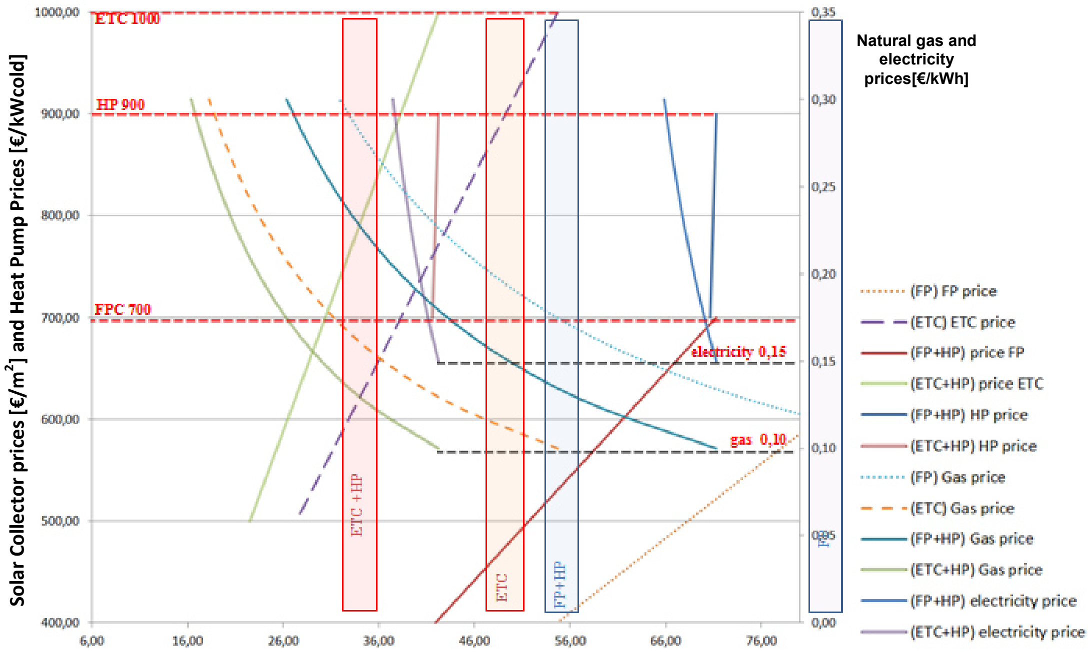
Serbia: Beograd *Ireland:* Birr, Clones, Dublin

Bulgaria: Bourgas, Dobritch, Varna

In the studied locations, no flat plate facility would be studied because the needed collectors to achieve the studied objectives occupy an area larger than the available roof surface.

For the ETC case, without HP's the firstly obtained ROI's didn't show a possibility of installing the collectors to cover the DHW heating demand. With HP's, a combination of efforts done on the first investment costs with prizing the kWh delivered to the building could give an opportunity to the technology. Electrical prices and sorption machine prices don't play significant roles in the ROI, although it would be very complicated to reach values closed to 20 years.

6.5.16 Zone D4



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
47,34	191,71	44,69	4123,5	1230,71		-6311,17	3571,75		1429,33		76,78	33,27

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	56,52%	59,68%	66,30%	64,66%
Summer Coverage			72,57%	71,80%
SimpleROI	79,15	48,54	55,27	34,93

Studied locations: (14 locations belonging to 6 different countries)

Bosnia Herzegovina: Banja Luka; *Bulgaria: Sliven*

Serbia: Novi Sad, Pristina, Surcin*Hungary:* Szeged

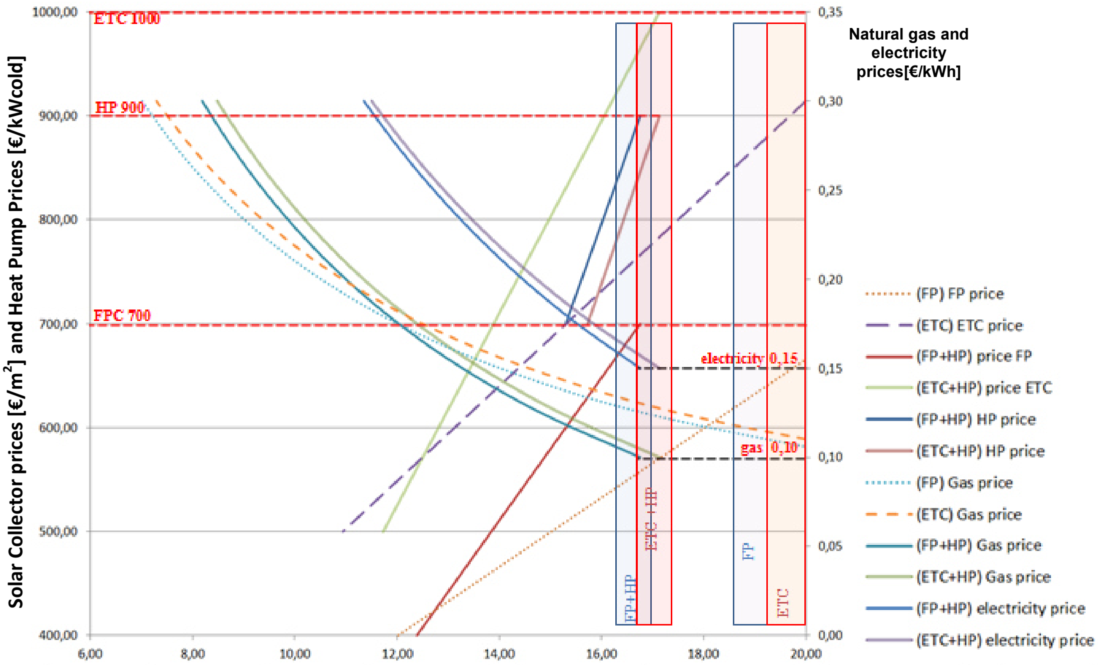
Romania: Arad, Oradea, Constanta, Craiova, Timisoara

Great Britain: Aberdeen, Eskdalemuir, Leuchars

In the studied locations, no flat plate facility would be studied because the needed collectors to achieve the studied objectives occupy an area larger than the available roof surface.

For the ETC case, without HP's the firstly obtained ROI's didn't show a possibility of installing the collectors to cover the DHW heating demand. With HP, a combination of efforts done on the first investment costs with prizing the kWh delivered to the building can give an opportunity to the technology. Electrical prices and sorption machine prices don't play significant roles in the ROI. The combination of prizing and subsidies politics together, it would reach ROI values in the interval between 15 and 20 years.

6.5.17 Zone E1



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
41,68	0	16,09	2424,8	1523,01		-864,68	4047,91		1794,53		9,47	7,46

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	73,68%	76,98%	78,36%	79,06%
Summer Coverage			55,53%	60,40%
SimpleROI	18,42	19,80	16,80	17,17

<u>Studied locations:</u> (2 locations belonging to 2 different countries)

Spain: Vigo

Portugal: Porto

In the studied locations, cooling demand is much more important than heating one, but both of them are pretty small. The available radiation alone the year allows the use of solar collectors for heating and cooling.

All four layouts get similar ROI times.

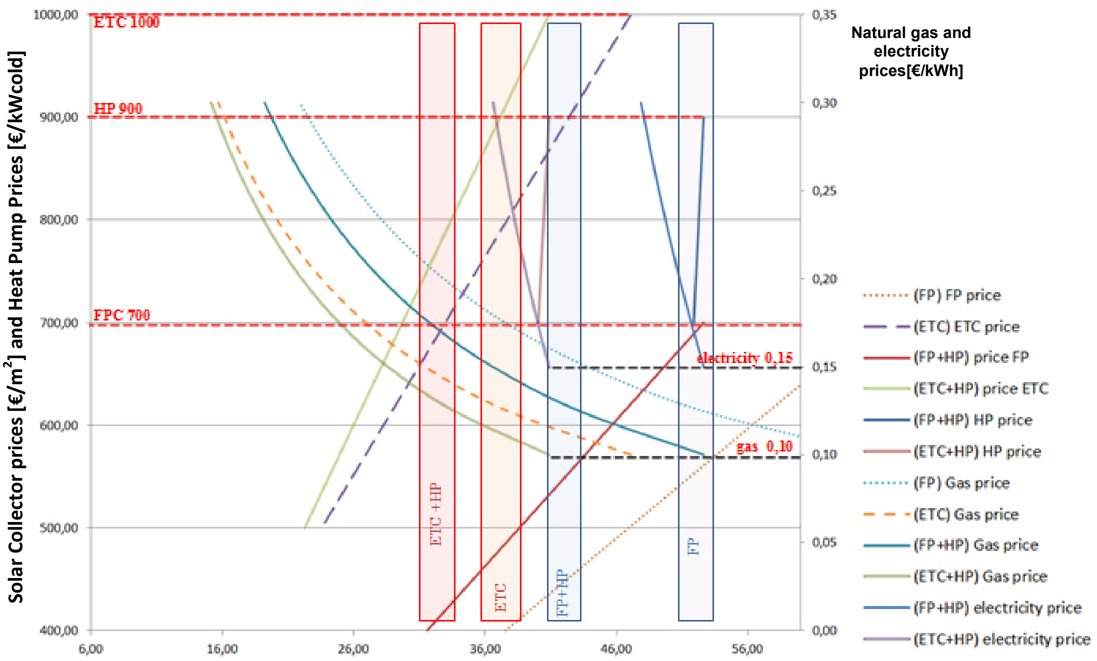
Solar installations without HP: Gas price increases make the return of investment periods shorter than a similar percentage variation of collector prices. For every ROI calculated under 7 years for FP and 11 years for ETC collectors, the collector prices become more important than the substituted gas.

Solar installations with HP: Gas price increases, electricity price increases, collector price decreasing and HP installation price decreases, in this order; make the simple ROI times shorter. The importance of the variables changes for both FP and ETC facilities in the interval between 5 and 10 simple ROI years.

Helping politics proposed:

In these zones, all systems are profitable with the calculated prices, but if it is decided to strength here the solar installations, a good solution would be to help the owners in a first step with subsidies to decrease the initial costs and prize every kWh introduced into the demanding building for a determinate number of years that would make the investment interesting from an economic point of view. As it has been previously said, this solution point on the facility optimization and keeps the interest of the owners/managers on collecting as much as possible energy from the sun

6.5.18 Zone E2



Latitude [º]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]	Winter load [kWh/y]	Summer load [kWh/y]	Latent summer load	FP [m2]	ETC [m2]
46	184,14	17,72	3378,5	1269,64	-4986,34	2156,68	935,68	41,53	22,56

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	60,51%	62,99%	70,41%	67,61%
Summer Coverage			88,89%	87,7%
SimpleROI	52,17	38,81	40,33	32,36

<u>Studied locations:</u> (7 locations belonging to 4 different countries)

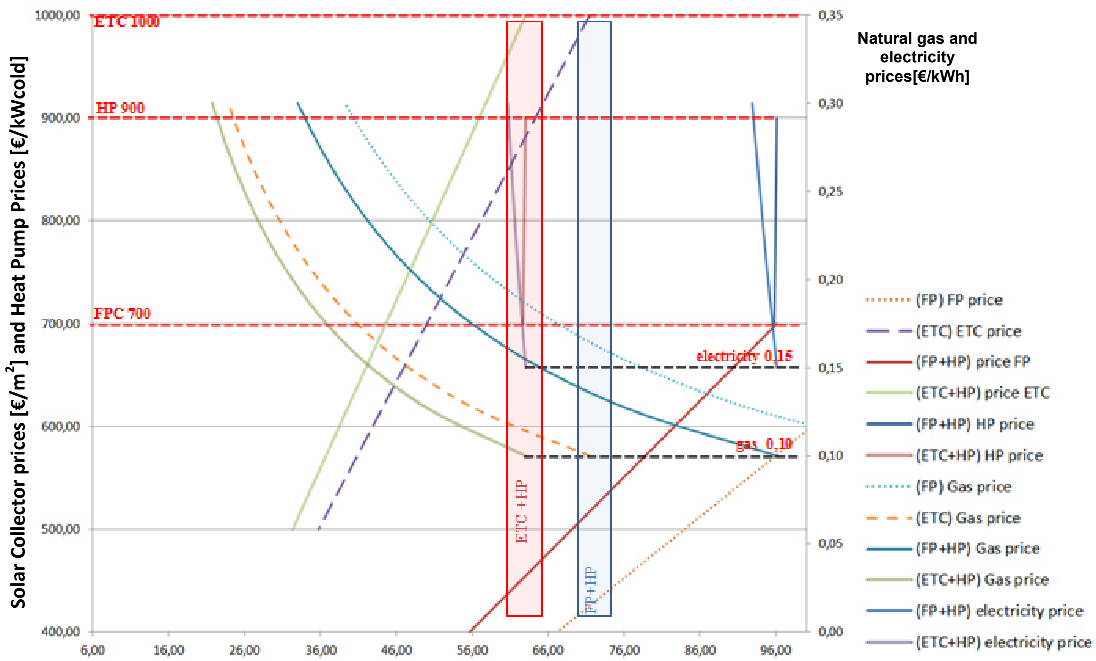
Spain: Orense *Great Britain:* Camborne

France: Bourdeaux, Agen, Biscarrosse, Millau*Ireland:* Cork

Seven locations are studied in this chapter, where heating loads are slightly higher than the cooling ones, but the low temperatures and radiation along the winter season doesn't allow to install flat plate systems without large areas and as a consequence, with a need of high political support to expand the technology. In the studied locations, no flat plate facility would be studied because the needed collectors to achieve the studied objectives occupy an area larger than the available roof surface ETC base facilities have an opportunity when combined with heat pumps, where the collector prices are the predominant variable to make the systems profitable, followed by gas prices. Electricity and overall the sorption machine prices and don't play any financial role.al problem

The way to make viable ETC+HP facilities come from a first monetary help to buy the facility, approaching the ROi's to 15 years and lately, prize every kWh introduced into the building that would make interesting the installation of a system with a ROI of around 12 to 15 years.

6.5.19 Zone E3



Latitude [º]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summerload		FP [m2]	ETC [m2]
51,93	66,92	3,27	4143,1	997,08		-6648,65	324,87		113,36		116,06	52,13

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	59,42%	63,17%	70,78%	69,77%
Summer Coverage			69,23%	69,23%
SimpleROI	123,36	74,40	100.96	65,80

<u>Studied locations:</u> (13 locations belonging to 5 different countries)

France: Villeurbanne

Belgium: Oostende

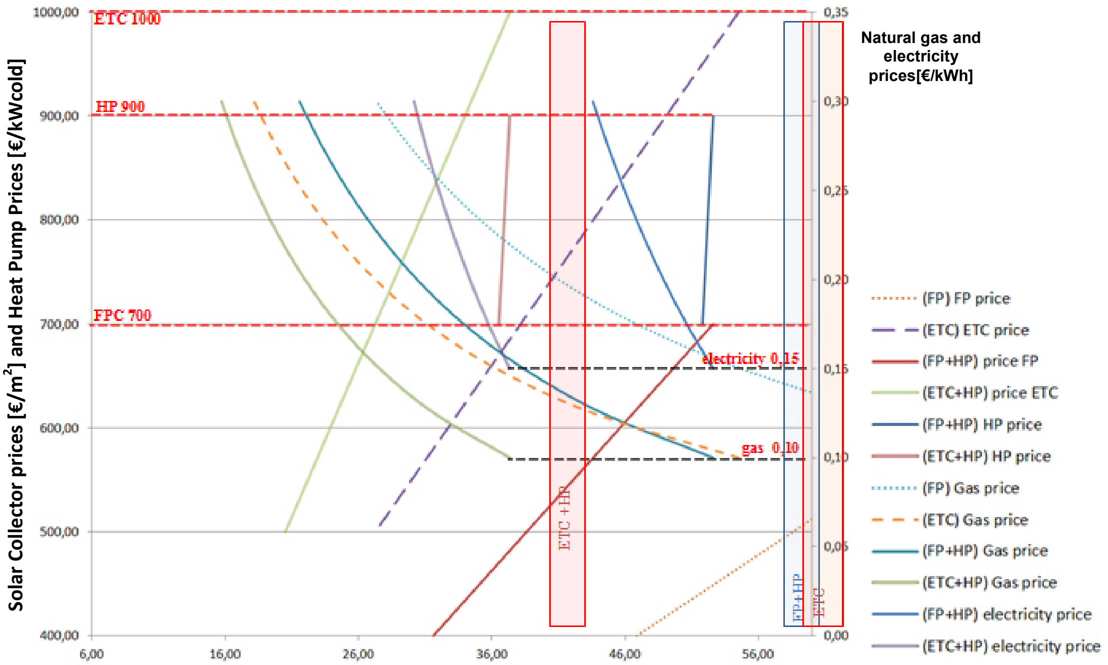
Netherlands: De Kooy

Ireland: Kilkenny

Great Britain: Aberporth, Aughton, Birmingham, Cardiff, Fairfield, Garston, Hemsby, Silsoe, Sutton

For the studied climatic zone, no flat plate or evacuated tube facility would be proposed. In the first case the limiting factor is the large collector areas demanded to serve the building while for the second case, the problem leads in economical fields, where a combination of subsidies and energy prizing would not achieve simple ROI's of 20 years.

6.5.20 Zone E4



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
48,66	159,43	25,72	4104,9	1149,25		-6337,1	3255,64		1296,87		85,44	39,79

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	56,58%	59,19%	66,21%	64,53%
Summer Coverage			98,1%	97,32%
SimpleROI	95,11	60,93	60,14	41,28

<u>Studied locations:</u> (7 locations belonging to 6 different countries)

Great Britain: Cawood*Germany:* List

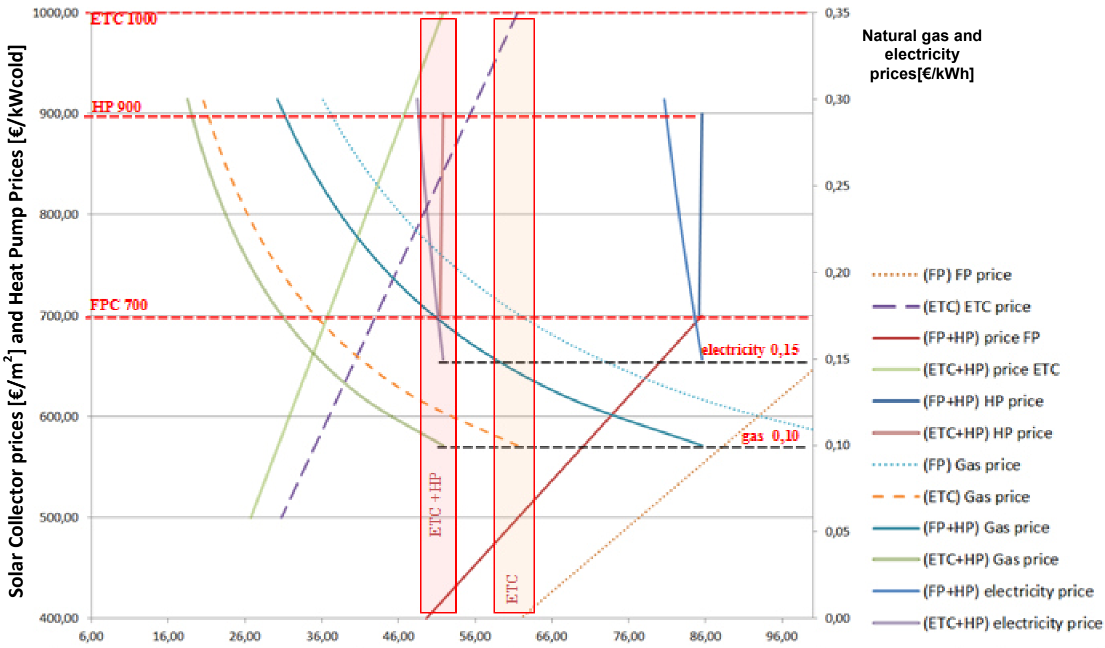
Bosnia Herzegovina: Tuzla*Croatia:* Zagreb

Hungary: Pécs, Székesfehévár*Slovakia:* Bratislava

For the studied climatic zone, no flat plate facility would be proposed. In this case the limiting factor is the large collector areas demanded to serve the building.ETC base facilities have an opportunity when combined with heat pumps, where the collector prices are the predominant variable to make the systems profitable, followed by gas prices. Electricity and overall the sorption machine prices and don't play any important role in the financial problem.

Helping politics proposed: The way to make viable ETC+HP facilities come from a first monetary help to by the facility that would bring the ROi's to 24 years and lately prize every kWh introduced into the building that would make interesting the installation of a system with a minimum ROI of around 15 years.

6.5.21 Zone E5



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
52,3	327,35	8,39	5087,1	1053,88		-9430,59	976,62		341,84		139,61	55,61

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	56,30%	59,19%	66,37%	65,00%
Summer Coverage			64,25%	64,04%
SimpleROI	122,73	66,79	95,97	55,74

<u>Studied locations:</u> (14 locations belonging to 11 different countries)

Belgium: St Hubert*Denmark:* Alborg, Arhus

Germany: Braunlage, Dresden*Poland:* Gdansk

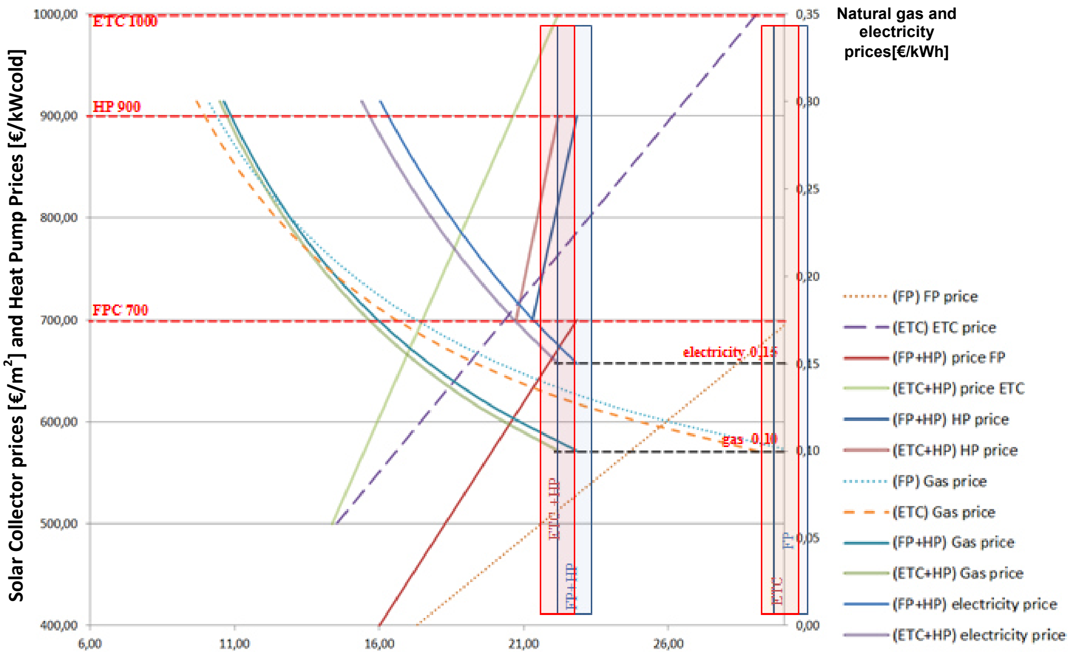
Czech Republic: Churanov*Hungary:* Budapest, Kecskemet

Slovakia: Pleso*Romania:* Satu Mare

Sweden: Boras, Goteborg*Lithuania:* Klaipeda

For the studied climatic zone, no flat plate or evacuated tube facility would be proposed. In the first case the limiting factor is the large collector areas demanded to serve the building while for the second case, the problem leads in economical fields, where a combination of subsidies and energy prizing would not achieve simple ROI's of 20 years.

6.5.22 Zone ExcCold1



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
43,38	58	5,95	2697,1	1281,9		-1264,5	3225,67		1708,86		16.38	11,78

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	70,48%	75,3%	76,77%	78,11%
Summer Coverage			64,81%	70,12%
SimpleROI	30,24	29,05	22,83	22,19

<u>Studied locations:</u> (6 locations belonging to 1 country)

Spain: Bilbao, Gijón, La Coruña, Oviedo, San Sebastián, Santander

In the studied locations, all of them in the Spanish north coast, heating demand is much lower than cooling one, but both of them are pretty small. The available radiation alone the year allows the use of solar collectors for heating and cooling.

<u>Solar installations without HP</u>: Gas price increases make the return of investment periods shorter than a similar percentage variation of collector prices. For every ROI calculated under 7 years for FP and 11 years for ETC collectors, the collector prices become more important than the substituted gas.

<u>Solar installations with HP</u>: Gas price increases, electricity price increases, collector price decreasing and HP installation price decreases, in this order; make the simple ROI times shorter. The importance of the variables changes for both FP and ETC facilities in the interval between 5 and 10 simple ROI years.

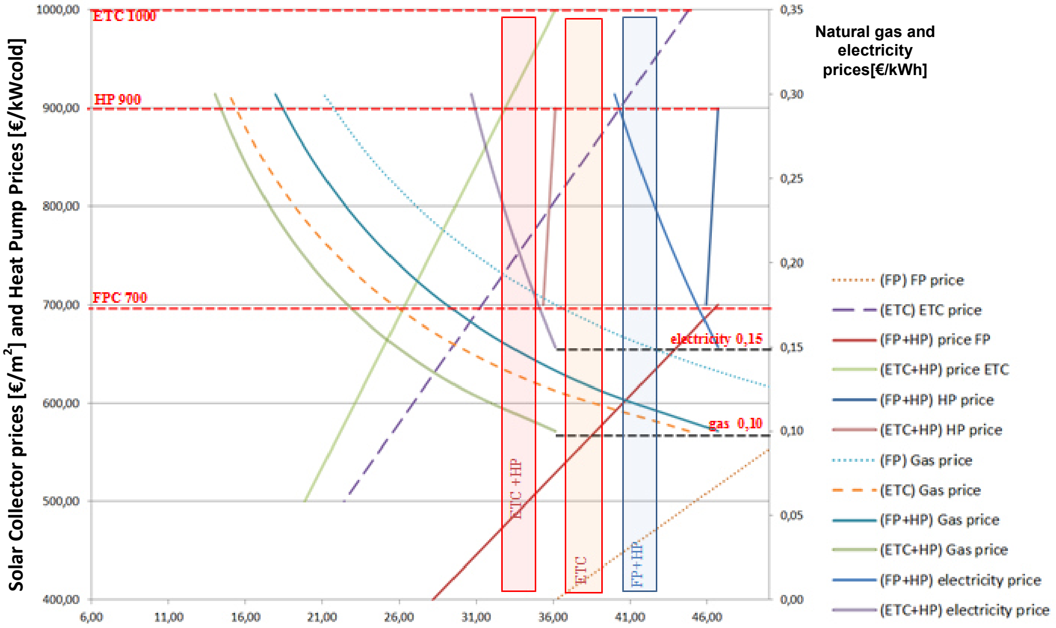
Helping politics proposed:

In this zone, under the limit of 20 years, only the HP based facilities are close to be profitable.

The no-HP in the loop cases, have ROI's around the 30 years, so the unique way of helping the expansion of this technology should be based on subsiding the initial cost of the installation and prizing the introduced kWh in the system. The combination of both monetary helps, would reach ROI's under 10 years for the two collector technologies.

For both HP cases, the initial ROI calculated is around 22 years, what make of the combination, helping the first investments and prizing the kWh distributed a good way of promoting this kind of facilities. The single use of subsidies to the initial costs, will close the ROI's to 13 years and every saving would make the installation profitable, but the combination of both measurements forces the system owner to get the best efficiencies of the system to achieve shorter amortization times.

6.5.23 Zone ExcCold2



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
47,28	56,55	7,85	3507,1	1193,82		-5909,33	1551,9		777,72		50,66	26,55

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	61,37%	64,01%	71,98%	69,07%
Summer Coverage			75,24%	75,19%
SimpleROI	55,62	40,46	42,59	33,73

<u>Studied locations:</u> (11 locations belonging to 3 different countries)

Turkey: Zonguldak*Great Britain:* Efford, Is. Jersey

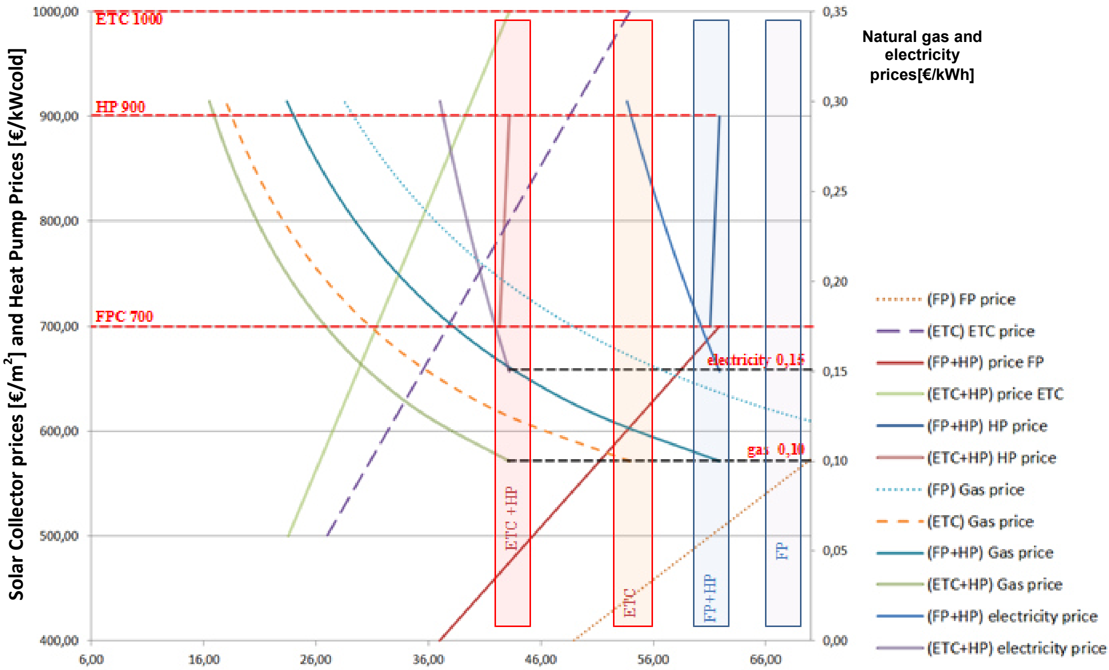
France: Le Havre, Nantes, Rennes, Brest, Caen, La Rochelle, La Roche sur Yon, Pau

The studied locations of this zone have pretty important heating demands compared to the low cooling ones. The low ambient temperatures and radiation along the winter season doesn't allow installing flat plate systems without large areas and as a consequence, with a need of high political support to expand the technology.

No FP layout is amortizable in this zone, while ETC base facilities have an opportunity when combined with heat pumps, where the collector prices are the predominant variable to make the systems profitable. The second variable in order of importance are the gas prices, while electricity and overall the sorption machine prices and don't play any important role in the financial problem.

Helping politics proposed: The way to make viable ETC+HP facilities come from a first monetary help to by the facility that would bring the ROi's to 27 years and lately prize every kWh introduced into the building that would make interesting the installation of a system with a minimum ROI of around 12 to 13 years.

6.5.24 Zone ExcCold3



Latitude [º]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
48,29	163,33	15,30	3875,3	1128,79		-7058,82	1683,12		743,35		79,45	37,22

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	57,75%	60,36%	69,15%	66,39%
Summer Coverage			98,09%	97,83%
SimpleROI	83,17	53,47	59,43	42,24

<u>Studied locations:</u> (27 locations belonging to 7 different countries)

Italy: Bergamo*Neatherlands:* Vlissingen

Turkey: Karabuk*Germany:* Mannheim

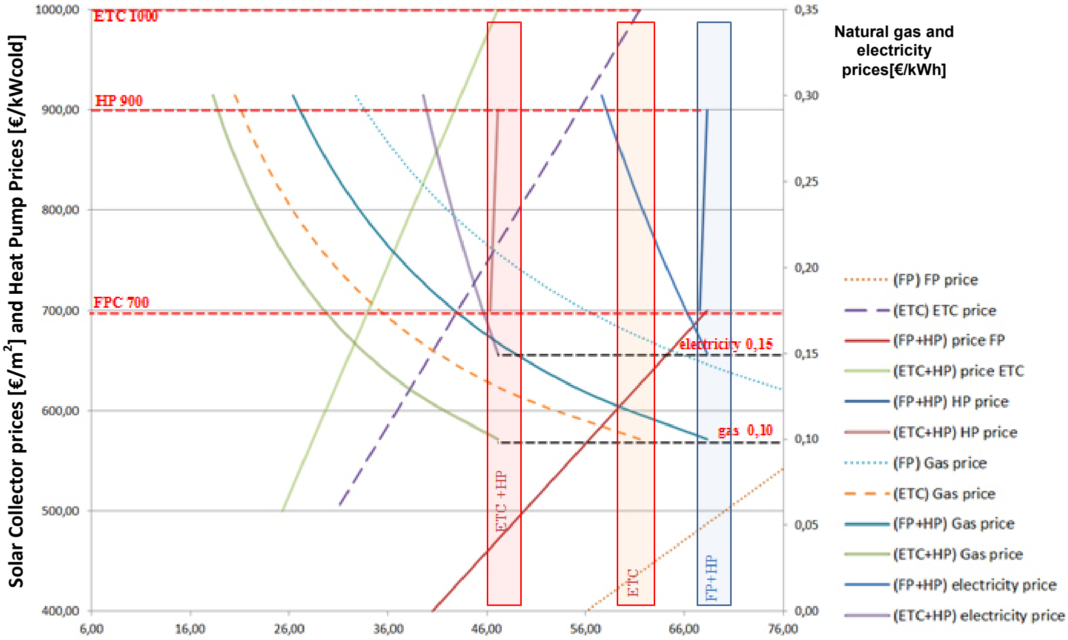
France: Amiens, Auxerre, Bourges, Cl. Ferrand, Le Mans, Lille, Limoges, Lyon, Macon, Orleáns, Paris, Rouen, Saint Etienne, Tours, Trappes, Troyes.

Great Britain: Bracknell, Cardington, Grendon Underwood, Kew, London

Switzerland: Lugano

For the studied climatic zone, no flat plate facility would be proposed. In this case the limiting factor is the large collector areas demanded to serve the building. ETC base facilities have an opportunity when combined with heat pumps, with a firs monetary help to approach ROi's of about 22 years and lately prize every kWh introduced into the building that would make interesting the installation of a system with a minimum ROI of around 12 years.

6.5.25 Zone ExcCold4



Latitude [º]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
48,91	285,27	13,246	4293,2	1088,44		-7241,78	1445,81		495,9		93,54	43,15

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	55,13%	58,56%	66,05%	64,72%
Summer Coverage			92,43%	92,27%
SimpleROI	99,43	61,85	69,64	47,73

<u>Studied locations:</u> (45 locations belonging to 11 different countries)

Italy: Lecco*Belgium:* Brussels *Austria:* Vienna
Liechtenstein: Vaduz *Bulgaria:* Sofia *Slovenia:* Ljubljana

France: Mulhouse, Reims, Strasbourg, Dijon, Le Puy en Velay, Nancy, Saint Quentin.

Neatherlands: Arnhem, Amsterdam, De Bilt, Groningen, Beek (Limburg)

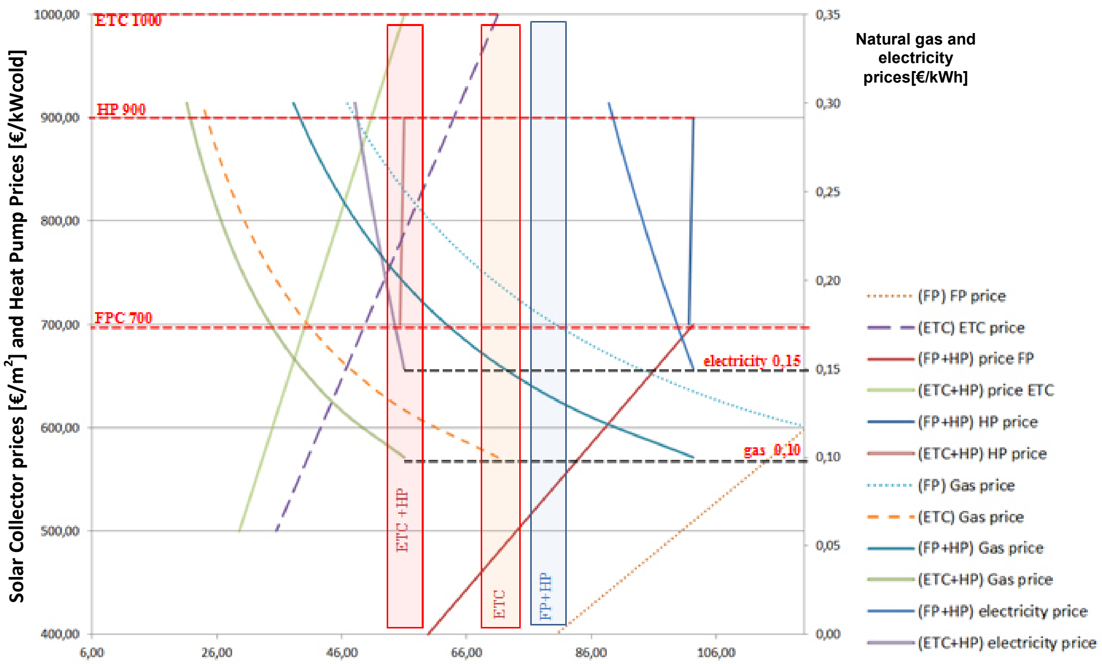
Germany: Bocholt, Bonn, Bremen, Frankfurt, Freiburg, Geisenheim, Giessen, Hamburg, Heiligendamm, Norderney, Osnabrük, Saarbrücken, Stuttgart, Würzburg

Switzerland: Basel, Bern, Geneve, Glarus, Interlaken, Luzern, Neuchatel, Sion, St. Gallen, Zurich

Bosnia Herzegovina: Sarajevo, Zenica

No flat plate or ETC facility would be proposed. In the first case the limiting factor is the large collector areas demanded while for the second case, the problem leads in economical fields, where a combination of subsidies and energy prizing don't achieve simple ROI's of 20 years.

6.5.26 Zone ExcCold5



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
49,49	355,02	11,54	4779,8	1124,87		-7953,35	1583,04		573,68		106,34	45,39

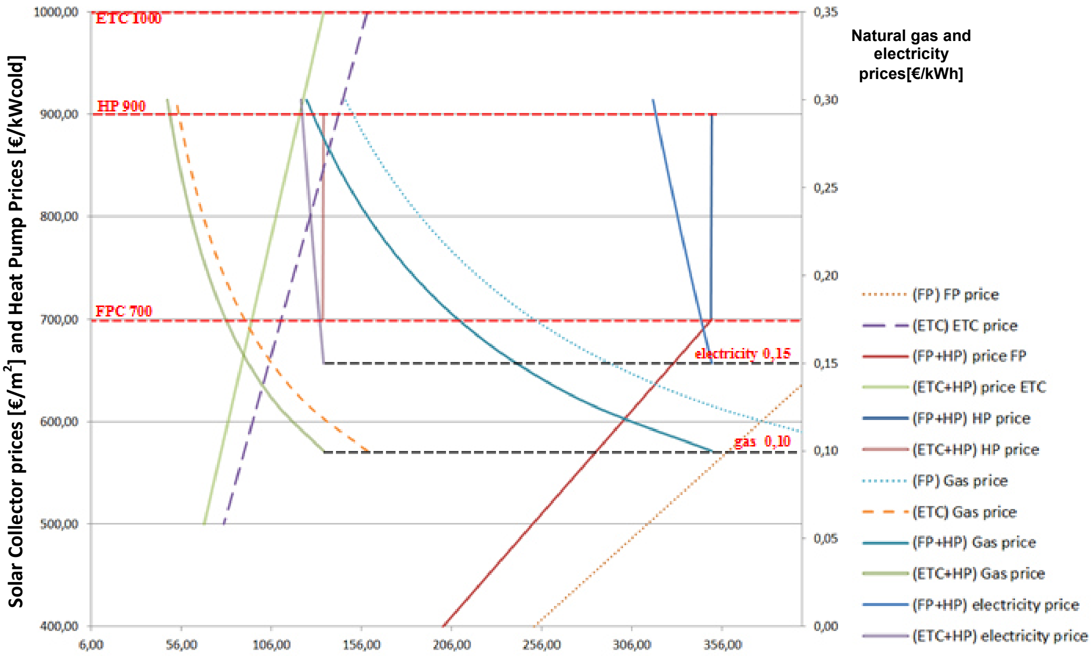
	FP	ETC	FP+HP	ETC+HP
Winter Coverage	54,77%	57,53%	65,13%	63,28%
Summer Coverage			92,98%	92,65%
SimpleROI	105,95	61,68	74,31	47,36

<u>Studied locations:</u> (51 locations belonging to 14 different countries)

Denmark: Copenhage; *Serbia:* Kopaonik, Sjenica, Zlatibor; *Bosnia Herzegovina:* Parg; *Austria:* Graz, Innsbruck, Klagenfurt, Linz, Mönichkirchen, Salzburg, Steyr; *Germany:* Berlin, Braunschweig, Coburg, Hohenpeissenberg, Lüdenscheid, Munich, Nuremberg, Passau, Postdam, Schleswig, Weissenburg; *Poland:* Kolobrzeg, Cracovia, Mikolajki, Poznan, Suwalki, Warsaw; *Lituania:* Kaunas; *Chech Republic:* Kucharovice, Ostrava, Hradec Królové, Olomouc, Prague; *Hungary:* Debrecen, Gyoer, Szombathely, Miskolc; *Slovenia:* Marebor; *Slovakia:* Kosice; *Rumania:* Baia Mare, Peatra Neamt Rimnicu Vilcea, Cluj, Sibiu Suceava, Tirgu; *Sweden:* Lund, Norrköepping, Vaexjoe

For the studied climatic zone, no flat plate or evacuated tube facility would be proposed. Large collector areas and no economic viability to achieve 20 yr. ROI's are respectively the causes.

6.5.27 Zone ExcCold ExcCold



Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
59,6	76,1	1,37	5960,4	963,38		-11939,7	772,98		208,99		444	121,23

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	55,80%	58,50%	64,89%	63,77%
Summer Coverage			100%	100%
SimpleROI	334,49	122,22	259,95	102,99

<u>Studied locations:</u> (10 locations belonging to 4 different countries)

Finland: Helsinki, Jokioinen, Tampere, Turku

Sweden: Borlaenge, Karlstad, Stockholm

Latvia: Daugavpils

*Estonia:*Tallin, Tartu

For the studied climatic zone, no flat plate or evacuated tube facility would be proposed. In both cases, the large collector areas needed to serve the building make impossible the economic viability of the technology.

7. Evaluation of different sets Building/System for a determinate climate

All the previous work described, represents in a general way, a feasibility study of different solar thermal technologies when applied to a previously defined building. It was decided, in order to realize the European comparison, to have certain insulation levels, certain window definition and a fixed wall ratio between opaque and transparent surfaces. Those suppositions delivered a first approximation to the feasibility of installing the studied technologies in each European zone. That way it was found the most equitable to compare and evaluate the technologies around Europe, but on the other hand the results should be recalculated if the intention is applying on of the studied technologies in a determinate location.

This chapter develops an example of joint optimization for the building described, located in a determinate zone, through the variation of some of the parameters considered fixed in the previous studies done. The performance increase could be done on the only base of maximizing the solar platform utilization and reducing its ROI's, but that direction would imply an energy demand increase for the building. Energy demand increases would improve the system economic figures but, increasing fossil energy costs isaantagonist result from the one searched in this work.

The building considered in this chapter, is identical in shape and occupancy profiles to the one moved around Europe, but thermal characteristics of its walls, floors, roofs and windows are to be changed as well as the ratios between opaque and translucent surfaces, studied by orientations. The initial installation prices, electrical and gas tariffs, are fitted to the actual reality of the country initiating the building/facility set optimization in a different point to the one obtained in previous chapters. (Building evaluation realized in this chapter was done in January 2015 based on gas and electrical prices of a similar house, paid along 2014.)As an example,it can be noted that price intervals used in Chapter 6.3 were wide enough to cover all the existing prices found along Europe. Those prices are now fixed to the geographical zone here studied.

7.1 Initial values considered for a building placed in Valladolid

Valladolid is a north Spanish city placed in the C2 climatic zone, as it was described in Chapter 3: Climatic Distribution. The altitude is 735 meters, and geographical coordinates are latitude: 41,31'08" N, longitude: 4,43'24" W.

It is positioned in the middle of "Meseta Castellana", as it is called the wide plain that constitutes the biggest part of the "Castilla y Léon" region. On the borders of the plain, stands an extended mountain range that decreases rains intensity and protects the inner area from cold and hot winds. Only the west side (border with Portugal) is free of mountain: there, air masses from Atlantic sea can penetrate bringing important rainfall in autumn.

Climate can tautly be defined as continental, with long and hard winters and dry, hot and short summers. It is interesting to describe the factors which affect it:

- Winters are quite cold, with fairly low temperatures and generally cloudy days. Mornings or even entire days are often foggy due to irradiation. This situation is more severe into the valleys of the main rivers (i.e. the Duero), like Boecillo zone.

- In summer, the diurnal temperature range is very relevant because of daylight flux of solar radiation, and also due to nightly radiative exchange to sky.

The climatology of the location implies a quite high heating demand for a long period; mostly from October to May. The available solar radiation along during these months causes appreciable temperature differences between day and night.

Considering these external conditions, it is possible to suppose a fairly high demand of heating during winter and necessity for internal cooling in summer.

Table 69: Simulation data main parameters obtained for Valladolid city (coincident format Chapter 0)

Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m²y]		Winter load	Summer load		Latent summer load		FP [m2]	ETC [m2]
41.65	735	70.53	3504.45	1574.16		-3927.14	3468.06		463.98		17.74	12.435

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	62.53%	65.54%	70.09%	68.33%
Summer Coverage			92.37%	91.67%
Yearly fossil costs	308.88	284.14	306.21	326.12
SimpleROI	24.10	23.03	12.33	12.54

Table 70: Climate values for Valladolid (reference period 1971-2000)

	T (ºC)	TM (ºC)	Tm (ºC)	R (mm)	RH (%)	DR (d)	DN (d)	DT (d)	DF (d)	DH (d)	DD (d)	I (h/mo)
Jan	4,0	8,3	0,0	40	83	7	3	0	11	17	4	100
Feb	6,1	11,4	0,9	32	72	6	2	0	4	12	4	141
Mar	8,4	15,0	2,3	23	62	5	1	0	2	8	6	209
Apr	10,1	16,3	4,0	44	62	8	1	1	1	4	4	222
May	13,8	20,5	7,2	47	61	9	0	4	1	1	4	260
Jun	18,1	25,9	10,7	33	54	5	0	3	1	0	7	310
Jul	21,7	30,4	13,3	16	47	3	0	3	0	0	15	352
Aug	21,6	29,8	13,6	18	49	3	0	3	0	0	13	330
Sep	18,1	25,7	10,9	31	56	4	0	2	2	0	8	244
Oct	12,8	18,8	6,9	42	69	7	0	1	3	1	5	176
Nov	7,7	12,6	2,9	51	78	6	0	0	8	8	5	114
Dec	5,0	8,8	1,3	56	84	8	1	0	10	13	3	81
Total	12,3	18,6	6,2	435	65	71	8	17	42	61	76	2534

T: monthly average temperature; TM: monthly average of highest daily temperatures; Tm: monthly average of lowest daily temperatures; R: monthly average of rainfall; RH: monthly average of relative humidity; DR: monthly average of rainy days (rainfall ≥ 1mm); DN: monthly average of snow days; DT: monthly average of storm days; DF: monthly average of foggy days; DH: monthly average of frost days; DD: monthly average of cloudless days; I: monthly average of sunny hours

Table 69 and Table 70 represent in a monthly and yearly base the weather climatology in Valladolid and a resume of the results obtained in that climatic conditions when the studied building plus the solar system is placed in the location.

In previous chapters, the variation of monetary parameters where studied to explain the economical evolution of the problem when installation and fuel prices change. Now, for this determinate clima, the parametrical study was done on the building thermal characteristics to find the optimal set building/solar facility in Valladolid, keeping constant 100 square meter building area and the defined compactness ratio. It was expected before the realization of the thermal building variation that the increase on building behaviour would be in some cases negative in economic terms for the solar plant, but the resultant facility and the building would save money and energy when both would be optimized together.

The parameters studied were:

- Percentage of the external surface covered by windows from the total of the external walls (defined by orientations)
- U-value from walls, windows, roof and floors
- Transparency factors of the window glasses
- Air renovation rates.

The first approach to study all these parameters was done on the basis of the minimum values accepted by the Spanish building norm for Valladolid. This minimum values fix a reference to relate the quality of the materials/building components with the studied ones and the saturation of potential improvements curve.

Valladolid is placed into the Spanish building norm in zone D2, which obliges to assure:

- Opaque façades and walls in contact with soil: U_{Wmin}: 0.66W/m^{2}K.
- Floors with soil contact: U_{Fmin}: 0.49W/m^{2}K.
- Roofs: U_{Rmin}: 0.38W/m^{2}K.
- Window limits depends on the façade orientation and the internal building loads.

Table 71: Parameters defined by the Spanish Building technological Code for Valladolid

	Maximum Uvalue accepted for translucent surfaces [W/m2K]				g value for the window glass					
					Low internal loads			High internal loads		
% translucent surfaces	N/NE/NW	E/W	S	SE/SW	E/W	S	SE/SW	E/W	S	SE/SW
0 to10	3,5	3,5	3,5	3,5	-	-	-	-	-	-
11 to 20	3	3,5	3,5	3,5	-	-	-	-	-	-
21 to 30	2,5	2,9	3,5	3,5	-	-	-	0,58	-	0,61
31 to 40	2,2	2,6	3,4	3,4	-	-	-	0,46	-	0,49
41 to 50	2,1	2,5	3,2	3,2	-	-	0,61	0,38	0,54	0,41
51 to 60	1,9	2,3	3	3	0,49	-	0,53	0,33	0,48	0,36

7.1.1 Variation of the transparent external surfaces by orientation

Variations have been done in all the implicated parameters to analyse the repercussion of each one of them in the efficiency of the set building/solar systems.

For each orientation, the amount of transparent surfaces has been varied from the initial 20% of glass surface to a maximum of 100% glass façade. The five orientations tested South, East, West, South East and South West develop similar behaviours when the glass surfaces are incremented, although the incidence for the southern orientations is much more important due to the solar collecting effects along the summer season which highly increase cooling loads. In heating periods, the associated building costs decrease due to an increase of the solar energy caption but the sum of both effects, heating and cooling, creates a yearly demand increase directly related to the façade glass percentage. Figure 54 shows the above explained building behaviour and how the solar facilities installed only to deliver hot water for DHWS and building heating loose efficiency when the glass surfaces increase. In those cases, the heating demand is lowered and the installed system deliver less energy to the building when there is solar radiation available, most of the time along spring and autumn, while on the other hand the solar facility increases the energy delivered in summer time to a building that has increased its cooling necessities much with the glass percentage increase.

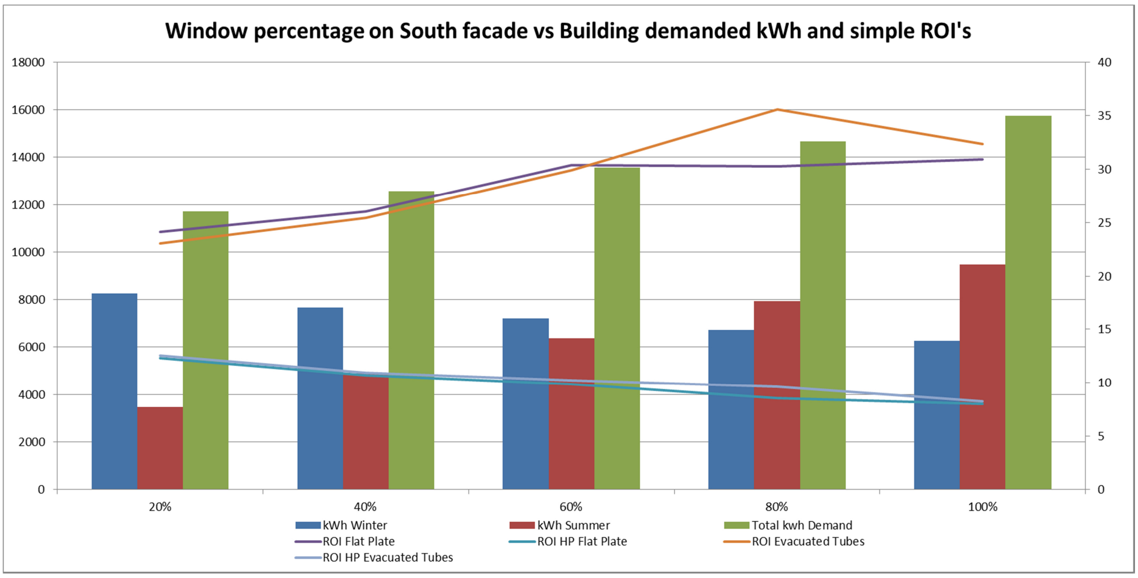


Figure 54: Building demands and simple ROI's for the solar systems when varying % of glass in south façade.

Three conclusions can be extracted from these options.

1. A change in the solar system dimensioning has happened, caused by the cooling demand increase. Up to a determinate glass surface, cooling building demands become more important than the heating ones, optimizing the solar plant to cover the maximum heating demand (which absolute value is lower than the cooling one).

2. The increase of cooling demand provokes higher returns of investment for the solar system, but the total energy costs for the building owner increases. The solar facility is better covering the cooling demand in terms of percentages, but in absolute values, the cooling demand not satisfied by the renewable installation is now bigger than for the initial cases of 20% glass surfaces, causing a negative effect in energetic and economical aspects.

3. The window orientations which influence more on the complete building/solar system are South, South West, South East, West, East respectively, as seen in Figure 55.

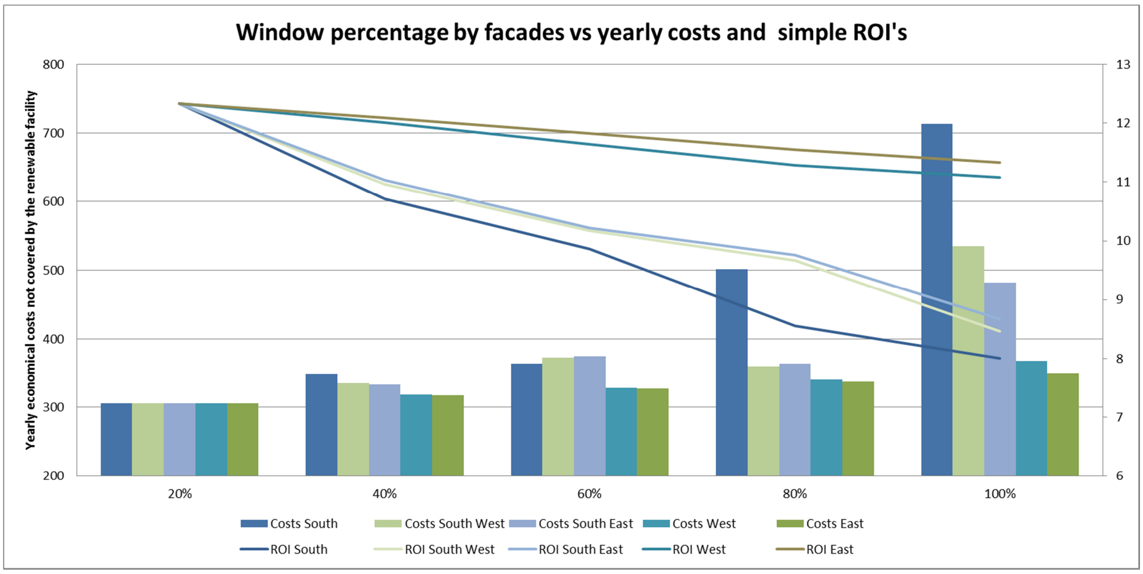


Figure 55: Yearly costs and simple ROI's based on the percentage of window area by wall orientation

7.1.2 Variation of the g_s factor of the transparent

G factor is a coefficient for measuring the amount of solar radiation entering through a glazed unit. The unit of 'g_s', known as the solar factor, is represented as a percentage of the total incident radiation that enters through the glass. This includes the direct radiant influx as well as the infrared radiation that is absorbed by the glass and then re-emitted internally. Solar control glass helps to gain control over infrared radiation, as well as solar gains.

It is expected, from the variation of g factors for the designed windows, that a decrease on the parameter would create higher demands during the heating season and lower in the cooling ones. This effect would decrease the economic benefits of the solar facility due to the difficulty of providing more energy in winter (low solar radiation availability) and over production of solar cooling in summer time, not demanded by the building. Figure 56 shows the evolution of the building demands and the simple returns of investment of the solar system when decreasing the glass transparency.

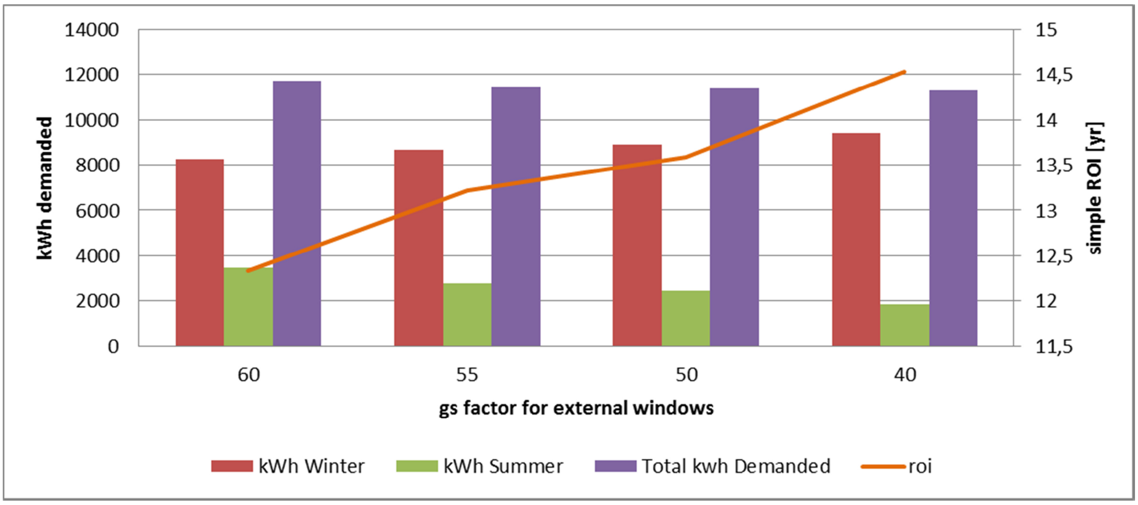


Figure 56: g_s factor variation for the transparent surfaces vs energy demanded and simple Roi periods

7.1.3 Variation of U-values for surfaces with exposed to the environment

In this category, the heat transfer coefficient (U-value) of walls, roofs and windows are varied. U values are changed for the studied basic case of 20% windows on the external walls for each orientation:

- External walls U-value change from the initial 0.5 W/m^{2}K to a minimum of 0.3.
- Windows change from 1 to 0.7 W/ m^{2}K.
- Roofs change from 0.4 to 0.3, although Spanish norms for the studied zone don't allow going over 0.35 W/ m^{2}K.

The results obtained after studying the three parameters deliver similar results. Further improvements on the envelope coefficients save energy along the heating season increasing the demands in warm periods, but always the decreasing of heating demands are more important that cooling increases, in energetic or economical terms. The higher differences appear when improving the external walls, from 0.5 to 0.3 W/ m^{2}K with variations up to ±14% in heating and cooling modus when compared with the ±5% obtained with windows and roof variations.

From a solar facility point of view, the resultant installation size doesn't change, increasing in both periods the solar coverage and profiting the simple ROI of the higher electrical costs existing in summer time and the higher quantitative decrease of kWh demanded in the heating season. Figure 52, Figure 53 and Figure 54 represent the explained evolution.

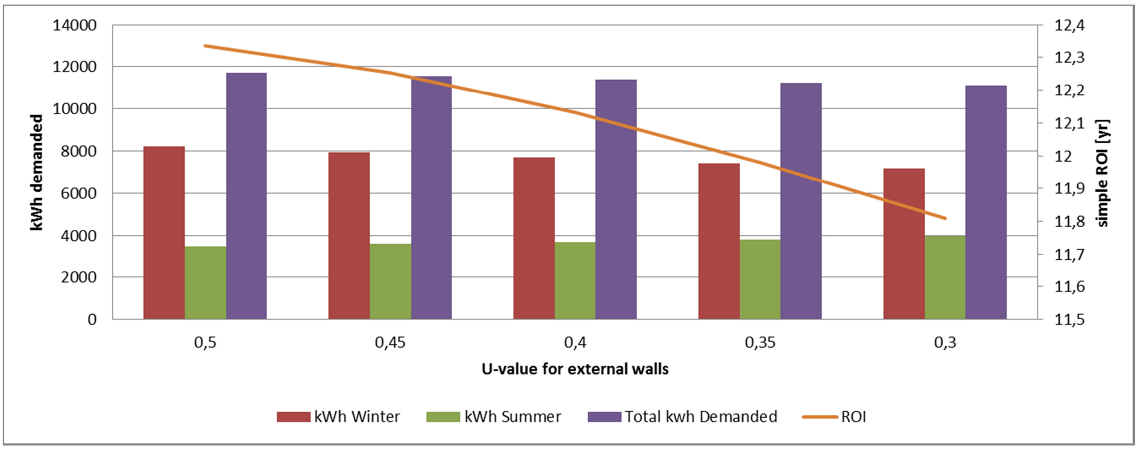


Figure 57: U-value variation of the external walls vs energy demanded and simple Roi periods

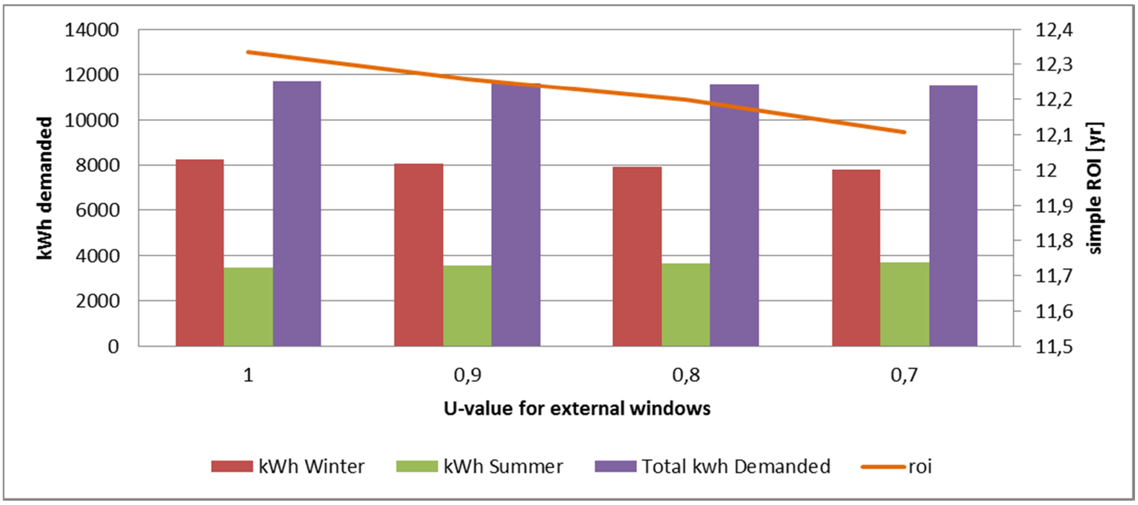


Figure 58: U-value variation of the external windows vs energy demanded and simple Roi periods

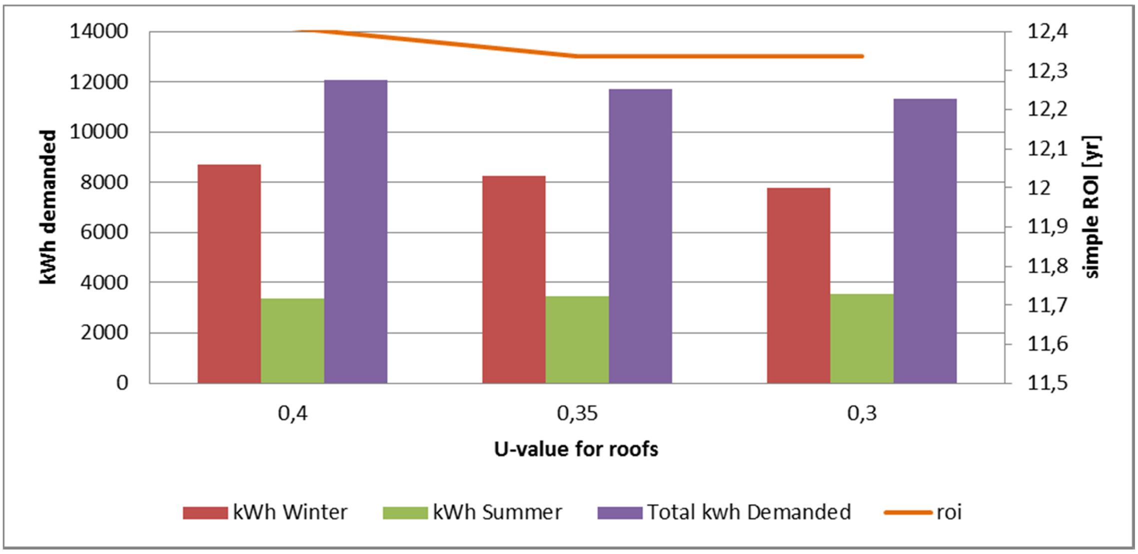


Figure 59: U-value variation of the roofs vs energy demanded and simple Roi periods

7.1.4 Variation of air renovation rates

Renovation rates, keep the internal air quality into determinate levels assuring proper ventilation of the occupied zones.

This parameter is the only one studied in this chapter that can be treated as active, due to the existing possibility of changing its value during working periods, and opposed to the previous ones that are kept stables for the complete building life with the unique exception of material time degradation.

The initial simulated value of 0.5 full air renovations each hour can be considered as the minimum one that keeps the air into acceptable conditions although higher renovation rates could provide higher air quality levels but causing most of the times an increase on the heating loads based on the air temperature difference between the environment and the internal building conditions.

A ventilation rate of one air renovation/hour has been studied for all the previous cases to understand how double ventilation affect a building with different characteristics. The obtained values after simulating the options studied in 7.1.1, 7.1.2 and 7.1.3 deliver similar results. There is a 20% increase for the heating demand, cooling demands decrease around a 25%, the resulting solar facility has shorter return of investment periods (-8%) but the yearly costs increases up to 35% although the solar facility introduce energy in the building, but less in relative terms that the demand increases.

7.2 Improved values for a building placed in Valladolid

The building geometry is to be studied in two different ways that could be defined as passive and active. The passive option keeps the building parameters constant along the year and no actuation over shadows or ventilation rates would be done, while the active one does allow the control of external gains as a function of the year time.

A wide enough number of building thermal simulations have been realized to abstract from the heating and cooling demands obtained, a correlation between them and ventilation rates, wall insulation, percentage of windows for each façade, and all the variables previously exposed. (Chapter 4)

7.2.1 Results obtained from a "passive building design"

In this evaluation, all the studied variables were moved into the studied intervals and kept constant along the year. As it was foreseen, ventilation rates resulted to be critical for the building study, being always the solutions correspondent with minimum renovation rate the ones that keep controlled building demands. Other limiting values found were those related to thermal insulation concepts that show a need of lower thermal resistances for external walls and windows. This solution helps in the aim to control building demands in both winter and summer periods. There is no obtained improvement with U-values over to 0.4 W/m^{2}K for the external walls or 0.9 W/ m^{2}K for the installed windows.

It has been obtained, a number of possible building configurations that decrease building demands and at the same time shorten the number of years needed to amortize the solar facility investment. This solution balances heating and cooling demands with respect to the solar availability by decreasing winter demands, when the renewable installation was not able to cover more than the 70%, and at the same time, summer needs will not increase so much, allowing the facility to reach slightly higher efficiencies. The design of those facades exposed to direct radiation tries to maximize solar collecting along heating season while in summer, due to the solar height, does not increase so much the building loads.

The studied case is defined by:

- 0.5 ren/h as ventilation rate
- 0.3 And 0.7 W/m^{2}K as External walls and windows U-values respectively.
- 20% window area for South, Southeast and Southwest orientation.
- 65% as transparency factor for the glasses installed in South, Southeast and Southwest facades.
- 40% window area for East and West orientations.
- 20% as transparency factor for East and West installed glasses.

Table 72: Simulation data main parameters obtained for the "passive building design"

Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [W/m2]		Winter load	Summer load		Latent summer load		FP [m2]	ETC [m2]
41.65	735	70.53	3504.45	1574.16		-2701.80	3340.72		506.97		17.74	12.44

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	67.87%	68.95%	72.73%	71.99%
Summer Coverage			93.21%	92.93%
Yearly fossil costs	239.31	217.72	247.08	257.70
SimpleROI	26.88	25.71	11.98	12.08

Results obtained in the case related in this chapter show how the Return of Investment times where increased in both cases where the collected energy is only introduced in the building for heating (Building demands where decreased along this period for the same size of solar facility) while Thermally Driven Solar Systems are used all along the year, ROI's where decreased despite the building is demanding less energy. In Table 69 and Table 72 were added a row called "*Yearly fossil costs"* to facilitate a comparison for the yearly energy costs not provided by the solar system. This parameter is at least a 23% lower in each of the four studied cases for the improved building when compared to the base one.

7.2.2 Results obtained from an "active building design"

The observed economic and thermal behaviour, with increased demands along the winter season and decreasing ones in summer when the ventilation rate is increased, in conjunction with a better window ratio and different thermal characteristics of building elements, suggest that the combination of all the studied parameters can minimize the fossil fuel dependencies, introducing in the building similar rates of renewable energies. Moreover, if it is intended to install fixed external shadowing on the facades to minimize solar gain effects during summer time without obstructing winter solar collecting. The obtained values obtained for the studied building show equilibrium between winter/summer demands related to seasonal solar radiation availability.

The building object of study has been "redesigned" in terms of thermal insulation for walls and windows as well as the façade percentage that windows cover, defined by orientation. Thermal insulations have been settled in the minimum value of the studied interval while the glass surfaces were incremented in every orientation except for the ones north oriented that would never increase the direct solar gains in winter time, when needed to decrease heating demands. South and South-east/South-west facades increase their glass surface up to a 60% of the total external surface, while West and East façade percentages comes up to 80%. In order to control solar gains along the summer season, fixed solar shadows are installed for each orientation, obtaining a 60% of window shadowing and ventilation rates are doubled to refresh conditioned area. Precooling strategies can be developed because of the "low" external night air temperatures registered.

The obtained results are the following:

Table 73: Simulation data main parameters obtained for Valladolid after improving the building

Latitude [°]	Altitude [m]	CDD [K/d]	HDD [K/d]	Radiation [kWh/m^2y]		Winter load [kWh/y]	Summer load [kWh/y]		Latent summer load		FP [m2]	ETC [m2]
41.65	735	70.53	3504.45	1574.16		-2315.05	4279.75		554.12		17.74	12.44

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	65.09%	68.8%	71.83%	71.56%
Summer Coverage			98.42%	97.84%
Yearly fossil costs	231.32	206.74	186.63	188.42
SimpleROI	26.59	25.34	11.73	11.89

7.2.3 Conclusions obtained after improving simultaneously building and solar system

Results calculated with the general building, studied in Chapter 4 and Chapter 6, have been further improved by modifications on the passive and active building design.

Passive measurements applied on the building led to a significant sensible demand decrease in winter periods (-31%) but only a small one (-4%) along the summer. (Table 74)

Table 74: Ratios between the general design case and one with passive improved measurements in terms of building loads (Representative C2 clima zone)

Winter load	Summer load	Latent summer load
-31,20%	-3,67%	9,27%

The combination of demand decreases with an increase of summer and winter solar coverage leads to an approximate *twenty per cent* economical savings for every studied solar facility. (Table 75)

The return of investment results vary, depending on the kind of use for which the solar systems where designed. If solar facilities where thought only to deliver hot water for heating and DHW along the year, payback periods increase because although solar coverage is higher and heating demand lower, solar availability is not enough. On the opposite side, if the system was designed with a HP able to deliver heating in winter and cooling in summer time, the increase efficiency obtained with the use of the thermal machine leads to shorter payback periods around a 3%.

Table 75 : Ratios between the general design case and one with passive improved measurements in terms of solar coverage, yearly costs and simple ROI's (Representative C2 climatic zone)

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	8,54%	5,20%	3,77%	5,36%
Summer Coverage			0,91%	1,37%
Yearly fossil costs	-22,52%	-23,38%	-19,31%	-20,98%
SimpleROI	11,54%	11,64%	-2,84%	-3,67%

The problems found in this case were related to the necessity of decreasing energy losses and increasing solar gains in winter period without increasing much building cooling needs in summer time. The first case of study was defined as “passive redesign” and it wasn`t possible the application of new ventilation strategies or solar radiation blocking ones, in dependency with the internal conditions. These limitations only left open the options of improving the external walls from an energy losses point of view and increasing the window area up to a limit that would increase much summer loads being the new design *contra productive* from an economical point of view.

The commented limitations didn’t exist when *passive* and *simple active strategies* where studied as a whole, and useful measurements to decrease winter loads, as can be an increase of window area in the sunny orientations with blinds or fixed shadowing devices that could limit incident radiation in summer time. If solar radiation blocking is combined with an increase of air renovations (in the studied case, most of the summer the external air temperatures are under 26ºC allowing free cooling and pre cooling strategies), the combination of the building and the solar facility have great behaviour.

Table 76: Ratios between the general design case and one with passive & active improved measurements in terms of building loads (Representative C2 clima zone)

Winter load	Summer load	Latent summer load
-41.,05%	23,40%	19,43%

In this particular case, Table 76 shows that the increase of most transparent areas decreases up to a 41% the heating building demand but, although solar shadowing and ventilation increases in summer time, cooling demand increases up to 23,4%. This combination delivers better solar coverage in winter time when compared to the base simulation case, but lower when done with the passive measurements case. As it has happen previously, building demands are lowered and the solar availability is not enough for complete demand coverage, and later on, when the sun potential is higher, this building does not demand any more heating. On contrary, summer cooling demands are higher but online with the solar availability, (higher window areas decrease the thermal insulation of the external walls, making the controlled zones much more dependent on the external weather conditions), being increased the summer coverage around a 6,5 % compared to the base case. This value corresponds to summer coverage percentages of 98% of the cooling demand. (Table 77)

In terms of yearly costs, the *active & passive* building design needs less money to pay consumes associated to the solar back-up fossil systems, being ROI periods larger for the only-heating case and lower for the heating and cooling ones.

Table 77: Ratios between the general design case and one with passive & active improved measurements in terms of solar coverage, yearly costs and simple ROI's (Representative C2 clima zone)

	FP	ETC	FP+HP	ETC+HP
Winter Coverage	4,09%	4,97%	2,48%	4,73%
Summer Coverage			6,55%	6,73%
Yearly fossil costs	-25,11%	-27,24%	-39,05%	-42,22%
SimpleROI	10,33%	10,03%	-4,87%	-5,18%

8. Conclusions

A summary of the conclusions obtained is described in the following points:

1. Relationship between climate conditions and building: When comparing climatic zones and energetic behaviour of a building located in different places, it is not enough to use the deviation between the internal ambient temperatures and the external dry air ones. Heating degree days define the exposition of a building to climatic changes where the importance of radiation and humidity (external and latent loads) is less important that the energy losses to the ambient. As it was described in the Appendix A, in long term comparisons the importance of temperature differences inside the building and the external conditions drive the highest part of the building energy changes with the ambient, but, when the aim of the study is based on short time magnitudes (i.e.: hourly and daily) the importance of the radiation acting on the external walls and the humidity contained in the renovation air becomes important. Moreover, if the studies to be developed are done over buildings whose behaviour depends on how clear the days are, as could be buildings with high glass window fraction on the facades, then the effects caused by solar radiation should be always taken into account.

2. Climatic Severity classifications: Theyallowed to divide Europe into a limited number of zones where the behaviour of a determinate building is similar. From the results obtained, it is seen how the differences appear in Europe mostly in Winter time where it can be appreciated climatic variations from South Europe until latitudes around 50º North. During the summer season, mostly every location above 45ºN latitude have a similar weather condition. In both cases, the main variables that define the climatic conditions are the latitude, proximity to water masses and altitude over the see.

3. Highest latitudes leads to shorter days in winter and longer ones in summer time .The ratio between the collected solar radiation in summer time and winter time goes from the four times occurring in warm places, to the seven times higher of cold locations. That means, that in summer time, three months in this work, the coldest European places collect a 90% of the solar radiation available on the year, and there is no building with enough heating or cooling load where that radiation, in a short time period, could be used. For the rest of the year, nine months, there is only a 10% of available radiation to drive thermal technologies, what made the solar solution not acceptable for those latitudes.

4. Combination of solar thermal collectors with heat pumps permits a quicker reimbursement of the installation costsdue to a better utilization of both technologies. The utilizability of solar thermal energy in winter time increases with the use of heat pumps from a 3% in the warmest winter zones to a 12 % in cases where winters are colder. This increased period helps to amortize the facilities along the year. The increased efficiencies and the combined potential derived from winter and summer use is represented in Table 78 and Table 79. It is seen how in Table 78, only the three warmest winter European zones have payback periods under 20 years for the two simple solar thermal layouts, without the application of helping monetary politics.

   On the other hand, Table 79 represents the same option, but for the facility layouts that integrate heat pumps in the loop. For this last case, the number of climatic zones is increased from the warmest European places, with more important cooling loads than heating ones, to zones where the energy demand of both cases are equal or even, in some zones where heating demand is a little bit higher than cooling ones. There utilization of evacuated tube collectors obtain better results for those colder zones. (Classes B3 and C2 to C5)

Table 78: Return of Investment simple for solar thermal installations (FP and ETC) around Europe without the application of monetary politics (Only values smaller than 20 years appear)

Flat Plate RoI [y]	Summer Climatic Severities's: Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's: Exc. Heat	---	---	---	---	---	---	---
Class 1	16,84	15,78	18,02				
Class 2							
Class 3							
Class 4							
Class 5							
Exc. Cold							

Evacuated Tubes RoI [y]	Summer Climatic Severities's: Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's: Exc. Heat	---	---	---	---	---	---	---
Class 1	18,26	17,16	19,35				
Class 2							
Class 3							
Class 4							
Class 5							
Exc. Cold							

Table 79: Return of Investment simple for solar thermal installations with Heat pump (FP and ETC) around Europe without the application of monetary politics (Only values smaller than 20 years appear)

Flat Plate + HP RoI [y]	Summer Climatic Severities's: Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's: Exc. Heat	---	---	---	---	---	---	---
Class 1	12,84	15,73	15,31	17,16	19,55	16,80	
Class 2	10,95	13,61	16,84	18,06			
Class 3	---	---	16,61	18,55			
Class 4	---	---	---	18,59			
Class 5	---	---	---				
Exc. Cold	---	---	---	---	---	---	

Evacuated Tubes + H RoI [y]	Summer Climatic Severities's: Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's: Exc. Heat	---	---	---	---	---	---	---
Class 1	13,14	15,94	15,48	16,95	18,30	17,17	
Class 2	11,65	14,20	17,10	17,90			
Class 3	---	---	16,15	18,23			
Class 4	---	---	---	18,11			
Class 5	---	---	---	19,40			
Exc. Cold	---	---	---	---			

5. Financial supporting policies: In order to introduce or push the utilization of solar thermally driven technologies along Europe, there were proposed two different strategies to subsidize the installations. A first one based on helping the facility owners with the installation initial costs and second one based on prizing the renewable energy introduced into the system. In some cases, only a combination of both would bring the systems into profits close to 1o years, considered enough for a technological expansion.

   Further discussions should be done on the way of applying the subsidies, because the amounts needed for each installation depends directly on the geographical placement of the facilities and quality of the studied buildings, a situation that causes "legal" asymmetries. With subsidies thought for users located in colder zones, the ones sited in warm places would obtain higher profits and vice versa.

   Table 80 and *Table* 81 represent the potential returns of investment obtained after the application of different subsidiary politics. In comparison with previous Table 78 and Table 79, application of subsidies increased the number of zones where simple solar thermal facilities could be installed and decreased the amortization periods for Heat pump based layouts. To be observed that lower values always appear for warmer zones.

Table 80: Potential ROI's obtained after the application of different subsidies combination on simple solar thermal facilities (FP, ETC) (Approximated values)

Flat Plate RoI [y]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	10,00	10,00	12,00	15,00	15,00	10,00	10,00
	Class 2	15,00	10,00	15,00	15,00			
	Class 3				20,00			
	Class 4				20,00			
	Class 5				20,00			
	Exc. Cold							

Evacuated Tubes RoI [y]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	10,00	10,00	12,00	15,00	15,00	10,00	10,00
	Class 2	15,00	12,00	15,00	15,00			
	Class 3			15,00	20,00			
	Class 4				20,00			
	Class 5				20,00			
	Exc. Cold							

Table 81: Potential ROI's obtained after the application of different subsidies combination on Heat Pump based solar thermal facilities (FP, ETC) (Approximated values)

Flat Plate + HP RoI [y]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	6,00	7,00	6,00	10,00	10,00	10,00	15,00
	Class 2	5,00	10,00	10,00	10,00			
	Class 3	---	---	10,00	10,00			
	Class 4	---	---	---	10,00			
	Class 5	---	---	---	10,00			
	Exc. Cold	---	---	---	---	---	---	

Evacuated Tubes + HP RoI [y]		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	6,00	7,00	6,00	10,00	10,00	10,00	15,00
	Class 2	5,00	10,00	10,00	10,00	15,00	15,00	15,00
	Class 3	---	---	10,00	10,00	20,00		
	Class 4	---	---	---	10,00	20,00		
	Class 5	---	---	---	10,00			
	Exc. Cold	---	---	---	---	---	---	

6. Building and facilities *joint optimization* as a single system: Combinations between energy efficient buildings and the proposed facilities may obtain better efficiencies than the studied cases but in those cases the set building/facility design must be done jointly. Solutions that minimize building demands can increase drastically the number of years needed to recover the investments done. Higher insulation levels and window qualities, combined with control on the ventilation rates and installation of fixed / controlled shadowing systems, allow further solar facility designs that increase the delivering of renewable energy at the same time that the overall building demand decreases.

7. The facilities studied tried to fully cover one of the two seasonal demands as a premise.

   It is clear that:

   - In case of studying solar thermal facilities without heat pumps in the layout.
   - and without the intention of covering as maximum as possible of the lower seasonal demand,

   Small collector areas would obtain acceptable payback periods by only covering domestic hot water demands and a portion of building heating demands. For the Valladolid case, studied in Chapter 7, the installation of 25%, 20%, 15% and 10% of the proposed area is described Figure 60. It can be noticed that the smaller installation could fully cover the DHW demands from April to October. This kind of facilities were not object of study in this work.

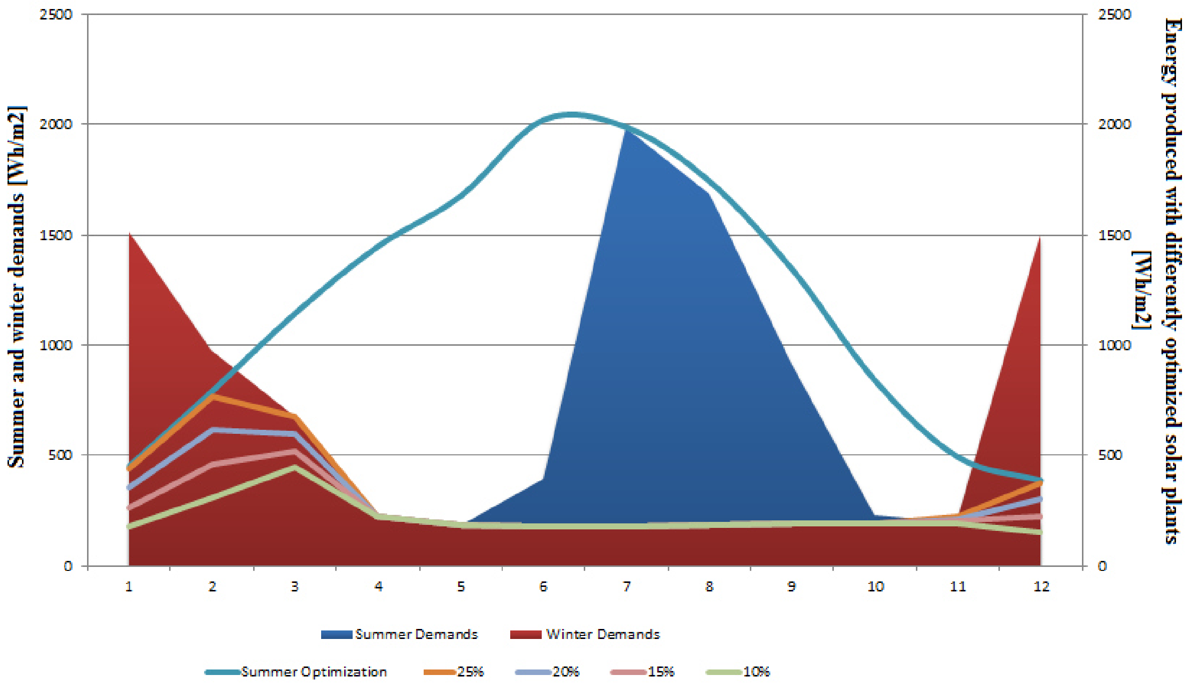


Figure 60: Yearly behaviour of a solar plant optimized for summer operation and four others with 25%, 20%, 15% and 10% of its collector area.

8.1 Further research

It would be interesting to follow the actual work with:

1. Potentiality studies of the combination of solar photovoltaiccollectors and Air to Air, water to air or water to water heat pumps, keeping similar supposes as were done with the previous work. (No energy is sold or accumulated for more than a day)

2. Introduction into the studied problem that calculates ideal simple ROI's, of storage and energy losses due to distribution and control strategies. This second approximation would fit better to the real amortization periods, but need of more accurate simulation engines that allow an exact thermodynamic representation of the layouts.

3. Developing of new methods to dimension solar thermal facilities, the elements to be installed in them and the building in a linked way. In these methods, every single building component should be economically rated to obtain the compressive ROI.

4. It has been seen, that in Europe the proposed layouts only obtain acceptable results for latitudes under approximately 45º North. These values represent only a small part of the total studied area, but if those limits are extrapolated to the complete world and supposed symmetrical behaviour of the systems with the equator, the potential areas where the studied systems could be installed represent a vast proportion of the populated areas. It must be noticed that for each country the relation between installation prices and substitutive energetic cost should be investigated to extrapolate the technological potentials.

   It is remarked in the north hemisphere,that red dotted lines drawn in *Figure* 61 represent the limits where installation of the studied technologies becomes not profitable while the green line is a geographical southern limit of the locations studied. From the results obtained, it can be said thatthe more to the south the facility, the easier is obtaining short return of investment periods.In the south hemisphere the results should be symmetrical.

   An important part of USA, China, Japan, Argentina, Brasil, etc. are potential places to install THDP within the studied boundaries. If supposed, that moving the facilities south in northern hemisphere and north in the southern one, improves system profitability, the oceanic continent, northern and south African countries as well as most of the Asian countries are included in the potential expansion zones.

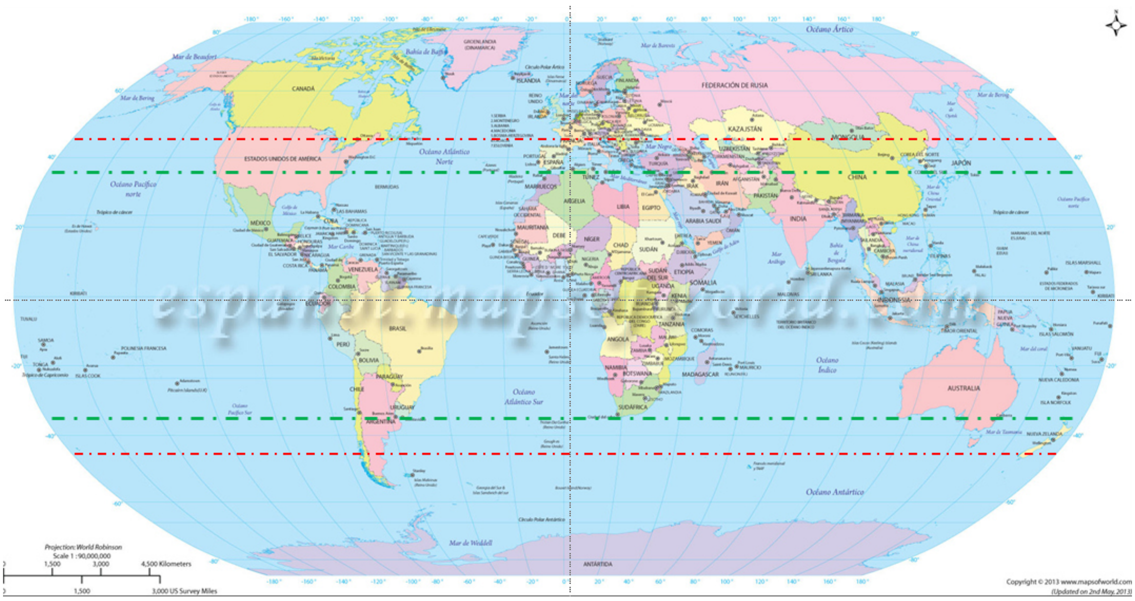


Figure 61: World potential areas for STDHP

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Authors are written using initial and surname. Books (including proceedings) are written in italics using the original title case. Titles of papers, chapters, etc are written using normal text with only the first word capitalized (with the exception of proper names, which may be capitalized). Each block of bibliographic information (i.e. authors, paper title, book title, date, location) is terminated with a period.

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Appendix A: Application of CSI's to evaluate different building consumptions.

Three different ways of evaluating climatic conditions have been described in 3.1.1, 3.1.2 and 3.1.3., based respectively in the concept of degree day, climatic severity and enthalpy latent days. The information that each of the methods uses to calculate the hardness of a climatic condition increases from the simplest degree differences between a given temperature and the ambient one to the inclusion in last term, of air enthalpies to evaluate latent implications in a climatic class.

The three methods have been applied to three different buildings sited in non-comparable climatic conditions to quantify the accuracy of each one of the three methods in heating mode. The authors didn't have enough recorded data of the buildings to evaluate cooling mode, what forced them to apply the method only in the building located in Kreta, (Greece).

A.1 Building descriptions

Three completely different office buildings in terms of envelopes, orientation, location and external weather conditions were chosen to evaluate the efficiency of the method.

For each building, there is a weather station that records the following variables:

- Dry and wet bulb temperature
- Relative humidity
- Air pressure
- Rain detection
- Direct and diffuse radiation on horizontal
- wind conditions (speed and direction)

A.1.1 ZUB building, Kassel.

Since the building has been gone into operation in 2001, there is already a high level of monitoring due to the more of 700 sensors installed. The performance of the building with its conventional control strategy and design is well known. All energy supply systems as well as most comfort aspects are already monitored.

Figure 62:External view of ZUB building

In base to the mean outdoor temperatures, it has been possible to calculate the HDD (heating degree days) as the difference between a base temperature (20 °C) and the daily mean outdoor temperature, and with latter and the radiation values, it was obtained the WCS for every considered year. As seen in Table 82 there were a difference among the studied years, winter ’03 and ’06 where colder and darker than the ones of ’07 and ‘08

Table 82: Winter Climatic Severity measured in Kassel (Years ’03,’06,’07,’08)

	2003	2006	2007	2008
WCS	1,96	1,93	1,61	1,68

The study has regarded the winter seasons of the years 2003, 2006, 2007, 2008 and whole period 2003-2008. Years 2004 and 2005 are not studied, due to the amount of data lost by the loggers based on one minute intervals. The evaluation of the data bases on different intervals, i.e. the accumulation of values for

- 1 hour,
- 1 day,
- 1 week,
- 1 month or
- 1 year.

The hourly interval is not useful, since our period under review usually covers at least one day. The evaluation only covers the period where there is a heating demand (for that day). Data for the cooling energy is not available for the ZUB building.

A.1.2 TUC building, Chania (Crete).

The second Demonstration Buildings is as a part of an office block at the Technical University of Crete an existing office building that has been recently renovated. So far, there is no central building automation system installed, thus, only a limited number of measured values are available from the last year's operation. Based on energy audits and simulation results the energy consumption of the specific building is quite high and reaches 130 kWh/m² for the whole year. The building has a relatively low level of building automation, energy generation and supply systems.

In this case, the building has not being operated under summer conditions with enough sensing equipment to evaluate the demands, so it was used a simulation model calibrated during winter time to create hourly summer values for the example, and real data to get winter results.

Figure 63: External view of TUC building

A.1.3 Cartif building, Valladolid (Sp)

The third building is Cartif I, a 2001 office building of 7500m2 sited in Boecillo (Spain) where approximately 150 people deploy their research activities in 3 floors. The building is fully conditioned with a variety of different and complementary heating and cooling systems. It was design with a live lab concept to test different internal and external loads in combination with several generation and distribution systems. The building is completely monitored, which allows easy implementation of new strategies and management modes.

Figure 64: External view of CartifI building

A.1.4 Results and coefficients for the ZUB building

The evaluation of the four years of available datasets results in the coefficients of correlation displayed in Table 83. These coefficients represent the quantification of the energetic behaviour of the ZUB building monitored over four years. Applied on the NFEC equation using the climatic values of current radiation (Rad) and external temperature (included in HDD), the coefficients a, c and d (for Rad) corresponds to the window area and the thermal capacity of the walls and the coefficients b, c and e (for HDD) are dependent on the quality of the building envelope.

Table 83: Coefficients of determination (R^2) and correlation for the ZUB building (years 2003, 2006, 2007, 2008 and whole period of 4 years) obtained by Multiple linear regression of NFEC (CSI's)

year	R²	a	b	c	D	e	f
2003 (day)	**0,84**	-11,2022399	10,1644083	-2,08864116	1,81952997	0,24026005	-7,87059048
2006 (day)	**0,78**	-2,7932648	12,3170153	-1,73238972	1,13510494	0,27092288	-34,055932
2007 (day)	**0,86**	1,82508869	13,8697151	-2,43055494	0,8258927	0,26298199	-47,1506433
2008 (day)	**0,86**	-2,74294773	9,06854399	-1,61388845	0,5278521	0,26362766	-3,94378179
4years (day)	**0,81**	-2,35350141	11,7388002	-2,08398754	0,91860224	0,24717471	-25,6206392
2003 (week)	**0,93**	3,51042905	15,0636828	-0,43610348	0,09686306	0,0201155	-347,994095
2006 (week)	**0,91**	17,4994008	23,1105567	-0,4438085	0,02196025	-0,00645922	-785,096313
2007 (week)	**0,93**	-0,35194929	14,6452066	-0,42584949	0,22378361	0,0357745	-299,371901
2008 (week)	**0,95**	12,6474742	11,8370148	-0,33840299	-0,17257057	0,02832229	-209,113191
4years (week)	**0,91**	11,0044883	16,7830602	-0,43466347	-0,00847032	0,01687617	-446,092895
2003 (month)	**0,98**	43,4716076	20,1038769	-0,14127411	-0,08865913	0,00535983	-4803,94531
2006 (month)	**0,98**	144,171438	54,1310321	-0,28703612	-0,39062786	-0,02521005	-13230,1016
2007 (month)	**0,96**	31,7071135	22,1988965	-0,13683273	-0,03496473	0,00400589	-4081,29731
2008 (month)	**0,97**	4,63380596	8,25689425	-0,05586062	-0,02316326	0,00989387	-38,587025
4years (month)	**0,95**	47,588279	24,4947169	-0,14621259	-0,11317469	-0,00100376	-4789,98892

As it can be seen, the accuracies of the regressed values increase with the length of the evaluation interval. The time interval for the accumulation of data is varied from day to month.

In the same way, it has been adjusted the NFEC for the ZUB building was adjusted the linear relation between the NFEC and HDD in a daily, weekly and monthly base, for the previously defined years.

$$NFEC = a * HDD + b$$

Table 84: Coefficients of determination (R^2) and correlation for the ZUB building (years 2003, 2006, 2007, 2008 and whole period of 4 years) obtained by Single linear regression of NFEC (HDD)

year	R^2	A	b
Daily 2003	0,4203	0,0272	11,901
Daily 2006	0,6771	0,0359	7,9819
Daily 2007	0,6801	0,0308	8,8191
Daily 2008	0,6496	0,0466	6,8272
Daily 2003-2008	0,5856	0,0348	8,8033
Weekly 2003	0,5615	0,0293	80,125
Weekly 2006	0,7767	0,0435	48,424
Weekly 2007	0,8158	0,0372	52,326
Weekly 2008	0,7735	0,0546	40,06
Weekly 2003-2008	0,6994	0,0406	54,929
Monthly 2003	0,8804	0,0339	317,12
Monthly 2006	0,9295	0,0563	126,69
Monthly 2007	0,8614	0,0479	158,79
Monthly 2008	0,8820	0,0652	122,28
Monthly 2003-2008	0,8305	0,052	169,84

Again, the accuracy increases for longer studied intervals, but obtaining values smaller than the ones obtained with the CSI principles. , and it is compared the accuracy between the two methods and how it is always the CSI's method the one that adjust better the winter building demands for every timestamp studied. compare the values for a daily base correlation, and as it is seen, HDD's are not able in one case to obtain more than a 42% of accuracy for 2003 while the other 4 values, the correspondent to 2006 to 2008 and those that correlate jointly the four years stay in intervals around 65%. It must be said that 2003 was a very cold winter in terms of temperature, but the total radiation recorded by the pyranometers was much higher than Kassel's winter average. This radiation increase was evaluated by the CSI's indexes and couldn't by the HDD ones. Accuracy values are smaller for the daily base than for the other periods, but a high inertial building as ZUB has a time constant bigger than a day, what means that nearly every load or energy that affects the building in an instant t=0 will be noticed by the heating or cooling system in time t>24h, a period that cannot be correctly evaluated with the correlations of the last 24 hours of external temperature (HDD) and neither with the external temperature and the radiation, although this last one deliver better results, (Increments of 6% to 74% better accuracies.

Table 85: Comparison between the results obtained (ZUB building) with CSI's and HDD's (Daily base)

	Adjusted R^2 (CSI's)	**R^2 (HDD's)**	**Increment %**
Daily 2003	0,731	0,42	74,05
Daily 2006	0,718	0,677	6,06
Daily 2007	0,741	0,68	8,97
Daily 2008	0,771	0,65	18,62
Daily 2003-2008	0,714	0,586	21,84

A weekly evaluation of both cases,, keep the ratios between CSI's and HDD correlations, in similar values, although the absolute R^2 results are 16% higher for the CSI's and 20% in the weekly case (Relations between and). This result is easily explained by the annulation of the building inertial effects when the evaluation period is a week.

Table 86: Comparison between the results obtained (ZUB building) with CSI's and HDD's (Weekly base)

	Adjusted R^2	**R^2**	**Increment %**

	(CSI's)	(HDD's)	
Weekly 2003	0,847	0,561	50,98
Weekly 2006	0,821	0,776	5,80
Weekly 2007	0,876	0,816	7,35
Weekly 2008	0,909	0,773	17,59
Weekly 2003-2008	0,836	0,699	19,60

As happened before, the monthly base results obtained, , are in both cases higher than the ones obtained for the weekly case. The increment obtained for CSI's is around a 10 % and for the HDD case a 20%. (and). Nevertheless, the correlation based on CSI's has always higher accuracy levels for the inertial ZUB building.

Table 87: Comparison between the results obtained (ZUB building) with CSI's and HDD's (Monthly base)

	Adjusted R^2 (CSI's)	R^2 (HDD's)	Increment %
Monthly 2003	0,942	0,88	7,05
Monthly 2006	0,968	0,929	4,20
Monthly 2007	0,922	0,861	7,08
Monthly 2008	0,945	0,882	7,14
Monthly 2003-2008	0,931	0,83	12,17

A.1.5 Results and coefficients for the TUC building

As it was explained before, there were no enough reliable data to evaluate the demands of the TUC building until the year 2012. During the years 2010 and 2011 it was made a complete simulation model of the TUC building that was validated along the year 2012 as explained in Pebble, 2012. At the moment that the following data were calculated there were no summer data of the building, so the complete evaluation will be done on the base of measured data for winter time and on simulated results for the summer season.

This case of study has also included latent terms to evaluate during the summer season thanks to the existence in the building of direct expansion heat pumps that allow to dry the ambient, being feasible the calculation of summer latent loads.

Table 88: Comparison between the results obtained (Tuc building) with CSI's and HDD's

	Adjusted R^2 (CSI's)	**R^2 (HDD's)**	**Increment %**
Winter daily	0,838	0,735	14,01
Winter weekly	0,912	0,731	24,76
Winter monthly	0,981	0,842	16,51
Summer daily	0,873	0,847	3,07
Summer weekly	0,930	0,916	1,53
Summer monthly	0,977	0,947	3,17

As seen, again, CSI's winter evaluation fits better the building demand for every tested interval with a minimum increase of adjustment around 15%. Also, as it happened for the ZUB case, CSI's adjust better the demands as longer it is the time interval.

For the summer case, it is also seen that the CSI's adjust better the demands, but with much smaller increments due to the stability of the weather conditions during the summer. Also when compared the adjustment with and without the humidity effects, , confirm the usefulness of latent term in shorter evaluation intervals. (+6,07% better adjustment in a daily base adjustment) while again, summer weather stability does not remark considerable improvements in a weekly and monthly base.

Table 89: Comparison between the results obtained (Tuc building) with CSI's and ELD's

	Adjusted R^2 (CSI's+ELD's)	**R^2 (CSI's)**	**Increment %**
Summer daily	0,926	0,873	6,07
Summer weekly	0,936	0,930	0,65
Summer monthly	0,981	0,977	0,40

A.1.6 Results and coefficients for Cartif building

The existence of a complete minute base monitoring system installed in the building allows the evaluation of every electrical and thermal facility installed. To evaluate the accuracy of the WCS's method against the degree day one, it was chosen a complete winter season where the radiant floors were working and the users were not allowed to modify building internal conditions with the use of the existing water to air heat pumps, which would disturb the demands seen by the radiant floor probes installed.

It has not been tested the method along the summer season, because during those months there is no a constant occupancy of the building (summer holidays) and the installed cooling facilities are controlled by each zone users. That means a great disturbance in the demand profiles that impossibilities the obtainment of acceptable results.

CARTIF case describes again similar results as the ones exposed for the other two buildings. An evaluation based on Climatic Severity Indexes adjusts much better than the one done with HDD.

Table 90: Comparison between the results obtained (Cartif building) with CSI's and HDD's

	Adjusted R^2 (CSI's)	**R^2 (HDD's)**	**Increment %**
Winter Daily	0,96	0,56	71,43
Winter weekly	0,991	0,76	30,39
Winter monthly	0,998	0,91	9,54

Appendix B: Average results obtained for climatic variables.

From Table 91 to Table 98 are presented the mean averaged values of some meteorological variables studied during this work, classified by climatic zones.

First of all, the distribution of the climatic severities in Table 91 and Table 92.

Table 91: Average Summer Climatic Severities for each category

SCS		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	*1,15*	*5,30*	*7,72*	*8,80*	*9,48*	*9,74*	*9,92*
	Class 2	*0,82*	*5,66*	*7,93*	*8,95*	*9,49*	*9,72*	*9,87*
	Class 3	---	---	*7,99*	*8,82*	*9,51*	*9,74*	*9,89*
	Class 4	---	---	---	*9,01*	*9,52*	*9,76*	*9,92*
	Class 5	---	---	---	*9,02*	*9,59*	*9,76*	*9,90*
	Exc. Cold	---	---	---	---	---	---	*9,82*

Table 92: Average Winter Climatic Severities for each category

WCS		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	*0,89*	*0,79*	*0,88*	*1,18*	*1,03*	*0,65*	*0,96*
	Class 2	*2,51*	*2,02*	*2,07*	*2,47*	*2,26*	*2,33*	*2,47*
	Class 3	---	---	*3,54*	*3,61*	*3,58*	*3,57*	*3,54*
	Class 4	---	---	---	*4,38*	*4,50*	*4,66*	*4,51*
	Class 5	---	---	---	*5,13*	*5,83*	*5,97*	*5,76*
	Exc. Cold	---	---	---	---	---	---	*8,81*

Table 93 and Table 94 show the total incident radiation on horizontal and the average dry air temperature, both values that were combined to obtain climatic severities.

Table 93: Average Horizontal Radiation for each category

Radiation Htal Total		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	*55,99*	*58,30*	*58,56*	*54,77*	*50,89*	*57,28*	*49,88*
	Class 2	*56,02*	*55,97*	*53,08*	*52,94*	*49,18*	*49,48*	*47,28*
	Class 3	---	---	*56,04*	*54,01*	*46,15*	*41,18*	*45,32*
	Class 4	---	---	---	*52,03*	*48,01*	*45,82*	*44,04*
	Class 5	---	---	---	*57,11*	*46,05*	*42,95*	*45,15*
	Exc. Cold	---	---	---	---	---	---	*40,45*

Total radiation matrix presents a logical behavior with maximum values of energy collected on the top left corner and minimum ones on the bottom right one. It can be seen that there is no uniform color decrease from top to bottom or from left to right due to the fact that for the classification were used climatic severities that includes ambient air temperature in addition to the horizontal radiation. i.e. Zone A1 and B1 receive higher radiation than the one labeled with “Excessive heat 1 ” what means that cities belonging to this classification are surely in southern Europe (high radiation) and not close to the see. (Air temperatures near the see are a little bit lower). It is also easy to see the variations existing along summer class C where lower ambient winter temperatures in C3 and C5 delivers higher winter climatic severities to places with higher radiations.i.e.: it is explained by the different altitude of the locations, foggy zones… .

Table 94: Average Dry Temperature for each category

Dry Temp		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	*18,40*	*17,36*	*16,25*	*15,10*	*15,12*	*14,60*	*13,73*
	Class 2	*15,60*	*15,10*	*14,48*	*13,30*	*12,24*	*11,96*	*11,51*
	Class 3	---	---	*12,45*	*12,06*	*10,66*	*9,67*	*10,56*
	Class 4	---	---	---	*11,20*	*10,09*	*10,03*	*9,39*
	Class 5	---	---	---	*9,68*	*7,03*	*7,13*	*8,04*
	Exc. Cold	---	---	---	---	---	---	*4,66*

Dry air temperature averages, described in Table 94 does maintain the expected decreasing profile with highest values on the top left corner, decreasing values to the lower diagonal point.

And finally, they are represented two different definitions of Cooling Degree days and Heating Degree days.

Table 95 and 96 show the average values of cooling degree days for a comfort temperature of 25ºC calculated in this work to assure maximum internal comfort conditions and those ones calculated over 20ºC used for the Summer Climatic Severity.

In the same way were represented the Heating degree days for a winter comfort temperature of 21ºC calculated in this work to assure maximum internal comfort conditions and 20 ºC used for the Winter Climatic Severity. (96Table 97 and 96Table 98)

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Table 95: Average Cooling Degree Days (25ºC base) for each category

CDD 25 Total		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	20,48	12,35	7,29	5,04	8,74	4,36	4,87
	Class 2	23,02	13,42	9,07	5,82	4,42	2,45	2,15
	Class 3	---	---	10,18	7,36	3,74	1,42	2,43
	Class 4	---	---	---	6,86	4,33	3,17	1,89
	Class 5	---	---	---	7,07	2,86	2,38	2,53
	Exc. Cold	---	---	---	---	---	---	2,26

Table 96: Average Cooling Degree Days (20ºC base) for each category

CDD 20 Total		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	29,76	20,60	14,05	10,77	9,36	4,63	2,79
	Class 2	27,99	19,31	14,53	10,37	5,76	4,16	2,78
	Class 3	---	---	13,37	10,94	5,44	1,02	3,64
	Class 4	---	---	---	11,05	6,80	5,16	3,38
	Class 5	---	---	---	8,58	3,83	1,96	3,15
	Exc. Cold	---	---	---	---	---	---	1,11

Table 97: Average Heating Degree Days (21ºC base) for each category

HDD21 Total		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	127,07	130,29	139,29	161,67	161,63	161,04	178,43
	Class 2	189,77	184,60	186,13	204,37	221,32	224,10	232,72
	Class 3	---	---	233,31	236,41	258,21	273,76	257,40
	Class 4	---	---	---	260,70	276,21	273,98	285,80
	Class 5	---	---	---	290,38	344,36	337,00	318,28
	Exc. Cold	---	---	---	---	---	---	394,62

Table 98: Average Heating Degree Days (20ºC base) for each category

HDD20 Total		Summer Climatic Severities's						
		Exc. Heat	Class A	Class B	Class C	Class D	Class E	Exc. Cold
Winter Climatic Severities's	Exc. Heat	---	---	---	---	---	---	---
	Class 1	48,99	52,25	59,01	69,55	67,96	69,46	78,05
	Class 2	80,79	78,10	80,74	90,80	98,91	100,62	104,62
	Class 3	---	---	103,92	106,25	117,57	125,01	116,93
	Class 4	---	---	---	116,63	125,69	124,83	130,68
	Class 5	---	---	---	132,44	159,50	156,42	146,67
	Exc. Cold	---	---	---	---	---	---	185,17