Horizon 2020

Research and Innovation Framework Program

CHESS SET UP

Deliverable 3.6
INTEGRATION WITH OTHER ENERGY SOURCES AND TECHNOLOGIES

Deliverable Type:	Public
Date:	30/05/2017
Distribution:	WP3
Editors:	BCNecologia
Contributors:	WP3

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 680556.

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Document history

Date	Version	Editor	Change	Status
13/01/2017	0	BCNecologia		Creation
24/04/2017	1	BCNecologia		Draft
30/05/2017	2	BCNecologia		Final

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D3.6 Integration with other energy sources and technologies

1. Introduction

The CHESS SETUP concept aims to achieve an energy efficient system to supply heating and hot water in buildings mainly from renewable sources. The proposed system is based on the optimal combination of solar energy production, heat storage and heat pump use and may have an auxiliary system as a back-up.

However, the configuration of the system may be adapted and optimized according to the situation in different project types and locations. The integration with other energy sources and technologies should therefore be considered to understand the potential of replicating the system with the incorporation of some variables.

The adaptation of the CHESS SETUP, considering the integration of efficient technologies can help towards the EU Energy Performance Building Directive (EPBD) that aims to achieve 'nearly zero-energy buildings' (NZEB) by the end of 2020 (2018 for building occupied and owned by public authorities) with integration of renewable energy sources on site or nearby.

The following energy sources and technologies have initially been considered as potentially appropriate for implementation and have therefore been researched to understand its operation, availability, efficiencies, costs, market status and overall integration with the CHESS SETUP system:

- Solar hybrid panels (PVT)
- Biomass
- Geothermal
- Waste heat
- Absorption cooling
- Combined Heat and Power (CHP)
- Photovoltaic panels and Air Source Heat Pump (ASHP)

The integration of these with the CHESS SETUP system has been analyzed performing preliminary energy calculations to understand the potential energy and CO_2 savings and the results are shown in 'Chapter 3 Energy modelling results'.

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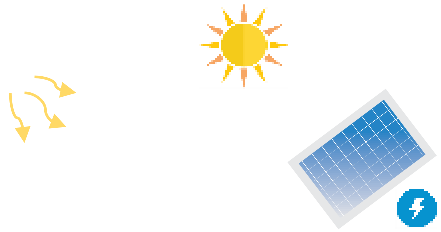
2. Analysis of other energy sources and technologies

2.1. Solar hybrid panels

The incorporation of solar hybrid panels (photovoltaic and thermal, PVT) is part of the CHESS SETUP proposal in this project but has been considered appropriate to include in this section as it is a variance from a more conventional configuration that could be based on solar thermal panels only.

2.1.1 Definition

Solar photovoltaic (PV) system:

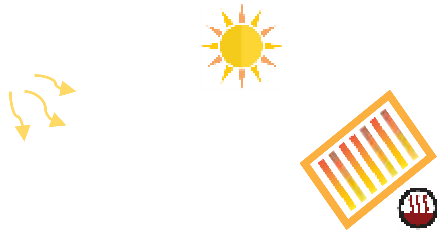


The basic element of a PV panel is the PV cell, which is a semiconductor device that converts solar energy into direct-current electricity. PV cells are interconnected to form a PV module.

PV modules are combined with a set of additional system components (e.g. inverters, batteries, electrical components, and mounting systems).

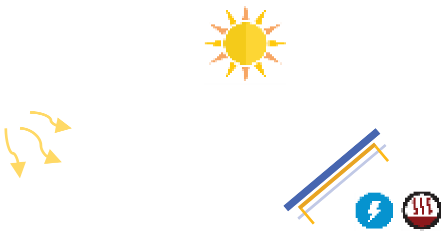
Note that most of the energy that is not transformed into electricity is converted into heat, and because PV modules are semiconductor devices, they become less efficient as their temperatures rise.

Solar thermal (ST) system:



Solar thermal panels capture solar radiation and convert it into heat for a wide number of applications. Several solar heating technologies are already mature and can be competitive in certain regions of the world in applications such as domestic hot water heating and swimming pool heating.

Solar hybrid (PV-T) system:



PV-T technology is intended to increase the amount of solar energy collected from a solar energy system by combining PV and solar thermal panels into a single system of collectors. The thermal collector (absorber) is attached to the back of a PV module.

The sun does not hit the thermal collector directly; instead the solar energy that is not converted into electricity by the PV panel can be collected as useful heat by the solar thermal collector resulting in an increase of the overall efficiency of the system (Alliance for Sustainable Energy, 2015).

$$E_{total} = E_{PV} + Q_{useful}$$

Water or air flowing through the thermal collector removes and captures heat from the PV cells, allowing a larger portion of the solar energy incident on the collector to be turned into either thermal or electrical energy. By combining the two technologies (PV and ST) in one physical

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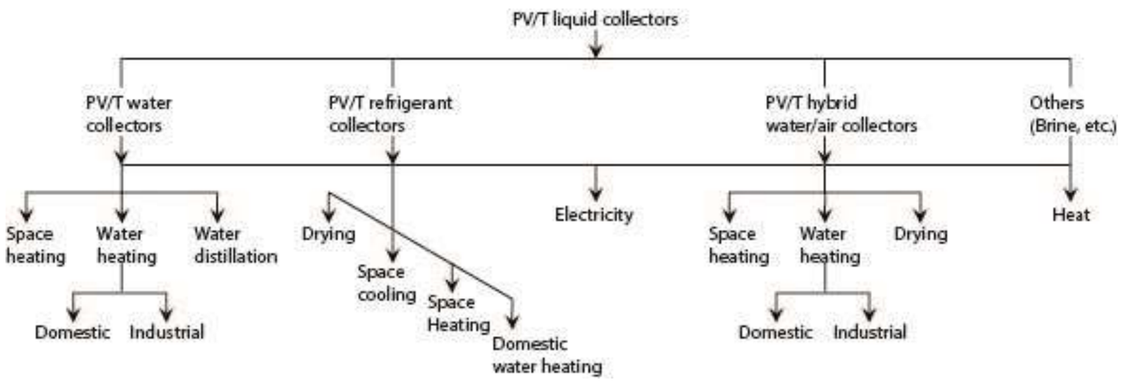
profile, PVT increases the energy production efficiency while occupying less space than would be required by separate PV and ST systems, minimising the requirement of roof space.

2.1.2 Types

PVT collectors are mainly of flat type in form and are distinguished in water, refrigerant and air cooled collectors. The diagram below shows a classification of the PVT collectors and the potential end uses (Öner, 2016).



Classification and potential uses of PV/T systems. Source: (Öner, 2016)

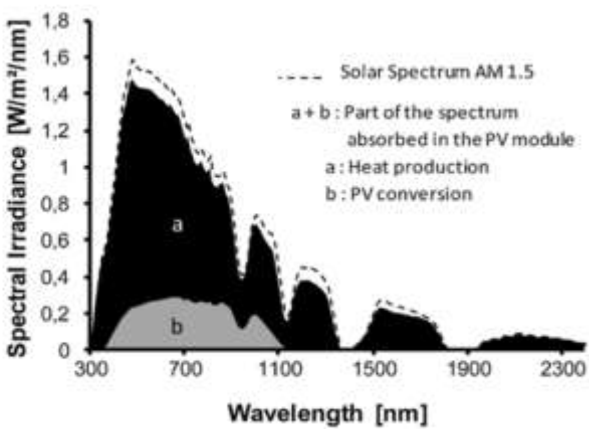
This study will focus on the use of water PVT collectors with the purpose of providing heat with an end use of space heating and/or domestic hot water.

2.1.3 Efficiencies, costs and market status

Efficiencies

The conversion rate of solar radiation into electricity by photovoltaic's depends on the cell type. Commercially available products' efficiency currently range between 12% - 18%, typically 15%. An important part of the absorbed solar radiation by photovoltaic panels is converted into heat, as shown in the figure below, increasing cell temperature (Dupeyrat, 2014).

This effect reduces their electrical efficiency - mainly to silicon cells - and is an essential difference between solar thermal collectors and photovoltaic's, for the required conditions for their effective operation. PV cells therefore achieve higher efficiencies when operating at lower temperatures.



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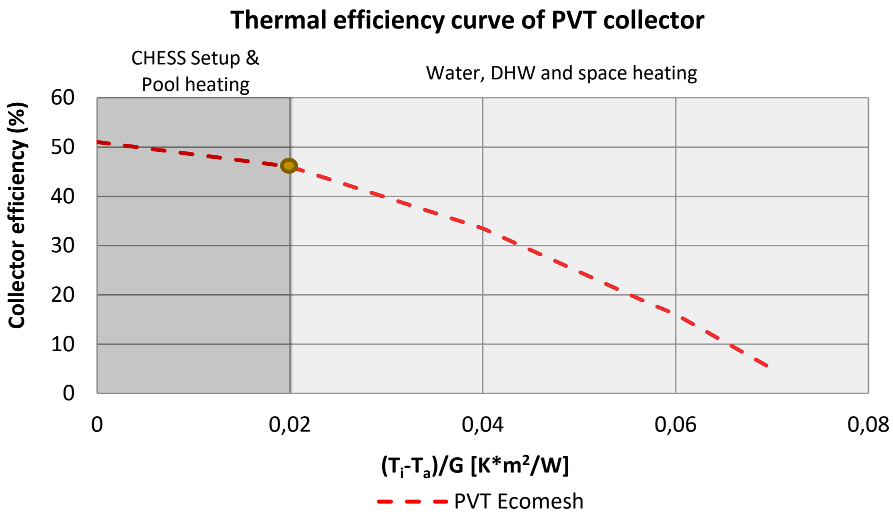
Absorbed energy in a PV module. Source: (Dupeyrat, 2014)

The solar thermal collectors instead, aim to achieve higher absorber temperature and provide heat removal efficiently. There are several thermal collector types but a seasonal efficiency of around 55% can be considered for conventional flat plate collectors.

When examining PVT, the requirement of low temperatures to result satisfactory electrical efficiencies, limits its operation to low temperatures for thermal production, although temperatures up to 60°C or 70°C could be achieved at lower efficiencies. Simultaneous cooling of the PV module can maintain the electrical yield at a reasonable level.

It is important to note that working at lower temperatures on the thermal side (lower temperature difference [ΔT] between collector operation and ambient temperatures) results in less thermal energy losses and less maintenance issues and greater efficiencies as shown in the graph below.



Source: (Ecomesh, 2017)

We are therefore looking at a seasonal thermal efficiency of approximately 45% plus a 15% electrical efficiency in the same panel (Ecomesh, 2017), thus PVT hybrid systems can provide greater advantage in terms of total efficiency.

Costs

The use of PVT panels is not extended and there is no sufficient information regarding its costs to analyse in detail. Some currently available products have shown prices that can range around 500-900 €/panel (approximately 250 W each). The costs are associated to the ones of PV, which are here examined.

The prices of cells and PV modules have been falling gradually and constantly in the last decades and are expected to decline further as deployment increases and technology improves in the next two decades. This roadmap expects module costs to fall to around $ 0,35/W by 2035 as per the graph below (IEA, 2014).

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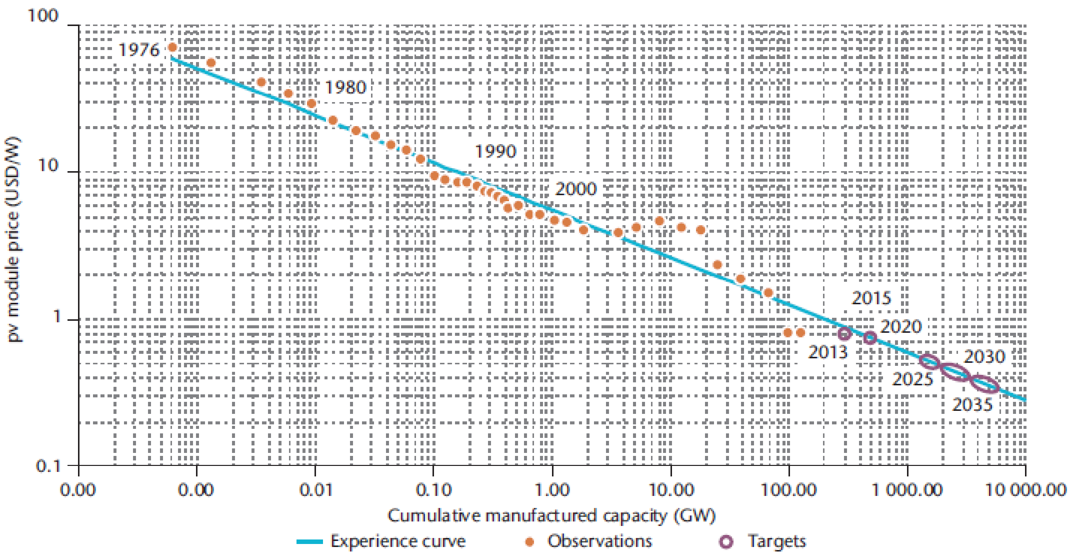
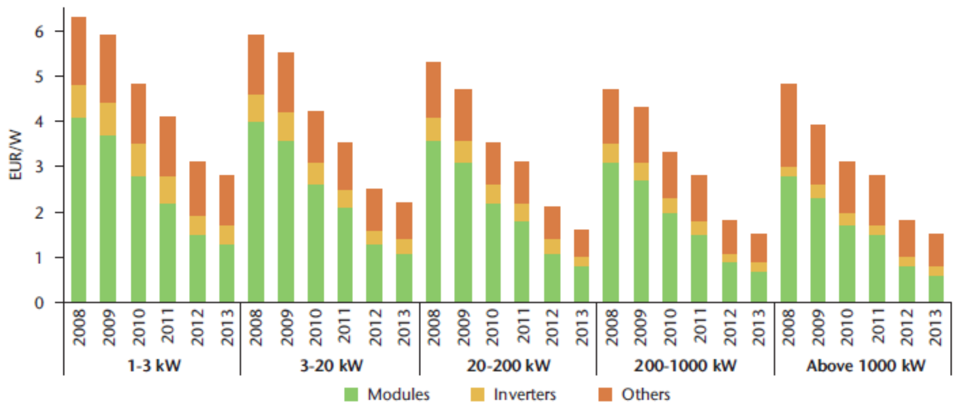


Past modules prices and projection to 2.035 based on learning curve
Source: (IEA, 2014)

More specifically, the graph below shows the decline in PV systems prices in Italy between 2008 and 2013.



System prices in Italy, 2008 – 2013. Source: (IEA, 2014)

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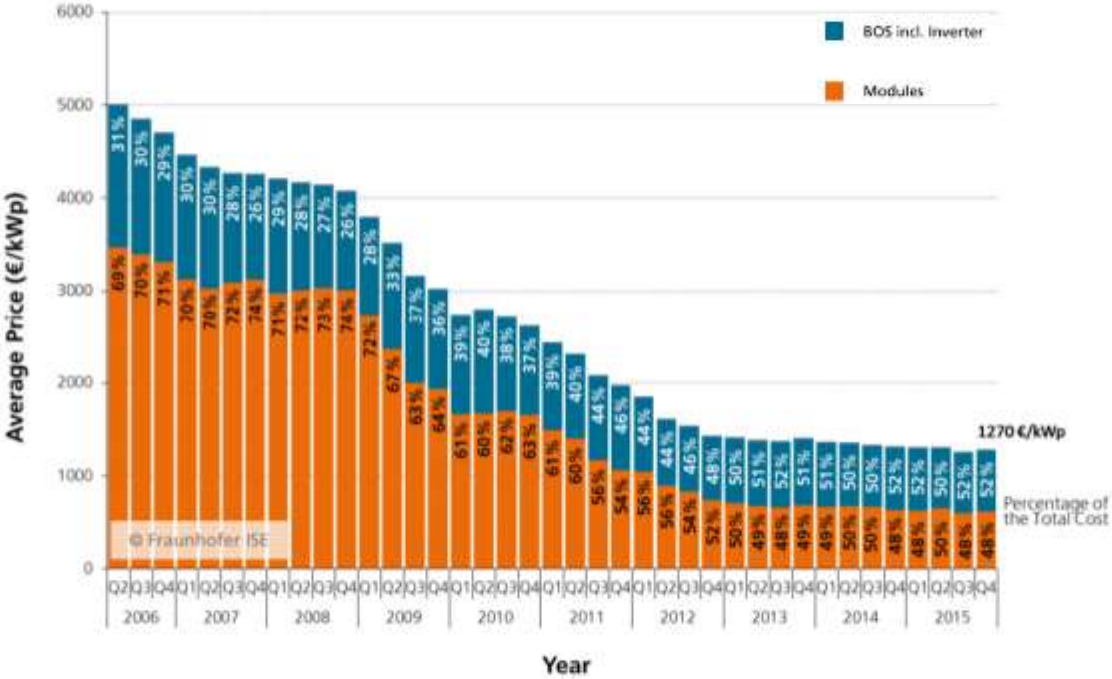
Similarly, prices of PV modules have decreased in the last years in Germany and seem to have stabilized in 2013, as shown in the graph below. Note that small systems, such as rooftop systems, are usually more expensive than larger ones, especially ground-based large systems.



Price Development for PV Rooftop Systems in Germany (10 - 100 kWp). Source: (ISE, 2016)

Prices vary significantly among countries for similar system types. Most of the gap comes from differences in “soft costs”, which include customer acquisition, permitting, inspection and interconnection, installation labour and financing costs, especially for small systems (ISE, 2016).

Market status

As mentioned earlier, the use of hybrid PVT panels is not extended yet and the commercially available products are still evolving from first to second and third ‘generations’ of PVT which try to improve their overall efficiency, specially on the thermal side.

In terms of the PV market status, cumulative PV installed capacity has grown at an average rate of 49% per year in the last ten years, as shown in the graph below. In 2013, about 37 GW of new PV capacity was installed in about 30 countries, or 100 MW per day, bringing total global capacity to over 135 GW (IEA, 2014).

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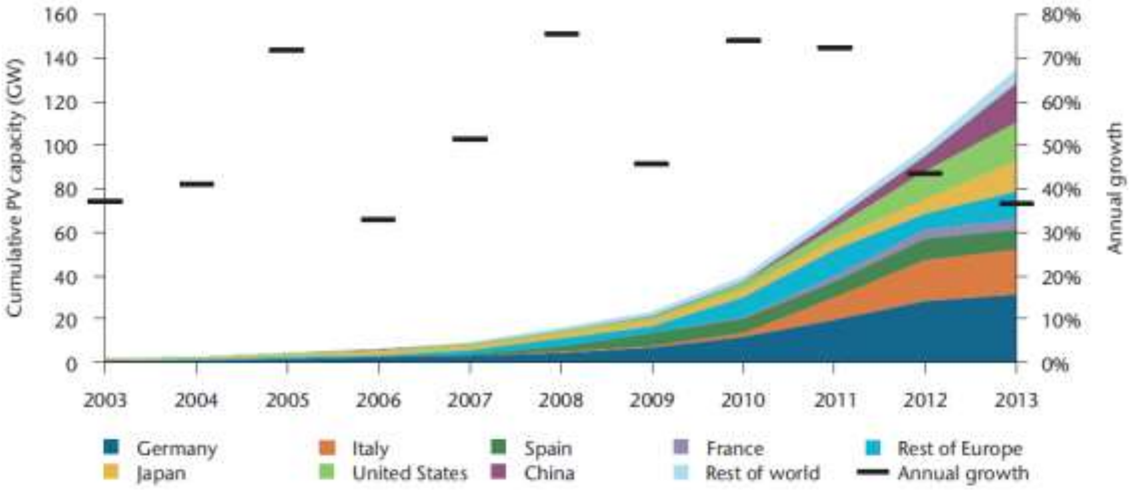

Global cumulative growth of PV capacity. Source: (IEA, 2014)

Crystalline silicon (c-Si) modules, whether single-(sc-Si) or multi-crystalline (mc-Si), currently dominate the PV market with around 90% share (IEA, 2014). Thin films of various sorts now represent only about 10% of the market, down from 16% in 2009, and concentrating photovoltaic's, although growing significantly, represent less than 1%.

Decentralized systems represent approximately 60% of the global market, while centralized, utility-scale systems represent close to 40%. Off-grid systems account for 1% at most.

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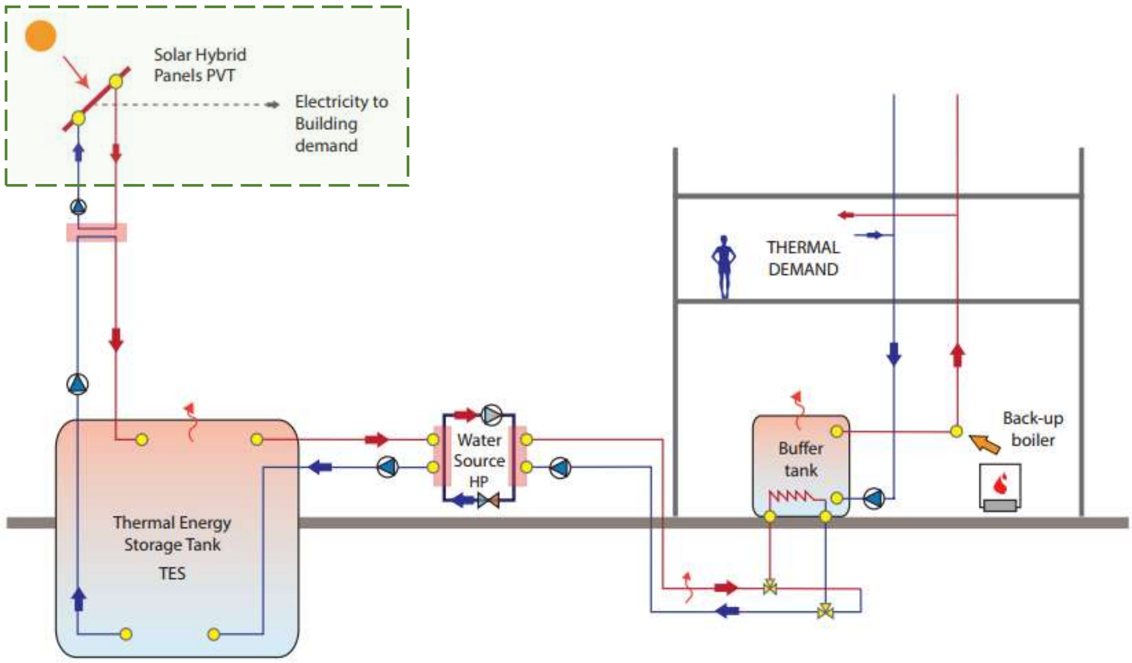
2.1.4 Integration with CHESS SETUP

As described earlier, the integration of PVT panels is inherent to the proposed CHESS SETUP system in this project. However, this can be considered an evolution of a more conventional configuration that could be based on solar thermal panels only.

A simple conceptual schematic of its integration is illustrated below.



Conceptual schematic of CHESS SETUP with PVT panels

In this configuration, the PVT panels have been considered to operate at a maximum temperature of 50ºC to ensure adequate efficiencies as mentioned in previous sections. The electricity produced can be utilised to run the water source heat pump (WSHP) and/or to serve any other electric requirements on site.

A gas boiler can serve as a back-up system in case the temperature of the tank goes under 20ºC, when the WSHP would not operate at the desired efficiency.

The integration of PVT should be studied for each project as its feasibility will depend on the building characteristics and its location. However, as a first approach, it should be applicable when there is enough physical space to install a large thermal energy storage tank that can provide inter-seasonal reliance, meaning that the heat gained in summer can be stored to be used in winter, or, if the space is limited, when there is significant hot water demand in summer so that no thermal energy generated is dissipated.

Preliminary energy calculations have been carried out to understand the outcome of the integration of this technology in the CHESS SETUP system and are presented in section '3. Simulated results'.

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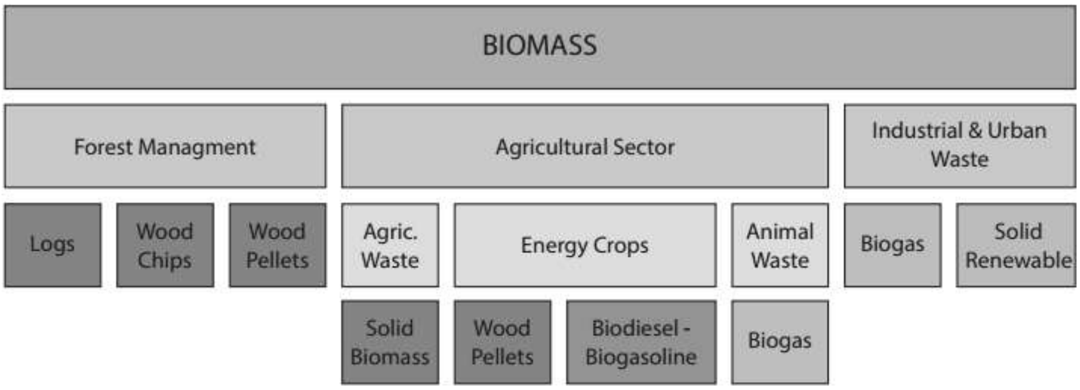
2.2 Biomass

2.2.1 Definition

Biomass is any organic material that has stored sunlight in the form of chemical energy. "All material of biological origin excluding material embedded in geological formations and transformed to fossil (CEN/TS 14588)", (Belbo, 2006). There are many types of biomass that can be used to derive fuels, chemicals, and power - such as the available from forestry, agricultural sectors and industrial and urban waste. The table below shows a schematic classification of biomass sources and types that can be found.



Example of the biomass types and sources

The thermal applications with the production of heat and hot water are the most common in the biomass sector although they can also be used for the production of electricity. Biomass can feed a space conditioning system in the same way as if it were made with gas, diesel or electricity (IDAE, 2007).

2.2.2 Availability

2.2.2.1 Forests management:

It is not easy to determine the forestry biomass availability in Europe, due to the complicated collecting system and to the variable amounts of feedstock available. However, it has been calculated that about 200 million cubic meters of forestry residues are available in EU (about 35-50 Mtoe/year not utilized). These data are calculated on the basis of a medium and not intensive mobilization. However, one of the main barriers is represented by the uncertainty of the potential evaluation.

Theoretical potentials can be quoted as the total forest biomass that could be harvested annually within biophysical limits (difficult lands, lack of access roads...) without depleting the existing forest stock. However, these potentials are rarely reached due to another common barrier, which consists on the technical, physical limits of extraction of wood from the ground, or during the pruning activity. Biomass for bioenergy production, if not efficiently monitored, can negatively affect forest biodiversity and carbon stocks through deforestation and unsustainable forest management within the EU and globally (EUBIA, 2014).

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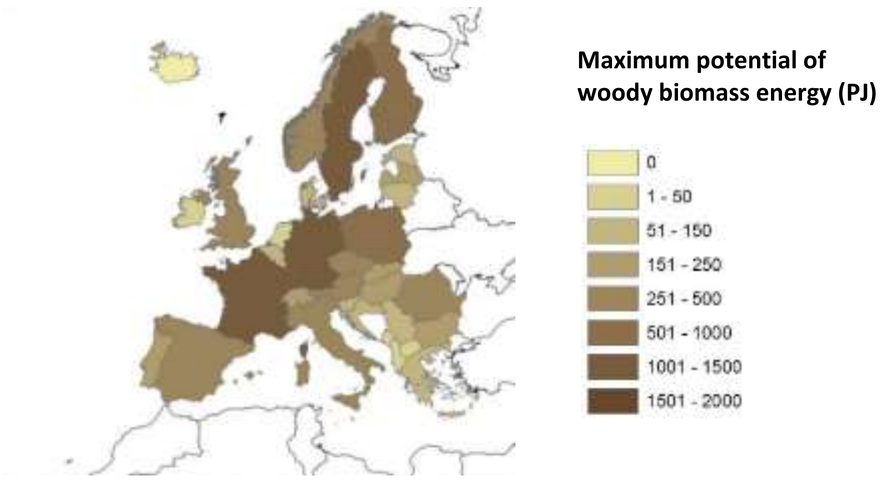
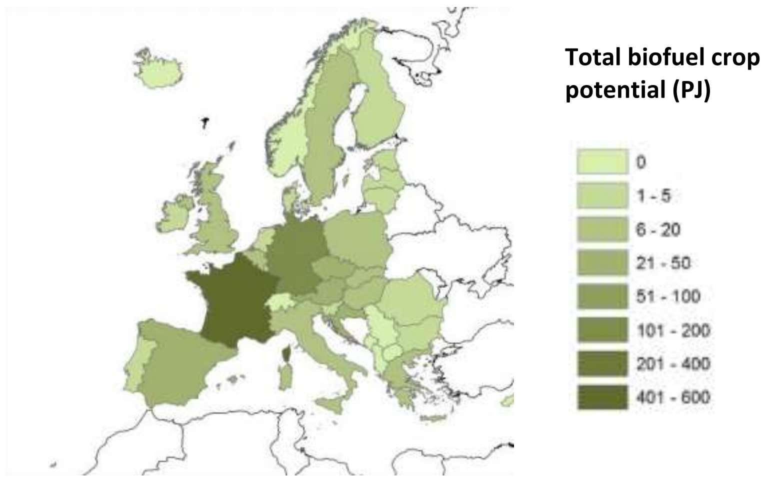


Total woody potential map in Europe in 2012

Source: (JRC Science Hub, 2015)

2.2.2.2 Agricultural sector

The sustainability risks related to agricultural biomass mainly consist in the loss of biodiversity, soil and water resources associated with intensive agricultural production. However, more than forestry, agricultural residues could represent a valuable solution to avoid pellets importation and to largely increase the sustainability of bioelectricity generation. Biomass agricultural wastes potential contribution to EU final energy consumption is estimated to be about 26% of final electricity and 6% of total final energy (EUBIA, 2014).



Total biofuel crop potential map in Europe in 2012

Source: (JRC Science Hub, 2015)

To reach these values, it would be required to overcome a set of barriers currently hindering sector development such as the transporting of agricultural residues to processing plants at short distances from the origin, safeguarding soil fertility and biodiversity.

2.2.2.3 Waste sector

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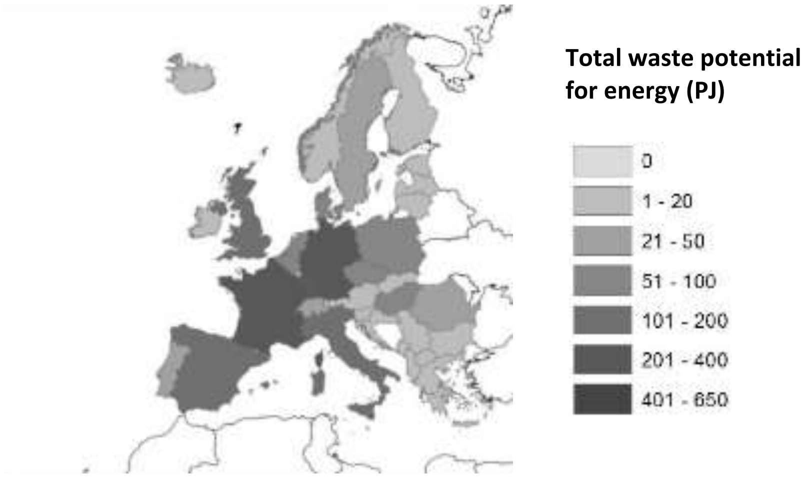
In 2014, production of primary renewable energy recovered by household refuse incineration plants across the European Union increased by 281 ktoe (3,2%) to reach 9 Mtoe. This output figure only includes the biodegradable part of household refuse; hence it excludes the energy recovered from non renewable municipal waste (plastic packaging, etc.).

According to the data gathered by EurObserv'ER, the production of electricity qualified as sourced from renewable municipal waste and heat sales to heating networks increased by around 5-6% during the study period. The rising number of heat and electricity outlets results from waste-to-energy incineration plants' improved energy efficiency (EUBIA, 2014).



Total waste potential map in Europe 2012

Source: (JRC Science Hub, 2015)

2.2.3 Types

Bioenergy covers – more than any other renewable energy – a wide range of raw materials and conversion technologies. As per the chart below, more than two thirds of biomass consumed in Europe consists of solid biomass (69%), biogas and bio fuels represent 12% and 13% of gross inland energy consumption of biomass and bio waste, and renewable municipal waste used for energy purposes reaches a 7%. Solid biomass is therefore the market driver for bioenergy, essentially comprising woody biomass. However, wood fuel is quite heterogeneous as it includes logs, chips and pellets. This diversity makes it difficult to properly assess the breakdown of each type of biomass products consumed in Europe (AEBIOM, 2017).

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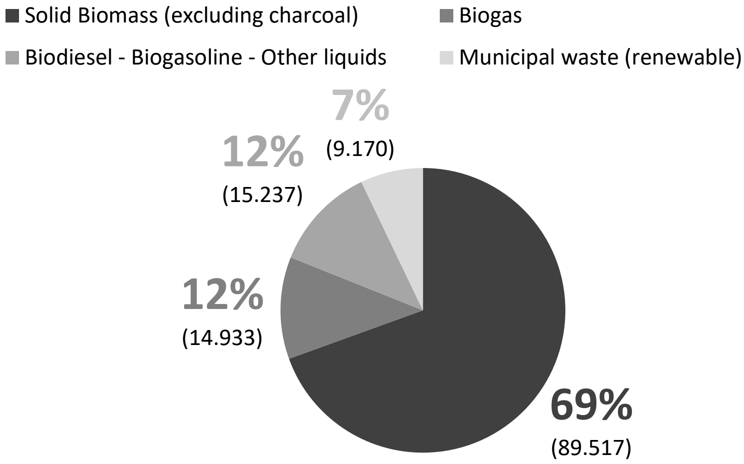

EU-28 gross inland energy consumption of biomass and biowaste (in 2014, ktoe, %)

Source: (AEBIOM, 2017)

2.2.3.1 Solid Biomass

Solid biomass includes all the solid organic components to be used as fuels. The following table shows the main types that can be considered from forestry and agricultural waste.

Biomass for heating	**Woods Pellets** 	**Wood Chips** 	**Wood Logs** 	**Agricultural Waste** 
PCI (GJ/t)	17-19,0	10,0-16,0	14,4-16,2	14,6-19,0
-per kg (kWh/kg)	4,7-5,2	2,8-4,4	4,0-4,5	4,0-5,2
Humidity (%)	<15	<40	<20	<20
Density (kg/m^3)	650	200	---	200-500
Long. (mm)	<5 diameter	---	> 2 diameter	---
Diam. (mm)	< 8	< 63	> 63	---
Ash (%)	<0,5	<1,0	<3,0	1,0-2,0
Price (€/t)	186,6	93,2	124,4	90,0
Price (€/kWh)	0,040-0,036	0,033-0,021	0,031-0,028	
Emissions ($kgCO_2$/ kWh)	0,016-0,018	0,004-0,006	<0,00612	---
Use	Boilers	Boilers	Boiler- Stove	Boilers
	Residential, Industrial			Industrial

Characterization of solid biomass
Source: (IDAE, 2007)

As shown in the chart below, the consumption of solid biomass in the EU is dominated by wood logs for residential consumption (Observ´ER (FR), 2015).

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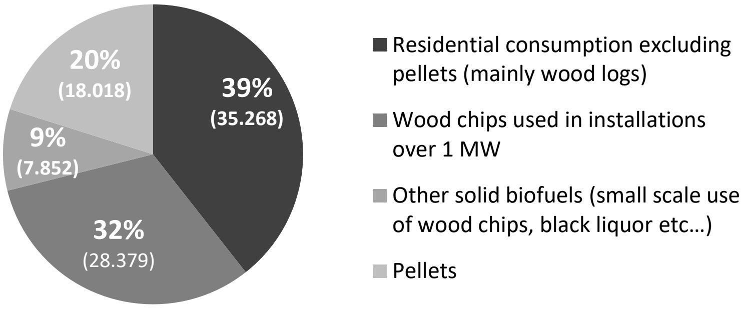

EU-28 gross inland energy consumption of solid biomass
(in 2.014, ktoe, %).
Source: (Observ´ER (FR), 2.015)

2.2.3.2 Biogas

Biogas can be fully harnessed with maximum energy efficiency to produce heat where there are outlets close to the methanization plant. It can also be refined into biomethane so that it can be put to use in the same way as natural gas, in the form of electricity in cogeneration plants, but also as biofuel for natural gas-powered vehicles or even injected into the natural gas grid.

In 2014, EU biogas energy output was estimated 14.9 Mtoe (6.6% growth on the previous year). Electricity production was the main outlet for biogas energy recovery in 2014 (Observ´ER (FR), 2015).

2.2.4 Efficiencies, costs and market status

Efficiencies and costs

Research of commercially available solid biomass products has been carried out and a summary table is shown below.

Technology	Stove	Stove - Boiler	Boiler	Boiler
Company	ESSE	Arada	ETA	Treco
Model	MF100	Ecoboiler 12	Hack 20	Biostar 12
Feedstock	Multi Fuel	Logs	Multi fuel	Pellets
Nominal Output to water	---	16 kW	19.9 kW	12 kW
Output range to water	---	12.3 kW	---	---
Output range to room	5.0 kW	4.3 kW	---	---
Nett Efficiency (%)	82.1	75.2	93.8	94.7
Operating water temp.	---	80 °C	70°C - 85°C	50°C - 80°C
Dimensions LxDxH (m)	0.6 x 0.4 x 0.6	0.6 x 0.4 x 0.6	0.7 x 1.3 x 1.7	1.1 x 0.9 x 2.0

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	 (source: ESSE)	 (source: Arada)	 (source: ETA)	 (source: TRECO)
Weight (kg)	83.6	148	736	298
Price approx. (£)	1000	1500	16500	12000 (includes 400 L fuel store)
Power (W)	---	---	147	---

Example of commercially available biomass technologies

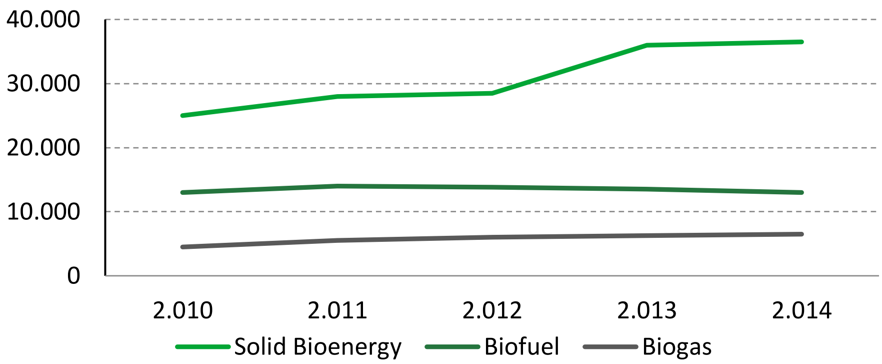
Sources: (ESSE Engineering, 2017), (Arada Stoves, 2017), (ETA, 2017), (Treco Green Heat, 2017)

Efficiencies of biomass boilers are usually around 80-95% and provide temperatures that can be used to serve space heating and domestic hot water needs.

CHP (Combined Heat and Power) fuelled by biomass are also available in the market but are not included as part of this chapter. Typically, the costs and maintenance associated with these are higher than the more common gas fired CHP units.

Market status

Since the entry into force of the Renewable Energy Directive in 2009, an important flow of investments in bioenergy has been noticed. According to Eurobserv'ER (Observ´ER (FR), 2015), from 2010 to 2014, the general bioenergy turnover grew 32% reaching 55 billion in 2014. The solid bioenergy segment experienced the biggest increase with 46% growth from 2010 to 2014.



EU-28 evolution of the turnover within the bioenergy sector

(From 2010 to 2014, million €)

Source: (AEBIOM, 2017)

Bioenergy contributes more to primary global energy supply than any other renewable energy source. The use of biomass for energy has been growing at around 2% per year since 2010. The bioenergy share in total global primary energy consumption has remained relatively steady since

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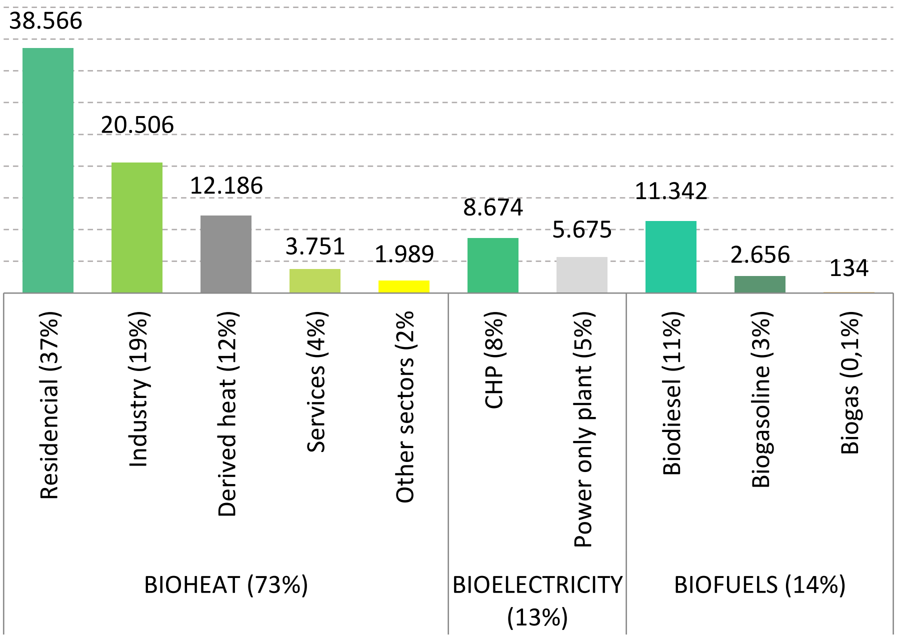
2005, at around 10%, despite a 24% increase in overall global energy demand between 2005 and 2015 (AEBIOM, 2017).

The graph below shows the bioenergy final energy consumption per market segment in the European Union in 2014, which is dominated by the bioheat consumption and with particular significance in the residential sector.



EU-28 gross final energy consumption of bioenergy per market segment (2014, ktoe, %).

Source: (AEBIOM, 2017)

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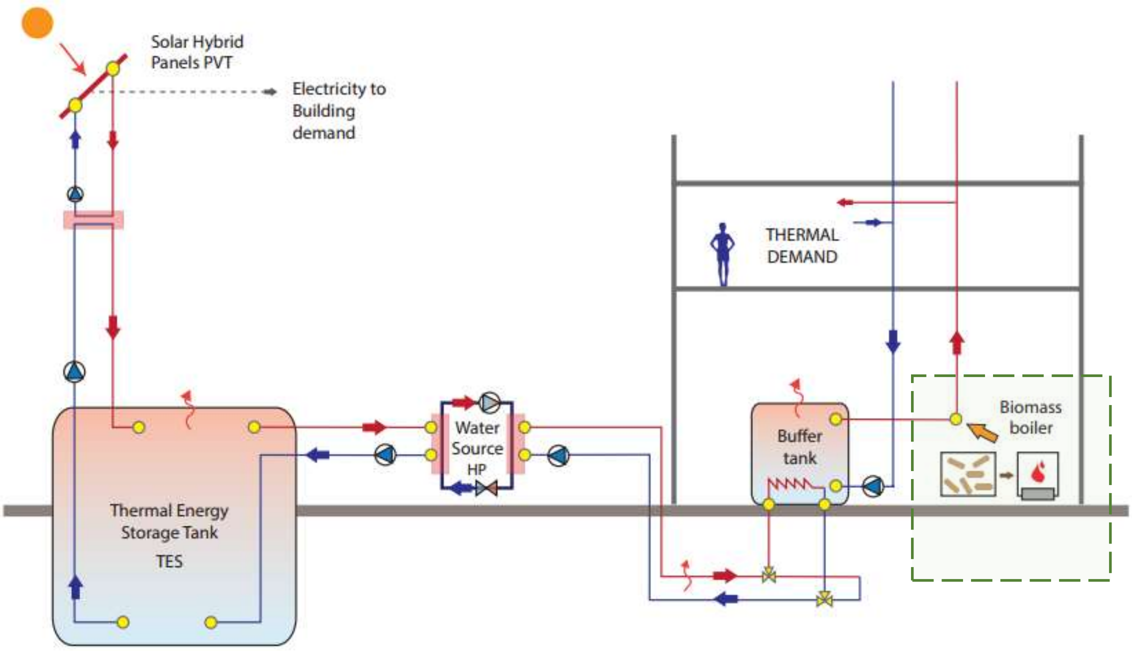
2.2.5 Integration with CHESS SETUP

Because solar energy is not constant, it is always necessary to have an auxiliary support system in case the temperature of the tank is too low (<20ºC) to operate the heat pump at high efficiencies. Whilst the reference CHESS SETUP system takes a gas boiler as the back-up, this could be replaced by a biomass boiler.

The configuration of the rest of the CHESS SETUP system would be maintained as per the previous considerations. A simple conceptual schematic of its integration is illustrated below.



Conceptual schematic of CHESS SETUP with biomass boiler

The integration of a biomass boiler will very much depend on the location of the project and biomass availability. In the case of being in a location with very high levels of biomass availability, it may result more beneficial to run the entire system based on biomass boilers and disregard the CHESS SETUP system.

Preliminary energy calculations have been carried out to understand the outcome of the integration of this technology as a back-up in the CHESS SETUP system and are presented in section '3. Simulated results'.

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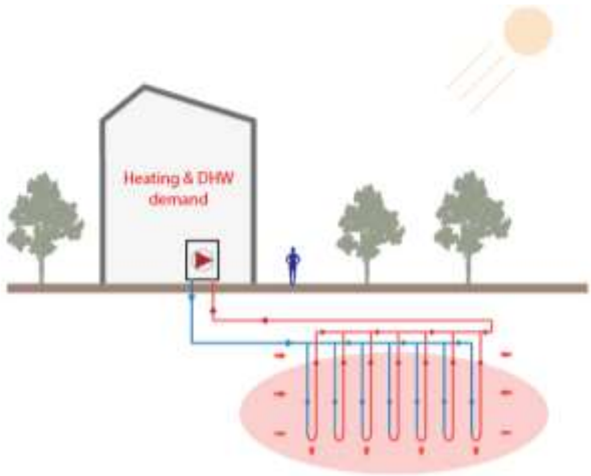
2.3 Geothermal

2.3.1 Definition

Ground source heating and/or cooling uses the relatively stable temperature of the ground or bodies of water as a source for providing heating and/or cooling in buildings (CIBSE, 2012).

The temperature of the subsurface will vary according to depth and the temperatures found are typically upgraded via a heat pump that can provide heating and/or cooling at elevated efficiencies. A loop needs to be installed to be able to extract this energy, known as geothermal.

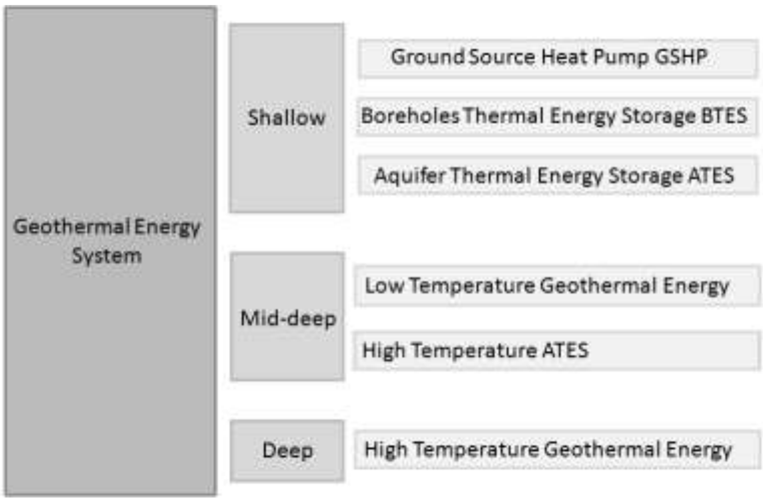
These kinds of energy systems involve certain technical risks and tend to require an important initial economic investment for drilling and installation.



Conventional geothermal energy example diagram

2.3.2 Types

There are different types of geothermal energy systems, which can be classified as follows:



Geothermal types classification overview. Source: (IF Technology, 2017)

For the CHESS SETUP project, the most commonly suitable option would be the Borehole Thermal Energy Storage (BTES), where heat is stored directly into the ground. As explained in

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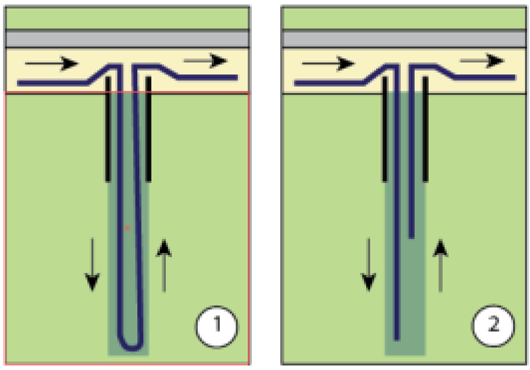
Deliverable 2.1 of the CHESS SETUP project, the heat is transferred to the underground by means of conductive flow from a number of closely spaced boreholes. The heat capacity and storage temperature will depend on the ground composition.

BTES are especially useful in a subsurface with a high heat capacity and impermeability (e.g. water-saturated clays and rocks). These are favourable because they are rarely subjected to groundwater movements that would cause heat losses (SDH, 2012).

BTES should be installed for economic reasons only in well drillable subsurfaces. It should be ensured that no groundwater leaks out due to heat losses in the ground drilled through. Extensive geological preliminary investigations must be carried out in any event (SDH, 2012).

There are two main configuration types in geothermal systems, open and closed loops, being used to transport the heat carrying medium in and out of the holes. The two principles are illustrated in the next figure.



Geothermal loop configurations: [1]closed system; [2] open system

Open Loop System: The warm water is obtained from a subsoil aquifer and used directly to heat and then the cold water is returned downstream aquifer or river.

Closed Loop System: The refrigerant circulates permanently between the collector (heat exchanger) and the subsoil.

The closed system uses U-pipes, and this means that the heat medium is pumped in a closed circuit, eliminating a number of potential problems with regard to water chemistry etc. that are inherent in the open system. The U-pipes act as a heat exchanger between the heat/cold carrying medium and the surrounding soil/rock.

The closed loop systems can be of different vertical and horizontal forms such as (IDAE, 2011):

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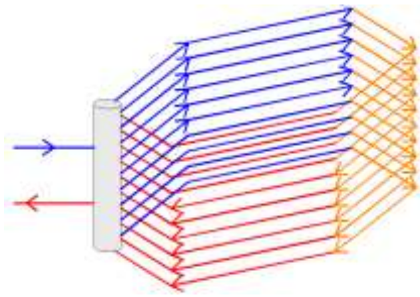
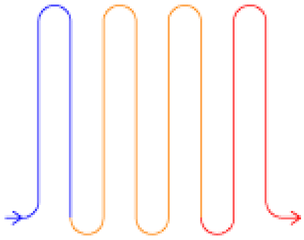
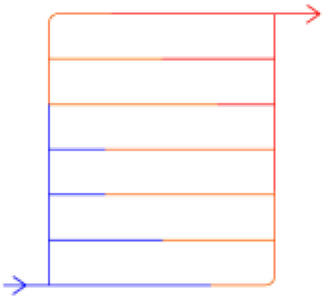


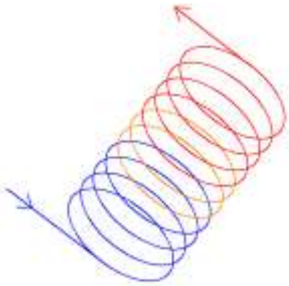
Connection in Trench



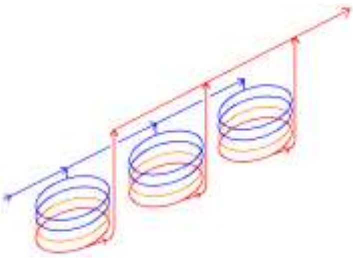
Horizontal Loop



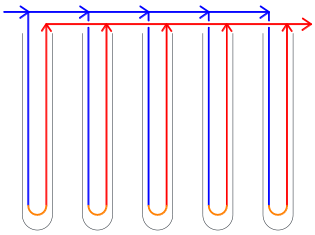
Connection in Parallel



Slinky Loop



Pond Loop



Vertical Loop with boreholes

Horizontal trenches are used to extract energy from the ground, where the depth is usually between 1 and 2 meters. For slip trenches, the width of the trench are normally equal that of a bucket of a digger (IDAE, 2011).

In vertical boreholes, heat is charged or discharged in depths of typically 30-200 m below ground surface. More shallow systems from 1 meter to 20 meters are also used in residential houses or small blocks of flats. On the other side, deep geothermal systems can go a few kilometers depth searching for higher temperatures.

Boreholes can have single or double U-pipes, concentric or coaxial pipes and the loop has the possibility to be buried under the building with the structure foundations (normally only possible for new builds) or under other spaces like parks or gardens next to the site (which would allow the opportunity to connect to existing buildings as well) (IDAE, 2011).

In conventional systems where the ground is not used to store energy, geothermal energy is mostly used for heating but could also serve to cover the cooling needs of a dwelling, inverting the cycle of the heat pump, although this is not applicable for the CHESS SETUP system.

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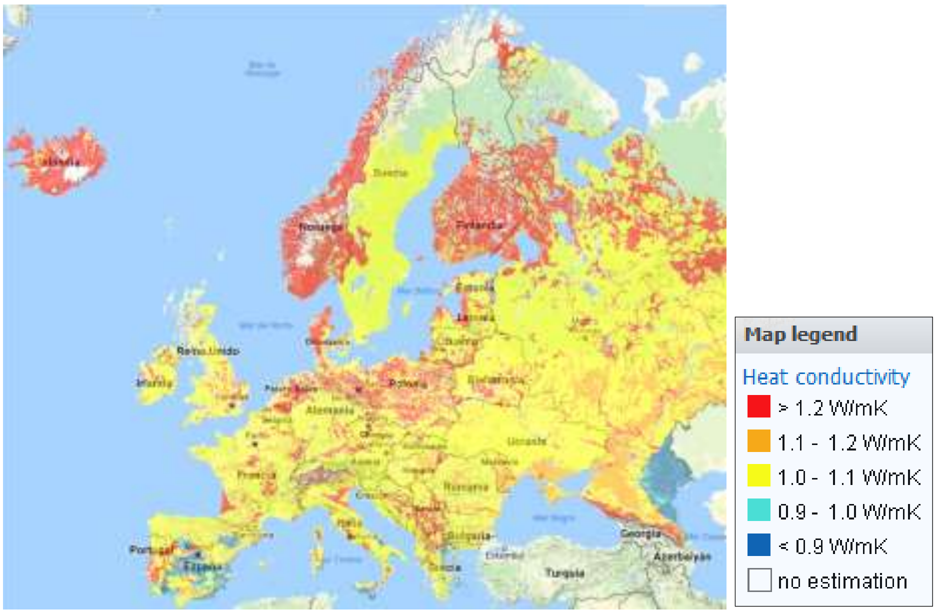
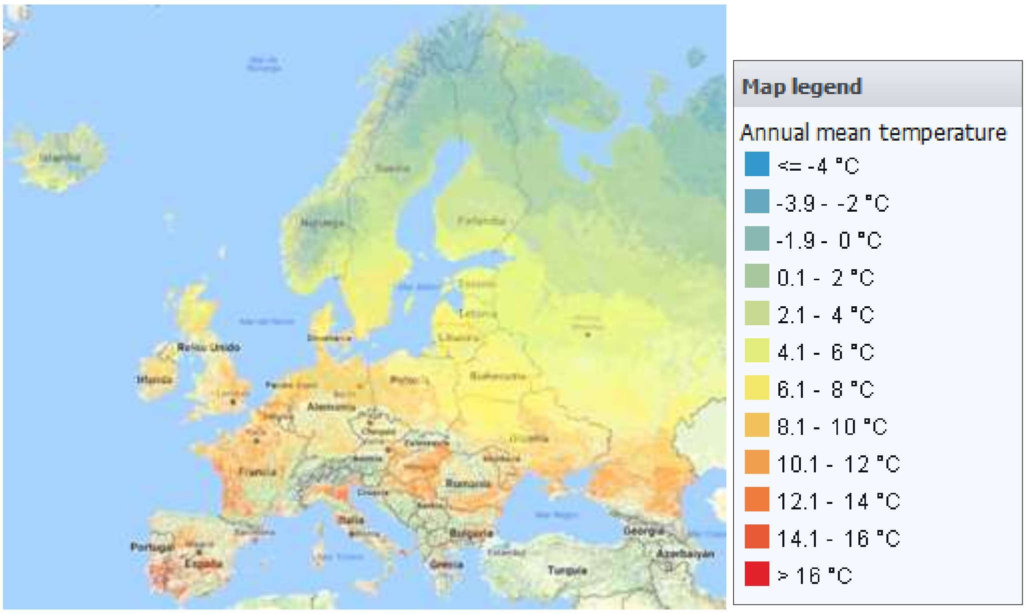
2.3.3 Availability

Soil conductivities and temperatures at 10 meters depth in Europe are shown below as reference.



Subsoil heat conductivity in Europe at 10 meter depth. Source: (ZGIS, 2010 - 2013)



Subsoil annual mean temperature in Europe at 10 meter depth. Source: (ZGIS, 2010 - 2013)

The temperature profile can vary depending of many factors such as the porosity of the rock, the degree of liquid saturation of the rock and sediments, their thermal conductivity, their heat storage capacity and the proximity of magma chambers or heated underground reservoirs of liquid. Despite for the CHESS SETUP project the focus will be on shallow geothermal systems, a vision of the potential of temperatures at greater depths is sown in the illustration below.

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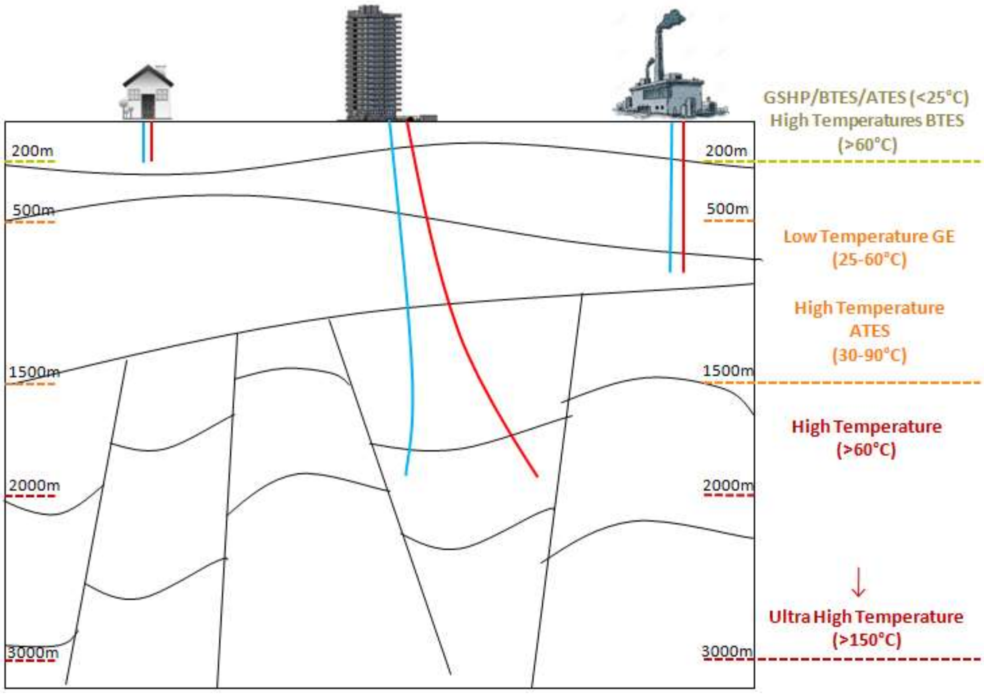
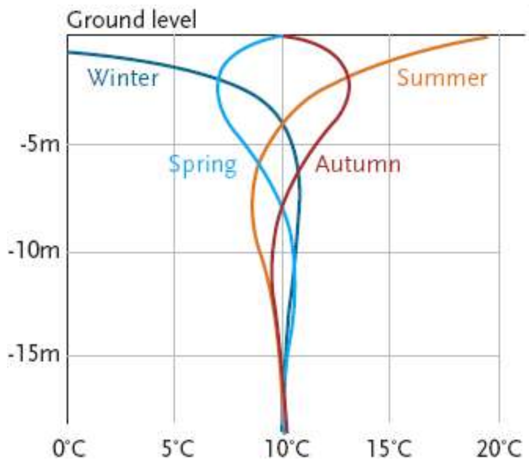


Temperatures that may be found at different depths. Figure based on (IF Technology, 2017)

The temperature increase with depth shown above means that boreholes must be very deep to reach high temperatures, which involves technical and economic risks associated with the difficulties in deep drilling and extraction. Note that suitable conditions may only available in a few locations.

When looking at very shallow installations it is important to consider that the temperature of the ground is still dependant and fluctuates based on the external conditions such as air temperature and solar radiation until depths of approximately 15 meters are reached, where the soil temperature becomes constant and is similar to the mean annual air temperature (8-11°C in the UK for example), see figure below (CIBSE, 2010). At depths below that, the underground temperature may increase around 2.6-3 °C per 100 meters depth (will vary depending on the location), due to the internal thermal energy of the Earth which is conducted upwards (BGS, 2011) (Andújar Márquez, Martínez Bohórquez, & Gómez Melgar, 2016).



Annual ground temperature from surface to 15 meters depth in the UK. Source: (CIBSE, 2010)

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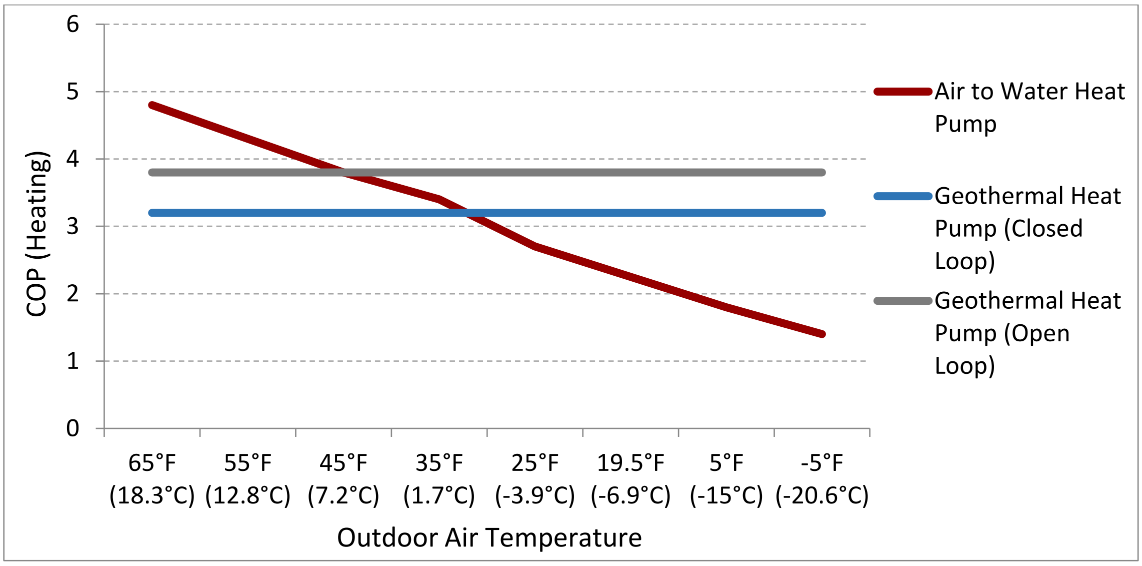
2.3.4 Efficiencies, costs and market status

Efficiencies

The heat pump's efficiency is measured using the coefficient of performance (COP) and is defined by the amount of heat that the heat the pump can produce (output) compared to the energy used needed to operate it (input).

The average geothermal heat pump has a COP of approximately 3.5 - 4 and may be higher but will depend on operating conditions. Compared to air source heat pumps (ASHP) which will see their efficiency vary according to external temperatures, meaning it will be reduced as the external temperature decreases (in peak winter times), the ground source heat pumps (GSHP) can have a stable efficiency throughout the year when looking at constant ground temperatures as the source (at depths below 15 meters as mentioned earlier). An example of this is illustrated below.



ASHP vs GSHP efficiencies. Source: (Maritime Geothermal, 2017)

Costs

The capital cost for a geothermal installation will vary from one project to another and be very dependent on aspects such as location, technology used and the depth of the wells. Some examples show that capital cost of a domestic geothermal system can range between USD 1000 and more than USD 3000 per kilowatt (kW) of thermal capacity (iAltEnergy, 2017).

Market status

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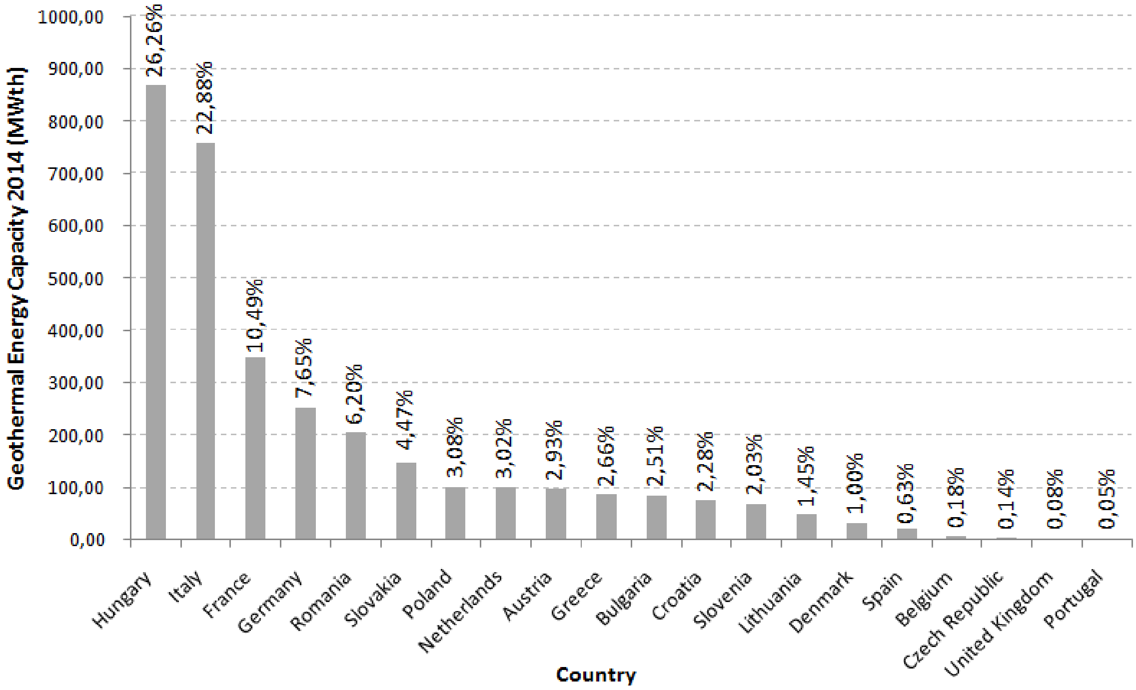
The graph below shows the European geothermal energy production capacity and proportion over total per country. It is clear that Hungary and Italy play an important role in the implementation of geothermal systems (EurObserv'ER, 2015).



Geothermal Energy Capacity by Country and Proportion of Europe Capacity in 2014.
Source: (EurObserv'ER, 2015)

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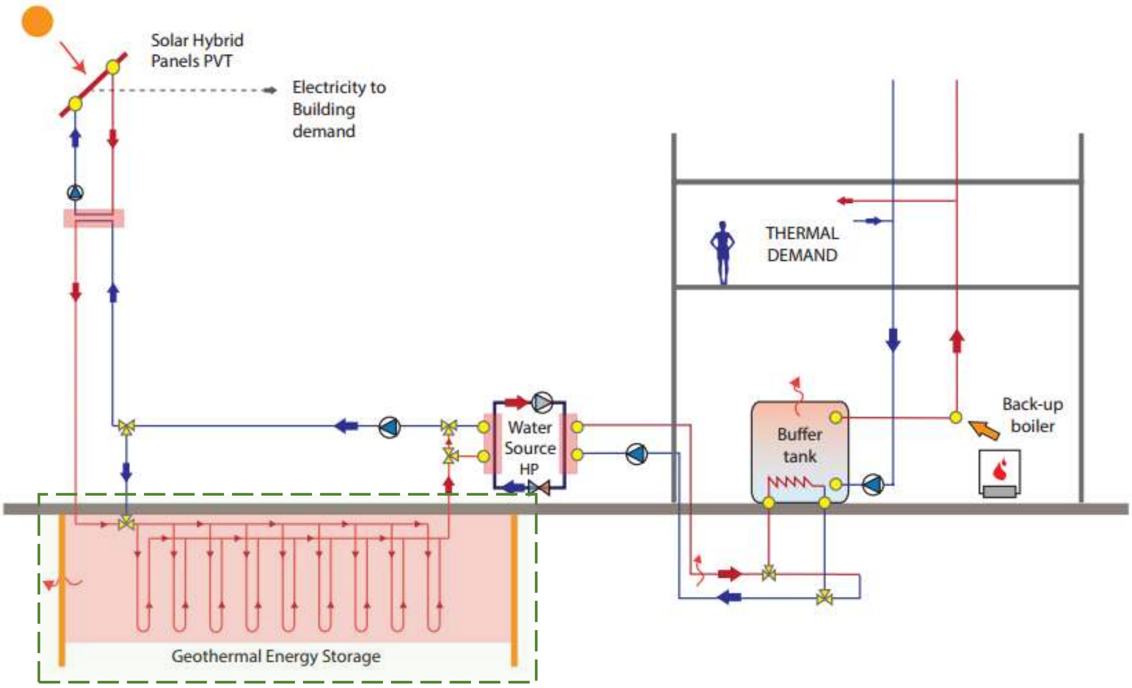
2.3.5 Integration with CHESS SETUP

The feasibility of integrating this technology will depend on the site conditions, which should allow the drilling/construction process to be carried out, and ground properties in order to ensure the feasibility of the system.

Whilst a conventional geothermal system would take benefit of the more stable temperature of the ground and would only extract energy (taking care not to collapse it with time), in the case of integration with the CHESS SETUP, the ground would become the thermal store as heat would be injected from the PVT panels, raising the soil temperature, to be used when it is required. The rest of the system would remain the same as per the original configuration.

A simple conceptual schematic of its integration is illustrated below.



Conceptual schematic of CHESS SETUP with geothermal energy

The depth of the boreholes is an important design parameter that will determine the dimension of the storage and the cost associated with the installation of this element and the system overall. Soil properties such as thermal conductivity and heat capacity are also key parameters to consider when analysing the feasibility of the system.

The 'earth energy bank' should be insulated on its upper side (adjacent to the surface/dwelling) in order to minimise heat losses. It is also considered important to insulate the sides to minimise the heat losses especially at the first meters below the surface, where the temperature of the soil fluctuates the most and possibly in the lower part also, depending on the case.

Preliminary energy calculations have been carried out to understand the outcome of the integration of this technology in the CHESS SETUP system and are presented in section '3. Simulated results'.

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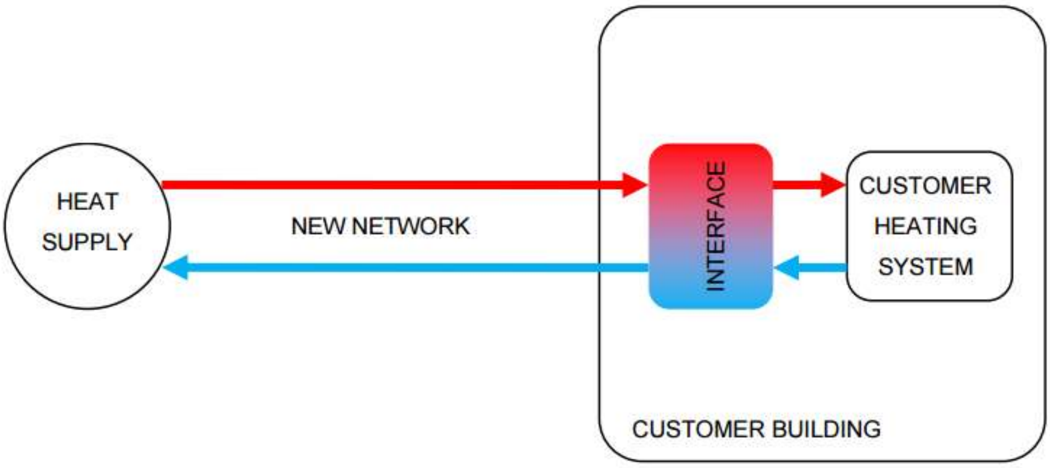
2.4 Waste heat

2.4.1 Definition

Waste heat refers to energy that is generated in industrial processes without being put to practical use. Sources of waste heat include hot combustion gases discharged to the atmosphere, heated products exiting industrial processes, and heat transfer from hot equipment surfaces. The exact quantity of industrial waste heat is poorly quantified, but various studies have estimated that as much as 20 to 50% of industrial energy consumption is ultimately discharged as waste heat (US Department of Energy, 2008).

While some waste heat losses from industrial processes are inevitable, facilities can reduce these losses by improving equipment efficiency or installing waste heat recovery technologies. Waste heat recovery entails capturing and reusing the waste heat in industrial processes for heating or for generating mechanical or electrical work. Example uses for waste heat include generating electricity, preheating or heating for domestic hot water/space heating, district heating networks and absorption cooling (US Department of Energy, 2008).

For the CHESS SETUP project, the use of waste heat for preheating and heating purposes is studied as a potential energy source. The figure below conceptually illustrates the main waste heat elements.



Waste Heat concept diagram. Source: (UK Department of Energy & Climate Change, 2015)

2.4.2 Types

Evaluating the feasibility of waste heat recovery requires characterizing the waste heat source and the stream to which the heat will be transferred. Important waste stream parameters that must be determined include (US Department of Energy, 2008):

- Heat quantity
- Heat temperature/quality
- Composition
- Minimum allowed temperature

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- Heat flow
- Distance from source
- Operating schedules, availability, and other logistics

These parameters allow for analysis of the quality and quantity of the stream and also provide insight into possible design limitations.

Supply continuity

Availability of waste heat will be very much site dependant and therefore project specific.

In order to ensure the feasibility of the installation and that profitability is maintained throughout the amortization period of the project, an allowance has to be made for uncertainty with regard to (ENERGY - Commission Of The European Communities, 1982):

- The continuity of supplies over the period, given the uncertainties involved in operating a factory or the waste heat source.
- The level of consumption remaining the same throughout the period, in view of uncertainty as to whether premises will continue to be occupied.
- Changes in economic factors over the period, including the price of fuels.

To limit the risks associated with the above, the design may rely on a multi-source energy system where possible in order to guarantee enough flexibility to be able to profit from fluctuations in the costs of access to the various sources of energy and to cover defaulting by one or other heat supplier, although in some instances with close proximity to the site and/or continuous supply, the demands may be covered through waste heat recovery from one source only.

Temperatures

Whilst some industrial processes work at very high temperatures, usually the heat can be recovered from relatively low-temperature process fluids, below 130°C; so the supply temperature of the water to the primary network is commonly 90-100°C and the return temperature is over 55°C in district heating applications.

If waste heat at lower temperatures is available closer to site, the possibility of recovering this may also be evaluated. A temperature of around 30°C could be upgraded for use in the building via a heat pump.

Heat losses

Heat losses vary depending on the pipes insulation. If the amount of heat available at the source is in excess of the demand, the investment in insulating the network may be limited to the strict minimum.

As an example, in the UK, installing a system with the levels of insulation required by the compliance guides would mean the following losses (CIBSE, 2013):

Distribution system	Losses
Pipe	10-20 W/m
Network (with return pipework)	20-40 W/m

Pipeline losses for 75°C distribution insulated system. Source: (CIBSE, 2013)

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The design and construction experience on projects shows that an estimated amount of heat lost between the point of supply and the point of connection with the demand is around 10% (ENERGY - Commission Of The European Communities, 1982).

2.4.3 Efficiencies, costs and market status

Efficiencies

In this case, the efficiency of the system will be very much dependant on the waste heat available temperature.

If the waste heat temperature is sufficient to be used directly at the demand point via a heat exchanger, the incoming heat may be considered 'free heating' in terms of energy as it was otherwise going to be wasted/dissipated.

When talking about lower available temperatures (e.g. 30 °C), this may be used as preheating and the efficiency of the system will depend on the system to top up the temperature to the required conditions. In the case of a heat pump, it will have to cope with a smaller temperature difference (ΔT) between origin and demand which will result in the possibility of achieving a high Coefficient of Performance (COP). Commercially available units offer COP figures between 4 and 7 depending on the operating conditions.

Costs

To install waste heat systems, the overall cost is mainly derived from the costs associated to the waste heat recovery equipment, installation of the network and the required heat exchangers, including the soft costs associated with designing, permitting and constructing the system.

Capital Cost	Unit	
Network Capital costs per length (main network buried)	£ / m	400 – 1500
Network capital costs per length (internal pipe)	£ / m	90 – 250
Domestic HIUs cost per dwelling	£ / dwelling	700 - 1400
Operation Cost	Unit	
Heat network maintenance cost	£ / MWh	0.3 – 0.9

Benchmarks for capital and operation cost.

Source: (UK Department of Energy & Climate Change, 2015)

2.4.4 Integration with CHESS SETUP

If waste heat is available at relatively high temperatures near to the site, the possibility of recovering this may be considered. A temperature of for example around 30°C or above could be upgraded for use in the building via a heat pump. A simple conceptual schematic of its integration is illustrated below.

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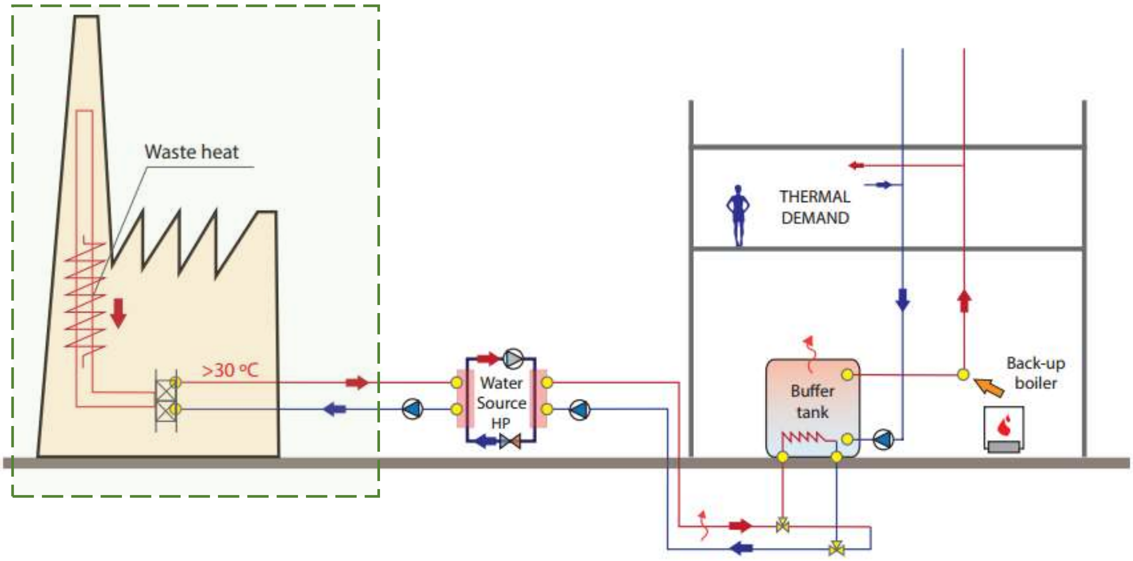

Conceptual schematic of CHESS SETUP with biomass boiler

The integration of waste heat will depend on the availability of one or more waste heat sources, ease of connection, temperatures and schedules of operation. The building may have a boiler as a back-up anyway in case there is a failure in supply.

In the case there is a waste heat source that can provide temperatures over 70ºC, the primary network could potentially be connected to the building via a heat exchanger to provide the heating and domestic hot water demands directly, without the need of a heat pump.

Preliminary energy calculations have been carried out to understand the outcome of the integration of this technology in the CHESS SETUP system and are presented in section '3. Simulated results'.

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2.5 Absorption cooling

2.5.1 Definition

Absorption cooling is a technology that uses heat to produce cooling, by taking advantage of material properties. Absorption chillers differ from the compression chillers in that the cooling effect is driven by heat energy, rather than mechanical energy (Office of Energy Effiency & Renewable Energy, 2013).

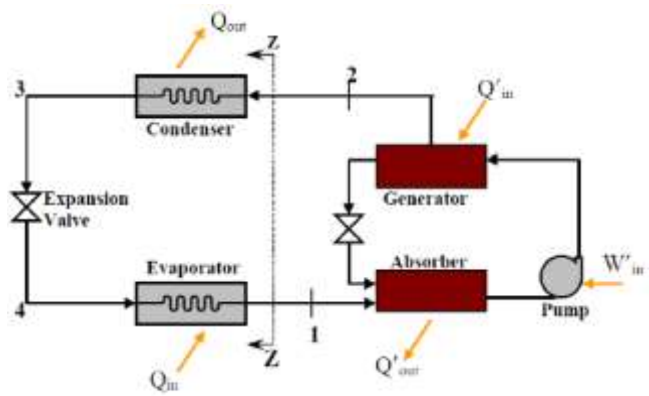
The heated fluid (liquid or vapour) temperature requirements for the operation of the absorption cooling system are 80°C - 160°C. At lower temperatures (60°C - 95°C), we talk about adsorption cooling.

A key factor to determine its application is the availability of surplus heat on site or nearby.

2.5.2 Types

Absorption

Absorption cooling relies on a thermo chemical "compressor." Two different fluids are used: a refrigerant and an absorbent. The fluids have high "affinity" for each other, which means one dissolves easily in the other. The refrigerant—usually water—can change phase easily between liquid and vapour and circulates through the system (CIBSE, 2009).



Basic Absorption Cooling System. Source: (CIBSE, 2009)

The high affinity of the refrigerant for the absorbent (usually lithium bromide or ammonia) causes the refrigerant to boil at a lower temperature and pressure than it normally would and transfers heat from one place to another. The cooling capacity of an absorption chiller ranges from 4,5 kW to 5 MW.

Absorption chillers are driven by hot water or vapour (80°C - 160°C) so may be applicable when there is a waste heat source available or for a CHP unit where there is surplus heat. Solar thermal could potentially be considered as a source of heat if enough solar energy can be harnessed at the required temperatures (CIBSE, 2009).

Adsorption

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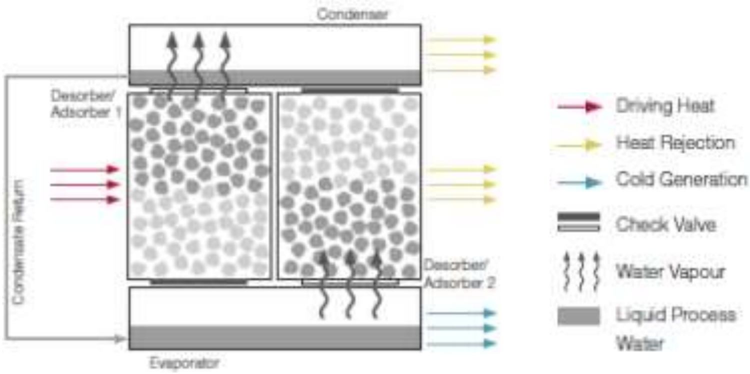
Commercially available adsorption chillers typically use water as the refrigerant and a desiccant like silica gel or zeolite as the adsorbent. The adsorption chiller consists of four main components: the condenser, the evaporator, and two desorbing/ adsorbing chambers. The typical cooling capacity of an adsorption chiller ranges from 5,5 to 500 KW (West Central Reseach & Outreach Center, 2006).



Basic Adsorption Cooling System. Source: (West Central Reseach & Outreach Center, 2006)

Adsorption chillers are driven by hot water at lower temperatures than absorption chillers (60°C - 95°C) which mean they could be used in combination with solar thermal panels.

2.5.3 Efficiencies, costs and market status

Efficiencies

The Coefficient of Performance-COP for an absorption system is defined as (FENERCOM, 2011):

$$COPc = \frac{Cooling\ Duty\ (kW)}{Generator\ Heating\ Duty\ (kW)}$$

In practice a typical COP for an absorption cycle in air conditioning would be about 0,7 compared to about 3,5 for a vapour compression system. It appears that absorption systems require about five times more energy than vapour compression, but of course, the energy for absorption is heat energy, not work (electrical) energy (CIBSE, 2009).

Heat energy is usually cheaper than electrical energy and when it is provided from sources such as waste heat, CHP or solar thermal, the use of absorption cooling may be feasible.

The main performance characteristics of absorption and adsorption systems are described and illustrated below (IDAE, 2011):

- The higher the heat supply temperature to the generator, the greater the COP.
- The higher the refrigerant evaporating temperature, the greater the COP.
- The lower the ambient temperature (air or water) for heat rejection, the greater the COP.

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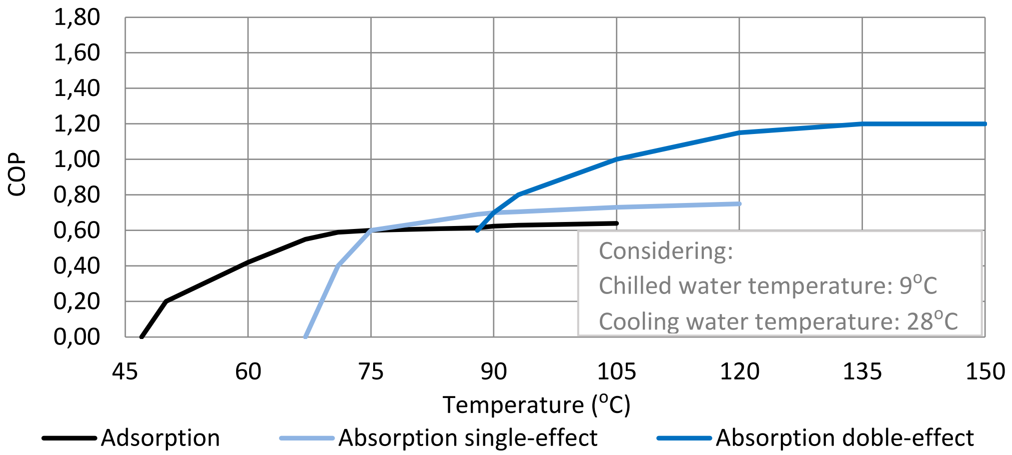

COP curves of absorption and adsorption chillers vs Hot water inlet(°C). Source: (Henning, 2007)

A potential selling point for absorption chillers is that they do not use global warming fluids such as HCFC, or HFC refrigerant fluids found in vapour compression systems. This is an important advantage of absorption units, noting that the environmental effects of refrigerant leakage on ozone depletion and global warming have to be analysed and compared to the effect on global warming of CO_2 generation from the energy production required to operate the system (CIBSE, 2009).

Absorption chillers are also marketed as environmentally friendly because their power input is not primarily electricity but heat. This would appear to produce lower CO_2 emissions than vapour compression systems, but will depend on the energy source for generating the electricity used in vapour compression systems. If the electricity generation for vapour compression is from fossil fuel, then overall CO_2 emissions may be lower from a gas powered absorption system. However, if greener electricity is produced, say from hydropower plants, then vapour compression systems will have lower CO_2 emissions than gas fired absorption. Each application would need to be considered with all the relevant data (CIBSE, 2009).

Considering primary energy requirements, today's absorption systems could be effectively applied for use with integrated energy systems such as waste heat or Combined Heat and Power (CHP).

The required temperatures for the operation of adsorption chillers may mean they can be used in combination with solar thermal panels although the intermittency of heat generation has to be taken into account. When looking at hybrid solar panels (solar thermal and photovoltaic, PVT) however, the temperatures produced by these are typically lower than the required for operating the adsorption chillers and its incorporation would not be considered appropriate.

A summary table of the main characteristics to be considered when looking at absorption/adsorption cooling is shown below.

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Process	Absorption		Adsorption
Steps	Simple effect	Double effect	Simple effect
Absorbent - Refrigerant	LiBr – H_2O		Silica gel – H_2O
	H_2O - Ammoniac		
Generator Temp.	80 °C - 110 °C	140 °C - 160 °C	60 °C - 95 °C
Feedstock	Hot Water	Hot Water o Steam	Hot Water
COP	0,6 – 0,8	0,9 – 1,2	0,4 – 0,7
Capacity	<35 kW	>100 kW	<50 kW
	35 kW– 100 kW		50 kW– 350 kW
	>100 kW		70 – 1.220 kW
Solar Collectors Utilizable	Flat plate	CPC (Cylindrical Parabolic Collectors)	Flat plate
	Vacuum tubes		Vacuum tubes
	Flat plate with concentrator		Flat plate with concentrator

Comparison of the characteristics of the processes. Based on (IDAE, 2011)

Research of commercially available products has been carried out and a summary table is shown below.

Company	SolarNext	SorTech	Sonnenklima
Model	Chillii PSC10	ACS 08	Suninverse 10
Technology	Absorption	Adsorption	Absorption
Working pair	NH_3/H_2O	H_2O/Silica gel	H_2O / LiBr
Cooling capacity	10 kW	8 kW	10 kW
Heating Temp.	85 / 78 °C	72/65 °C	95 / 75 °C
Cold water Temp.	12 / 6 °C	18 / 15 °C	12 / 6 °C
COP thermal	0.63	0.60	0.78
Dimensions L x D x H (m)	0.8 x 0.6 x 2.2	0.8 x 1.1 x 1.0	1.1 x 0.8 x 2.0
	 (source: SolarNext)	 (source: SorTech)	 (source:Sonnenklima)
Weight (kg)	350	295	550
Power (W)	300	57	120

Example of commercially available absorption/adsorption technologies
Sources: (SolarNEXT, 2017), (SorTech, 2017), (Sonnenklima, 2017)

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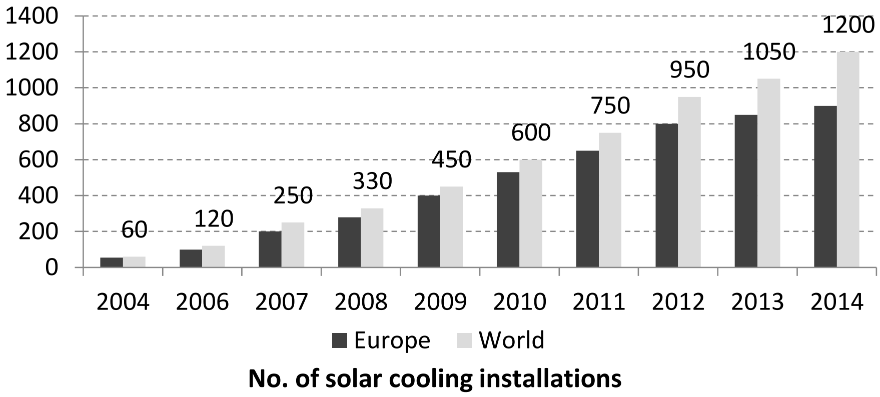
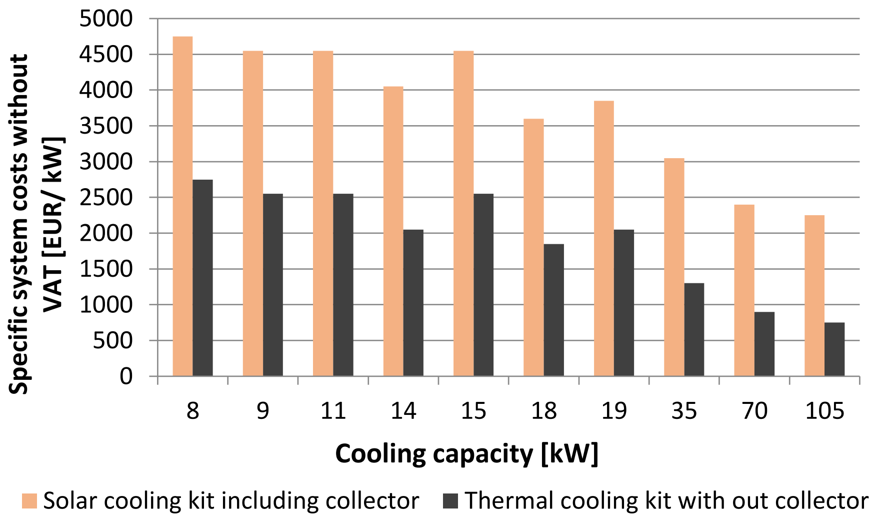
Costs

The solar cooling market has grown in the last 8 years between 40 and 70% per year (see graph below). The total number of installations as illustrated in the graph below shows that the solar cooling market is still a niche market (Mauthner F., 2016).



Market development of small to large-scale solar cooling systems. Source: (Mauthner F., 2016)

Solar cooling systems are often not yet economically viable. Long running hours of the adsorption chiller are crucial for the efficiency of solar cooling. Within the residential sector of Central Europe there are only about 50 to 200 cooling hours, in the southern Mediterranean around 1.000 cooling hours and in South East Asia 2500 cooling hours. The specific investment costs of solar cooling in the power range of 8 KW to 105 KW cooling capacity (no installation cost and cold distribution included) is between 4.500 EUR/KW for small-scale kits and 2250 EUR/KW for medium-scale kits (Mugnier, 2013).



Specific total costs of solar cooling kits (2012). Source: (Mugnier, 2013)

As shown in the table above, the cost share for the solar thermal collectors is about 45% to 65% of the total investment costs for the small-scale and medium/large-scale capacity range, respectively. Since 2007, a cost reduction of about 50% was realized within the last six years, because of the further standardization of the solar cooling kits (Kühn, 2013).

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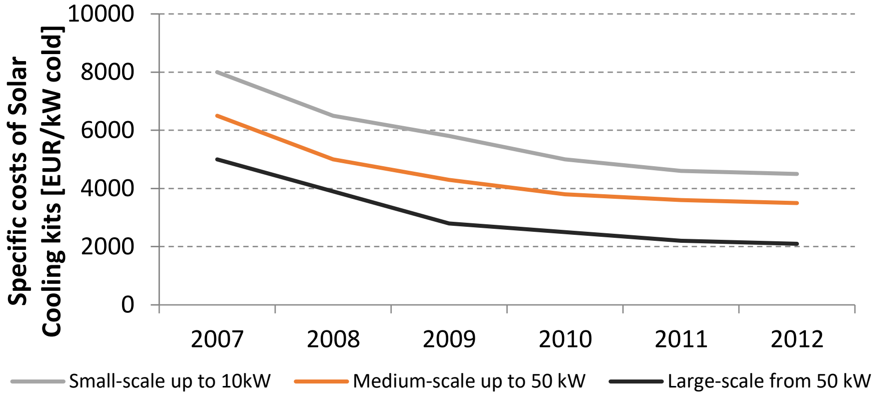
The costs of solar cooling kits has seen a decrease in the last few years as shown in the graph below and are becoming more attractive. However, the viability of the system should be analysed in detail also considering the maintenance costs in each case.



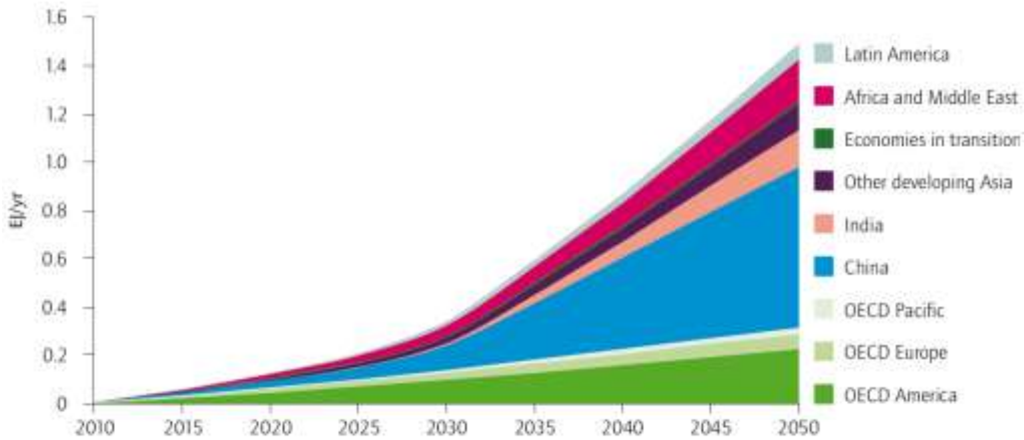
Specific total costs of solar cooling kits Source: (Kühn, 2013)

Market status

When looking at solar cooling, its implementation and market development varies considerably from country to country. Low fuel prices, combined with the still high costs and complexity of these cooling systems are a barrier for their installation. Demand for solar thermal-driven air conditioning systems has also been tempered by rapidly falling costs of solar PV systems in conjunction with conventional air conditioning systems.

The global solar cooling industry followed two divergent trends in 2015: a shift towards large-scale systems with a better performance and the development of plug-and-play system kits with cooling capacities below 5 kW. Among the absorption/adsorption chiller manufacturers worldwide, several European manufacturers launched or developed a new generation of compact and easier to install solar cooling system kits up to 5 kW in size (REN21, 2016).

The industry is still not extended but is expected to grow substantially in the future as shown in the graph below by the International Energy Agency (IEA, 2012). This will certainly depend on the associated costs of incorporating this technology.



Roadmap vision for solar cooling. Source: (IEA, 2012)

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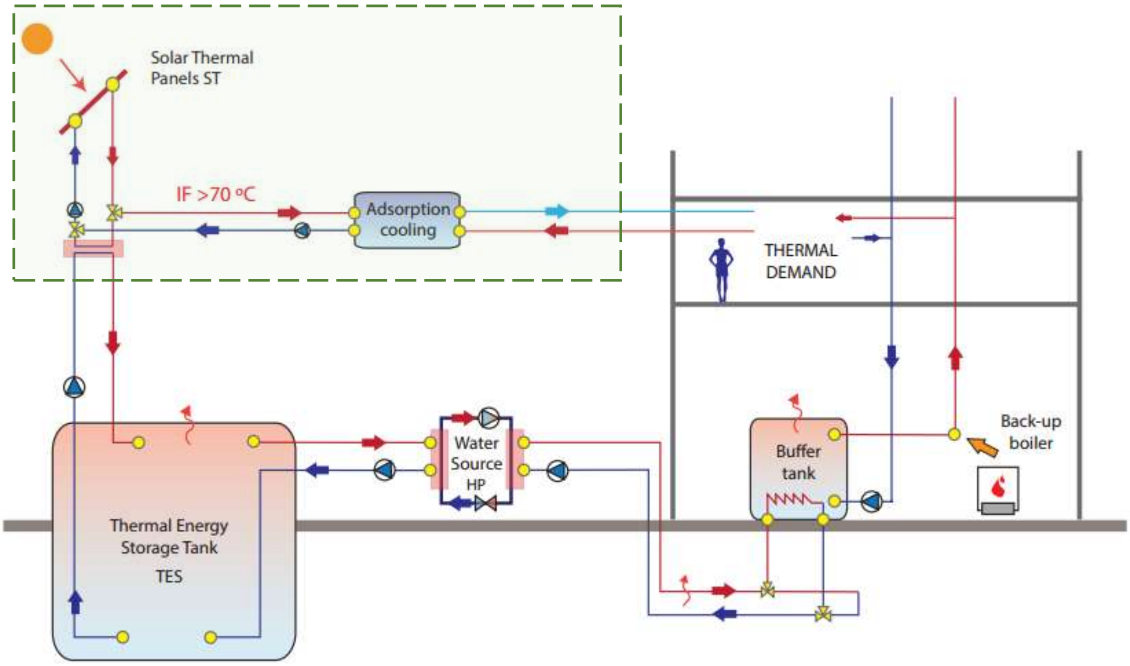
2.5.4 Integration with CHESS SETUP

In the case there is a significant cooling demand on site or nearby, the possibility of incorporating an adsorption chiller may be considered. In this case, as described earlier in this chapter, the CHESS SETUP system would need to be configured with solar thermal panels (not hybrid PVT) in order to achieve higher temperatures that allow the adsorption chiller to run.

The feasibility of integrating this technology will depend on the existence of cooling demand mostly at the time as there is thermal production on the solar panels, or may even be served by the thermal storage tank if there is excess energy (possibly in summer if the tank is not too large).

A simple conceptual schematic of its integration is illustrated below:



Conceptual schematic of CHESS SETUP with adsorption cooling

In this case, the rest of the system in terms of covering the heating demand would remain the same as per the original configuration (with the use of solar thermal panels, not PVT).

Careful considerations need to be taken when designing a system such as this one because problems such as discontinuity in thermal production from the solar panels may occur. The inclusion of adsorption or absorption chillers may be more suitable if the source of heat is an excess coming from waste heat or combined heat and power (CHP) for example.

Preliminary energy calculations have been carried out to understand the outcome of the integration of this technology in the CHESS SETUP system and are presented in section '3. Simulated results'.

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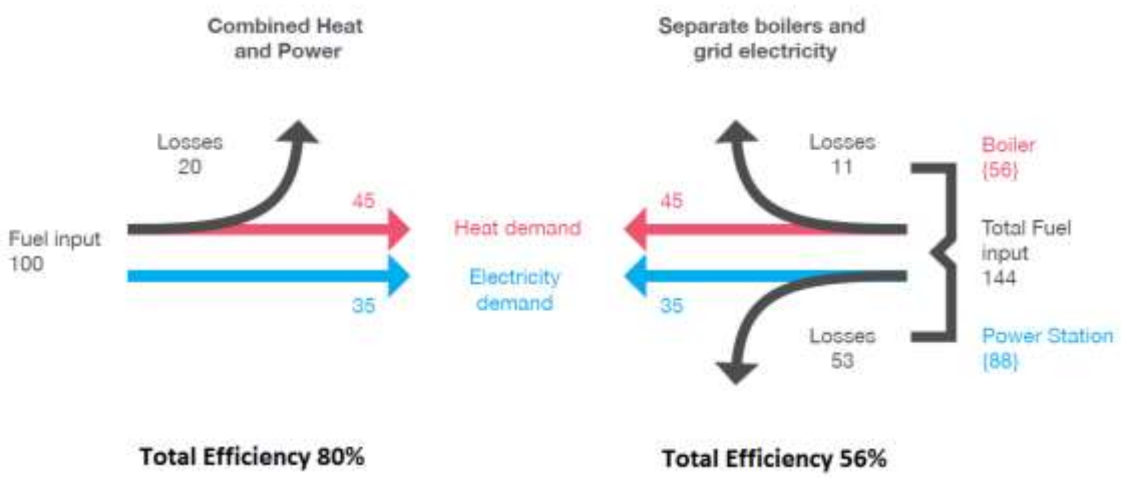
2.6 Combined Heat and Power (CHP)

2.6.1 Definition

Combined Heat and Power (CHP) or Cogeneration is the simultaneous production of electricity and heat.

CHP installations can typically convert around 70-90% of the energy in the fuel into electrical power and useful heat. This compares very favourably with conventional power and heat generation plants which may have an energy efficiency of around 56% as shown in the illustration below (Carbon Trust, 2004).



Efficiency of Combined Heat and Power. Source: (GLA, 2013) based on (Carbon Trust, 2004)

CHP can be designed at different scales, from an individual building, an industrial factory or a town/city served by district heating/cooling.

Therefore, cogeneration can offer significant energy savings when compared against the supply of electricity and heat from conventional power stations and boilers.

2.6.2 Configuration

There are different CHP engine types and can operate on a variety of fuels such as natural gas, biomass and biogas (EPA, 2015). The fuel is burned to run the engine with the aim of producing electricity, and heat is recovered as a sub-product. See a CHP unit diagram below.

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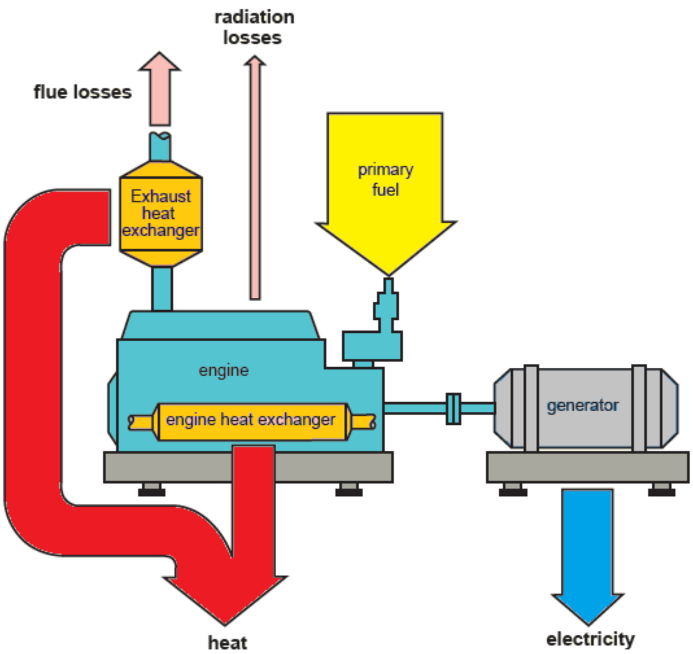
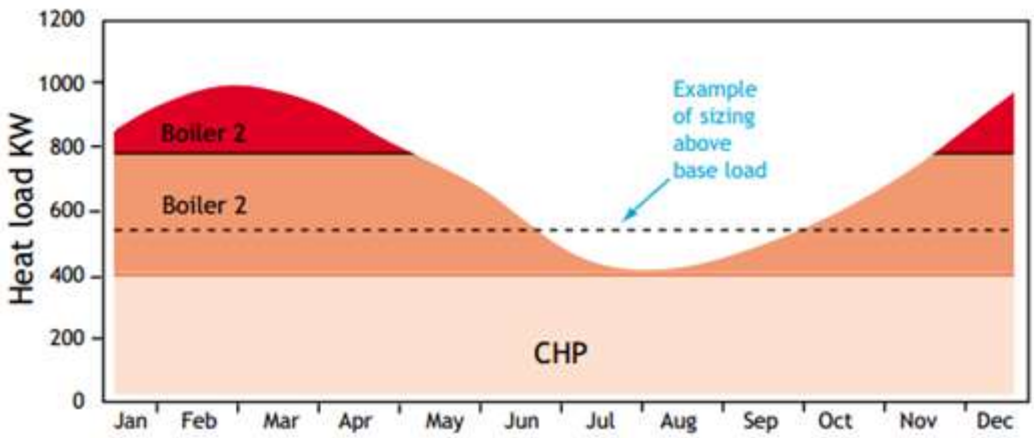


CHP System Diagram. Source: (Carbon Trust, 2004), (BRE, 1996)

Most small-scale units supply low temperature hot water (LTHW), around 80-90°C, and can consequently be directly connected to standard building heating systems. Units are also can offer medium temperature hot water (MTHW) at 90-120°C, which could be useful for district heating applications (Carbon Trust, 2004), (BRE, 1996).

CHP is usually not considered in isolation, but may be integrated with other energy systems on site. It is unlikely that all the power and heat requirements will be supplied by the CHP plant. Combined Heat and Power units are frequently designed to meet the base load therefore reducing considerably the required boiler capacity, which is utilized to meet peak heat demands (see graph below).



CHP unit sized to meet base load. Source: (Carbon Trust, 2004)

In some cases the heat generated by the CHP unit may be used for purposes other than heating or domestic hot water. For sites with significant cooling loads, absorption cooling can offer an appropriate demand for heat. This is known as trigeneration, which encompasses the generation of heating, cooling and electricity. Such opportunities or the possibility of exporting heat nearby

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for increasing the utilisation of the CHP unit should be considered when investigating the suitability of CHP (as shown in the dotted line in the graph above), as it can help to increase the hours of operation of the CHP (Carbon Trust, 2004), (BRE, 1996).

As a basic rule of thumb for CHP design, there should be sufficient heating demand allowing the CHP to run for more than 4000-5000 hours per year in order to obtain profitability of the system (Carbon Trust, 2004), (BRE, 1996).

2.6.3 Efficiencies, cost and market status

Efficiencies

The total system efficiency of a CHP system is the sum of the net useful electric output and net useful thermal output divided by the total fuel energy input (EPA, 2015).

The illustration below is an example of the typical efficiencies that can be found in a CHP unit. This has a 33% electrical and 50% thermal efficiency resulting in a total 83% efficiency, therefore a 1.52 heat to power ratio.

The heat to power ratio usually tends to increase for small units, up to around 2 (double thermal output), and decrease as the unit size increases (getting close to matching electric and thermal production).

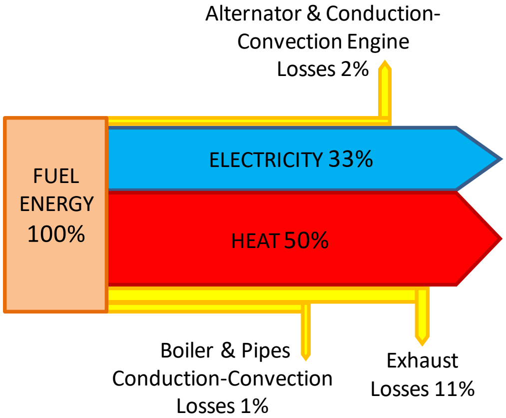

Diagram of Cogeneration efficiency. Source: (Comunidad de Madrid, 2010)

Costs

Whilst the capital and installation costs of a CHP unit are significantly higher than for conventional boiler, CHP can yield very considerable savings in running costs (Carbon Trust, 2004), (BRE, 1996).

The costs of commercial CHP units typically range between £ 800-1200 per kW (electric) for small scale units < 1 MW. The cost per kW decreases as the size of the unit increases as shown in the graph below (Carbon Trust, 2004), (UK Department of Energy & Climate Change, 2008).

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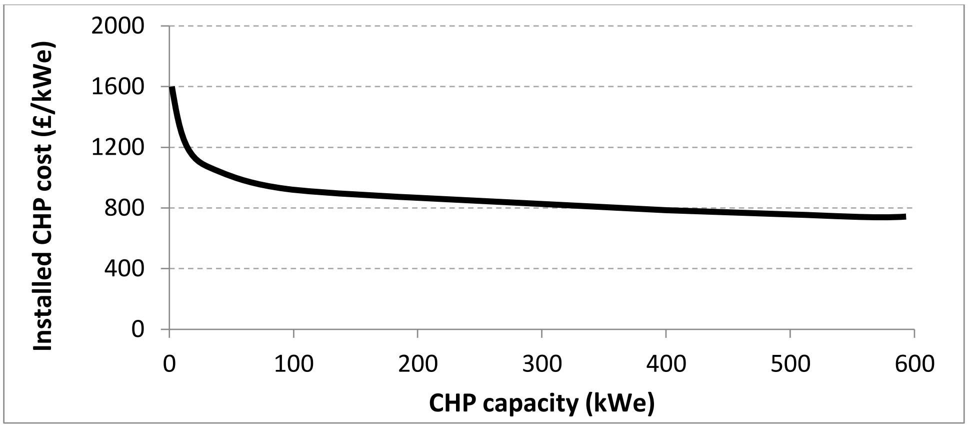
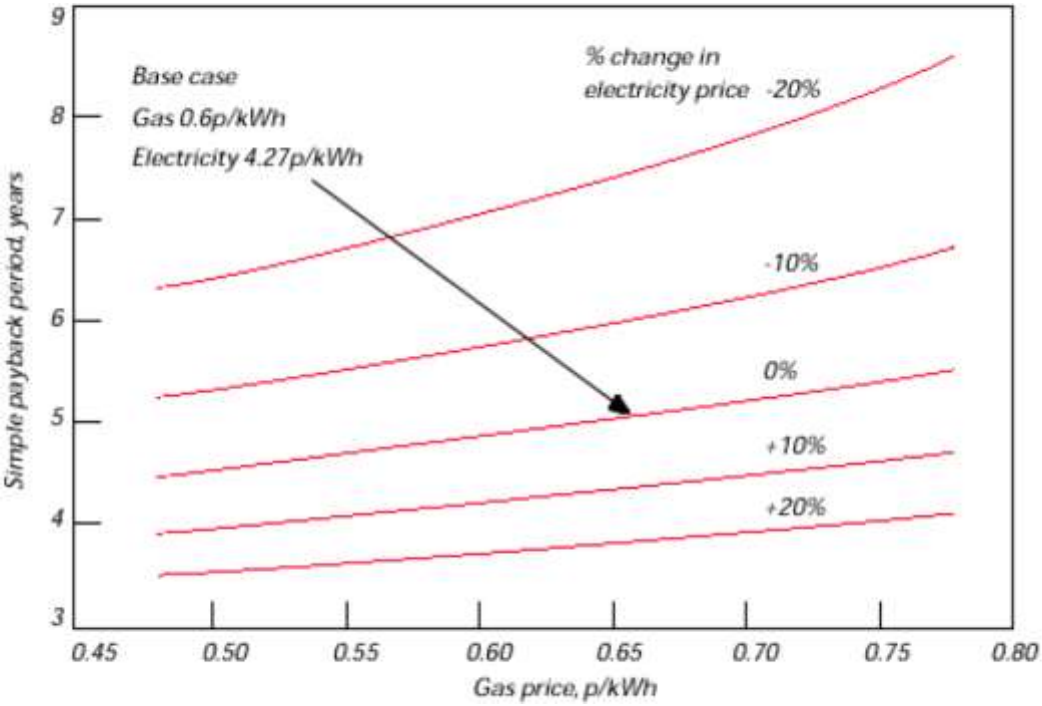


Typical small scale CHP installed costs. Based on: (Carbon Trust, 2004)

Non-fuel operation and maintenance (O&M) costs typically include routine inspections, scheduled overhauls, preventive maintenance, and operating labor. These typically range between 0.35-0.8 British pence/kWh (UK Department of Energy & Climate Change, 2008).

Considering that electricity is significantly more expensive than primary fuels, the economics of CHP schemes are, therefore, much more sensitive to changes in the unit price of electricity. At current typical prices, a 10% increase in electricity prices improves the payback on a typical CHP scheme by 10-15%, while, for comparison, a 10% decrease in gas prices improves the payback by 3-5% as shown in the graph below. The combined effect of both changes would be to improve the simple payback by between 12% and 18% (European Commission, 2001).



Note: The graph provides an indication of the likely effect of different energy prices on a specific CHP project payback period (*p* stands for British pennies).

Effect of energy prices on project payback. Source: (European Commission, 2001)

Market Status

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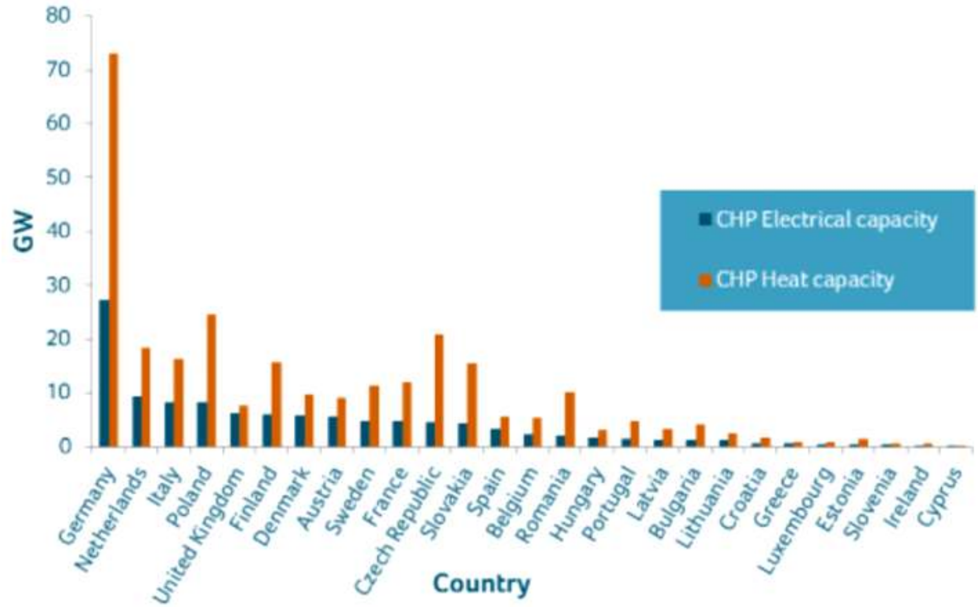
The EU member states have an important capacity in CHP generation, principally for renovating district heating plans and improving them to incorporate modern CHP systems where before only heat was distributed, in places with existing large district heating infrastructure (COGEN Europe, 2017). Installed CHP Capacity by UE country is shown below.



Installed CHP capacity by UE country.

Source: (COGEN Europe, 2017) (Based on Eurostat Data, 2015)

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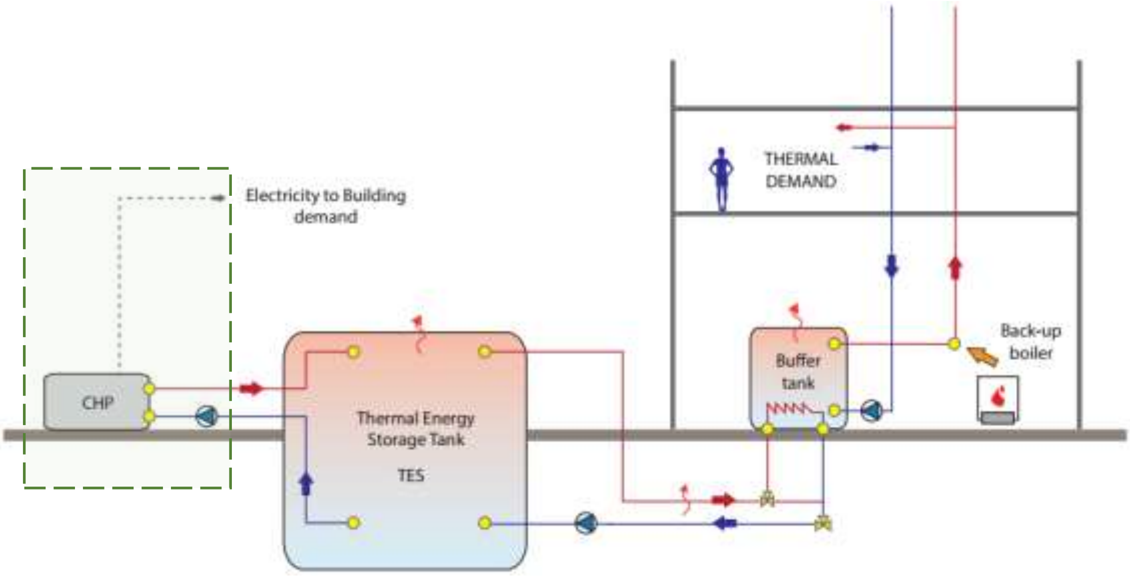
2.6.4 Integration with CHESS SETUP

Installing a CHP would result in an important variation to the CHESS SETUP system as the production element varies and no water source heat pump would be required to upgrade the incoming temperature from the thermal store. The CHP unit would deliver temperatures that are already as per the final demand requirements.

As mentioned earlier in the chapter, the CHP unit could be sized to meet the base load (typically the domestic hot water or swimming pool demand) to be able to operate for most of the year and the rest would be done by the back-up boilers.

The combined heat and power unit could be sized over this base load in order to generate more electricity and cover a larger part of the total thermal demand in the case any excess heat produced in summer can be exported nearby or an absorption chiller is installed (trigeneration).

A simple conceptual schematic of its integration is illustrated below.



Conceptual schematic of the incorporation of CHP

Considering the above, it is thought that the incorporation of CHP does not fit properly in the CHESS SETUP system and would become a different system overall. Therefore, energy calculations have not been carried out in this case as it falls out of the objective of this project.

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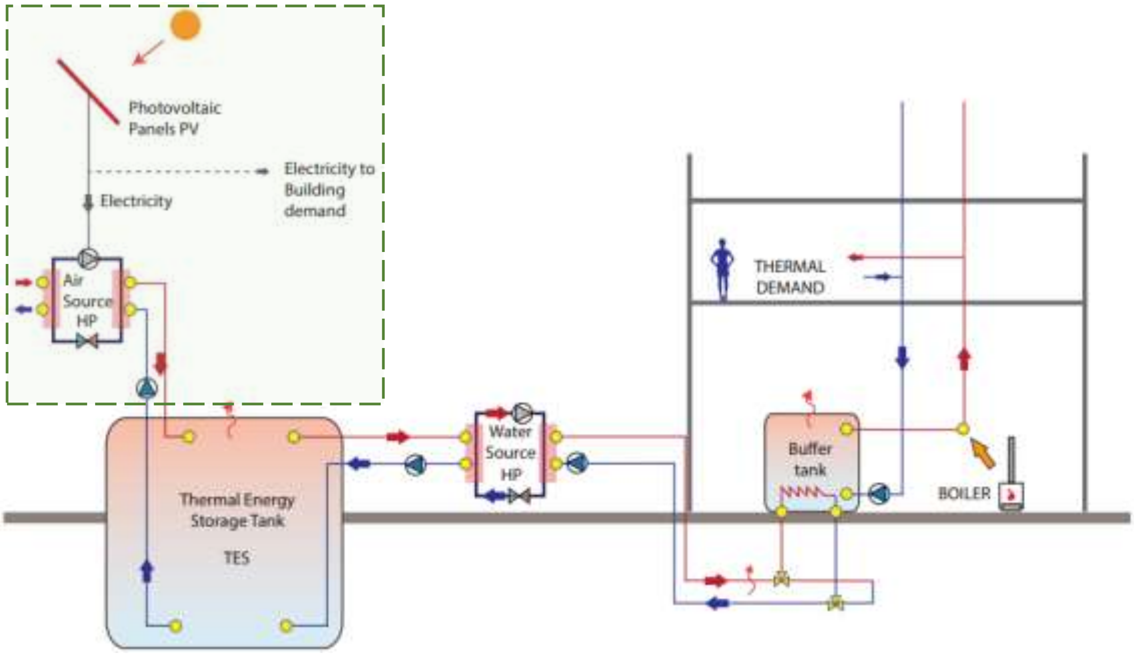
2.7 Photovoltaic panels and Air Source Heat Pump

2.7.1 Integration with CHESS SETUP

An additional variance to the CHESS SETUP system has been considered, which consists on the installation of photovoltaic (PV) panels (instead of thermal only or hybrid panels) and an air source heat pump (ASHP). This would mean modifying the energy production side of the system and maintain the energy storage element as well as the highly efficient water source heat pump and a boiler as back-up.

A simple conceptual schematic of its integration is illustrated below.



Conceptual schematic of CHESS SETUP with biomass boiler

By incorporating PV and ASHP, thermal energy would only be produced by the air source heat pump when required to heat up the thermal storage tank. The electricity produced by the photovoltaic panels would be used to feed this ASHP and any excess during the year and especially in summer could be used to feed any other electric demands of the building such as cooling, lighting and equipment.

The ASHP could also be used taking benefit of times when the electricity from the grid is inexpensive or even when there might be a surplus production by nearby renewable sources, to heat up the thermal storage tank.

In sites with limited possibilities for the incorporation of large thermal storage tanks and/or very low demand for heat in summer, this option may mean not having to waste any of the energy produced in summer (by the original PVT) and minimized maintenance.

Preliminary energy calculations have been carried out to understand the outcome of the integration of this technology in the CHESS SETUP system and are presented in section '3. Simulated results'.

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3. Energy modelling results

The integration of the different energy sources and technologies with the CHESS SETUP system has been analyzed performing preliminary energy calculations to understand the potential energy and CO_2 savings that could be achieved.

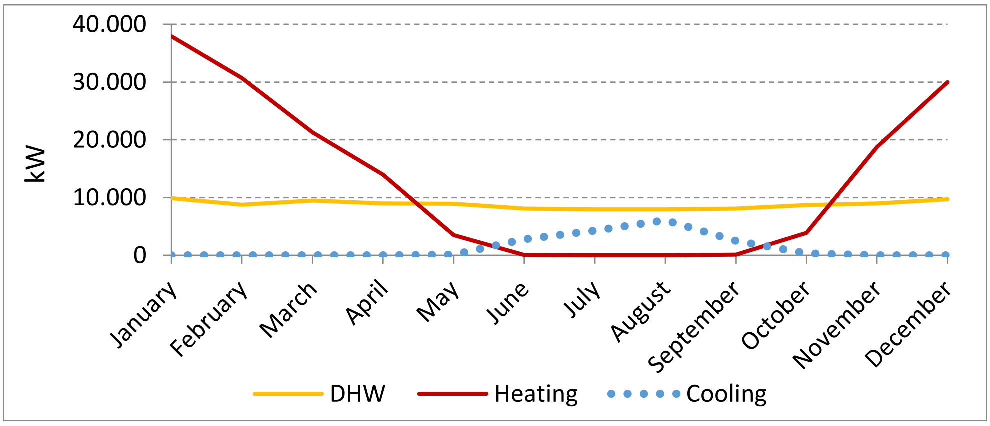
In order to increase the replicability of the system, the calculations have been performed for a reference residential block of flats as per previous deliverables of this project (such as D 3.2 and D 3.3), in three different locations (Barcelona, Madrid and London) to represent a coastal Mediterranean, continental and an oceanic climates.

Reference parameters

The reference building consists of 100 flats and with an area of 80 m^2 per dwelling and the following energy demands, which mainly show a relatively constant DHW load and space heating peaks in winter.

Location/ Energy demands	Barcelona	Madrid	London
Domestic Hot Water (DHW) (kWh/yr)	105,513	107,224	107,224
Heating (kWh/yr)	160,000	253,931	361,453
Cooling (kWh/yr)	16,000	28,099	2,116
Electricity (kWh/yr)	272,000	272,000	272,000

Annual energy demands



Thermal energy demands profile in Barcelona

With the purpose of comparing the different options that have been analysed, a baseline scenario has been generated considering the system is all served by gas boilers with a 90% efficiency.

Note that all cases have been sized according to two main limitations when incorporating the CHESS SETUP system, which are the physical space available for incorporating a large thermal

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storage tank (which has been set to a maximum of 1,200 m^3) and the available area for solar panels (which has been set to a maximum of 300 m^3).

It is also important to note the carbon dioxide factors and fuel prices will vary depending on location, in the case of Spain are the following.

Spain	Electricity	Gas	Biomass
CO_2 emissions factor ($kgCO_2$/kWh):	0.357	0.252	0.018
Cost (€/kWh):	0.239	0.066	0.038

Sources: (IDAE, 2014) (IDAE, 2007), (VaasaETT Ltd, Energie-Control Austria, & MEKH, 2016)

Note that this will vary from country to country and it is an important factor when considering the integration of the CHESS SETUP variances in different countries. For example in the UK, these parameters are as per the following.

United Kingdom	Electricity	Gas	Biomass
CO_2 emissions factor ($kgCO_2$/kWh):	0.519	0.216	0.039
Cost (€/kWh):	0.191	0.0527	0.020

Sources: (BRE, 2014) (VaasaETT Ltd, Energie-Control Austria, & MEKH, 2016)

The costs of the incorporation of the energy sources and technologies analyzed can vary significantly depending on the specific project and has therefore not been included in this section. Especially for existing buildings that may need to be refurbished to accommodate the new elements. Please refer to the research shown in the previous section for guidance on economic considerations.

The energy calculations for each technology are shown in the following tables for the reference case located in Barcelona, illustrating the main configuration parameters, thermal demand covered by the CHESS SETUP, temperature in the thermal storage tank and energy and CO_2 savings.

Note the following legend that will be used in the tables below:

Energy CO_2

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SOLAR HYBRID PANELS (PVT)

System configuration parameters:

PVT panels: 265 m^2. Seasonal efficiency = 45% thermal; 15% electrical

Thermal storage volume: 1,200 m^3. Design temperatures in tank: Min. 20 ºC; Max. 50 ºC

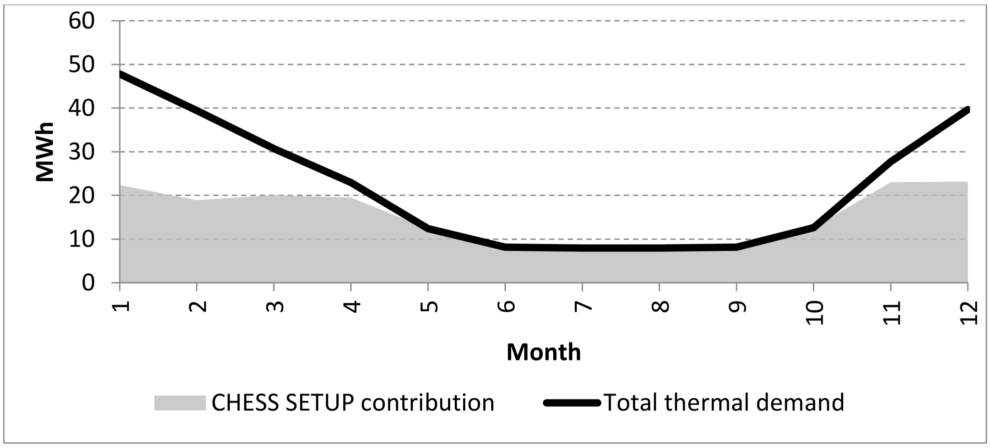
Water source heat pump: Coefficient of Performance (COP) = 5

Back-up: Gas boiler. Efficiency = 90%

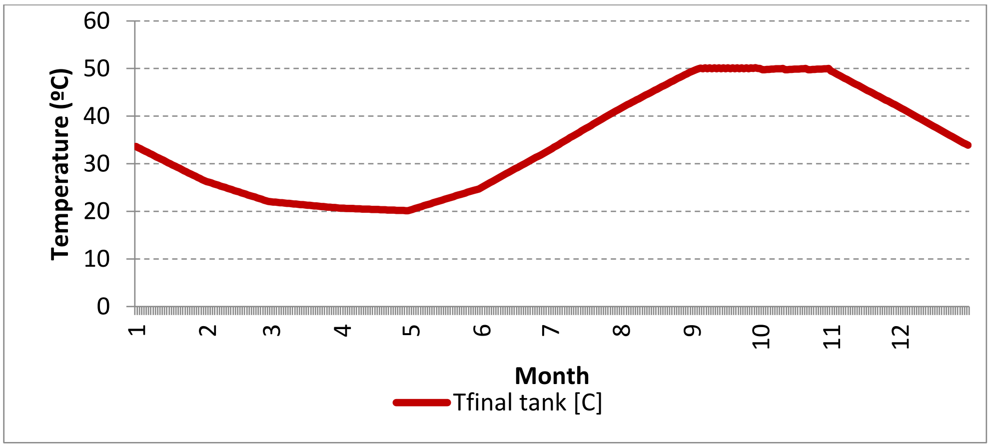
Cooling demand not considered

Results:

Thermal demand covered by CHESS SETUP	69%



CHESS SETUP contribution to thermal demand



Temperature in thermal storage tank

Savings		CO_2
Thermal	57 %	52 %
Total	41 %	36 %

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BIOMASS BOILER

System configuration parameters:

PVT panels: 180 m^2. Seasonal efficiency = 45% thermal; 15% electrical

Thermal storage volume: 700 m^3. Design temperatures in tank: Min. 20 ºC; Max. 50 ºC

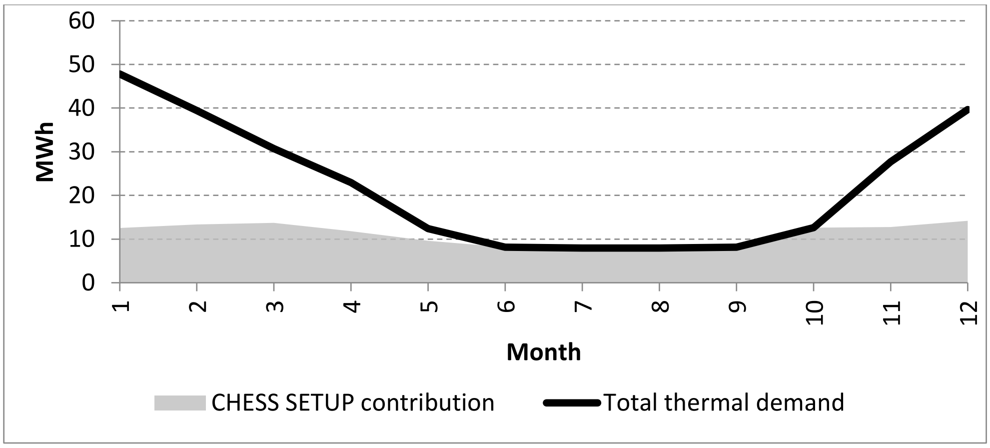
Water source heat pump: Coefficient of Performance (COP) = 5

Back-up: Biomass boiler to meet 50% of the demand. Efficiency = 90%

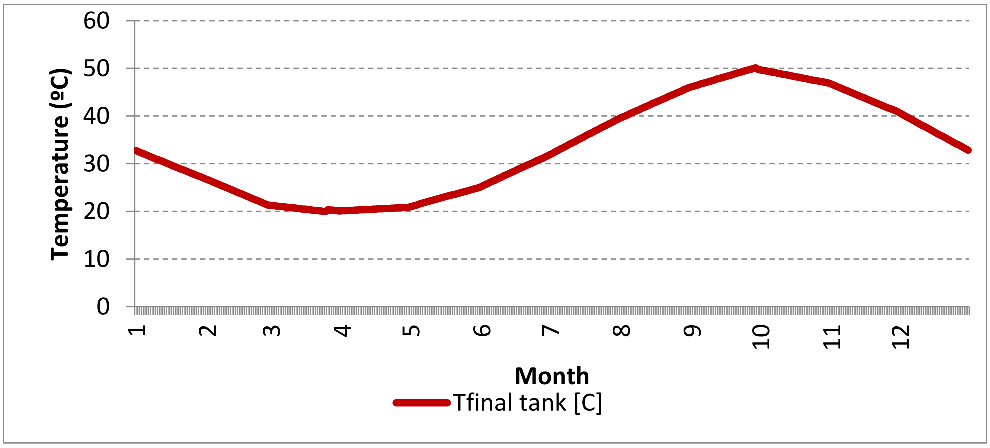
Cooling demand not considered

Results:

Thermal demand covered by CHESS SETUP	50%



CHESS SETUP contribution to thermal demand



Temperature in thermal storage tank

Savings		CO_2
Thermal	41 %	84 %
Total	29 %	45 %

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GEOTHERMAL

System configuration parameters:

PVT panels: 300 m^2. Seasonal efficiency = 45% thermal; 15% electrical

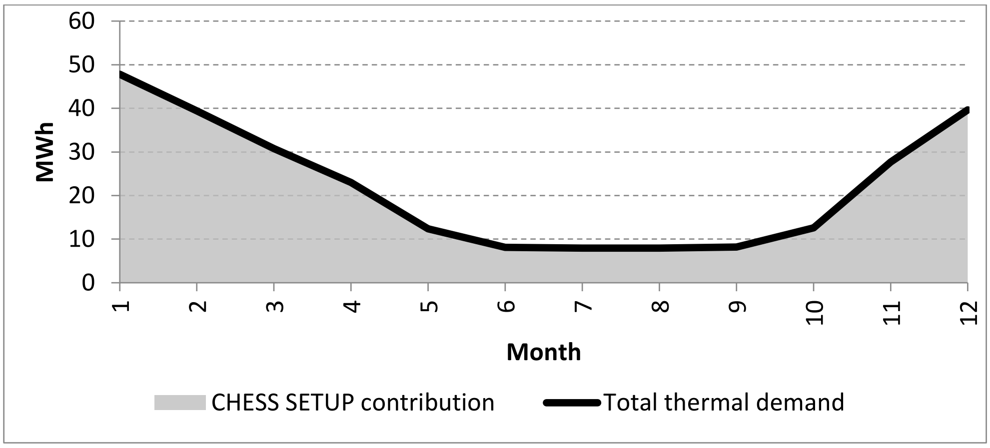
Thermal storage volume: 6,000 m^3 (affected soil volume)

Water source heat pump: Coefficient of Performance (COP) = 4

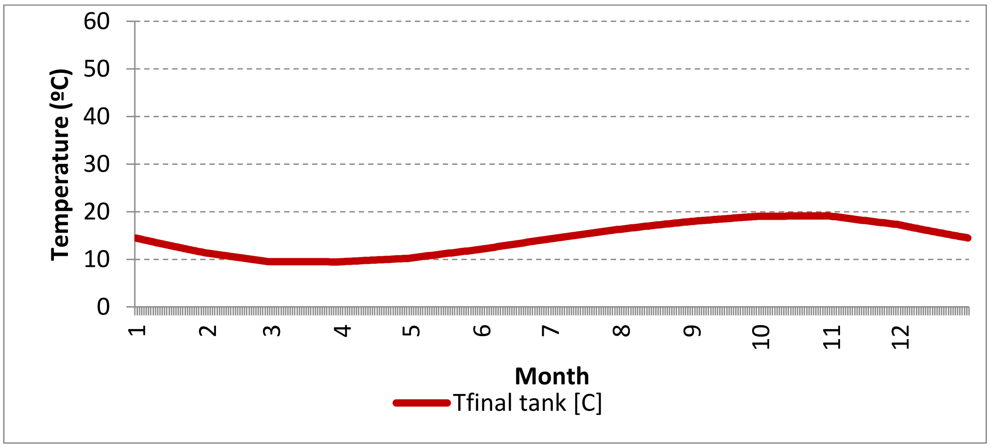
Cooling demand not considered

Results:

Thermal demand covered by CHESS SETUP	100%



CHESS SETUP contribution to thermal demand



Temperature in thermal storage tank

Savings		CO_2
Thermal	78 %	68 %
Total	53 %	44 %

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WASTE HEAT

System configuration parameters:

Incoming waste heat at 30 ºC constantly (no interruptions in supply)

Thermal store not consider important with a constant feed, but could be added otherwise

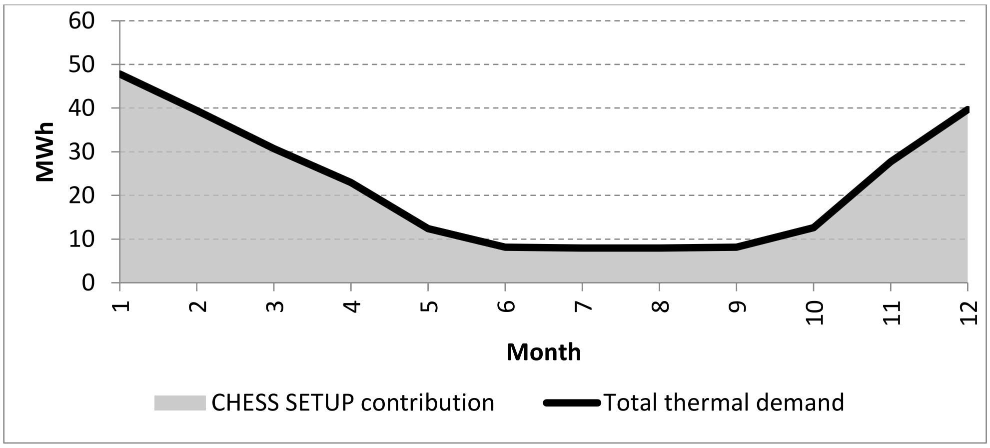
Water source heat pump: Coefficient of Performance (COP) = 5

Back-up: Gas boiler. Efficiency = 90%

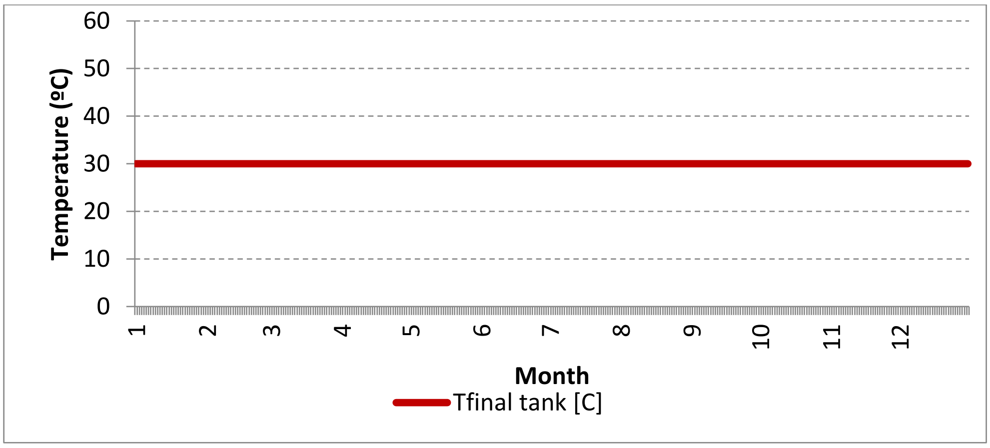
Cooling demand not considered

Results:

Thermal demand covered by CHESS SETUP	100%



CHESS SETUP contribution to thermal demand



Waste heat incoming temperature

Savings		CO_2
Thermal	82 %	75 %
Total	43 %	32 %

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ADSORPTION COOLING

System configuration parameters:

Solar thermal (ST) panels: 300 m^2. Seasonal efficiency = 55%

Thermal storage volume: 1,200 m^3. Design temperatures in tank: Min. 20 ºC; Max. 90 ºC

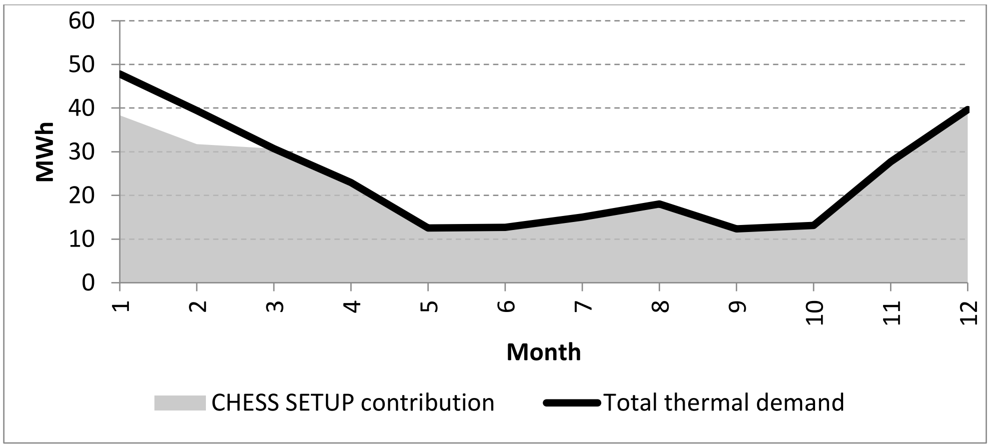
Water source heat pump: Coefficient of Performance (COP) = 5

Back-up: Gas boiler. Efficiency = 90%

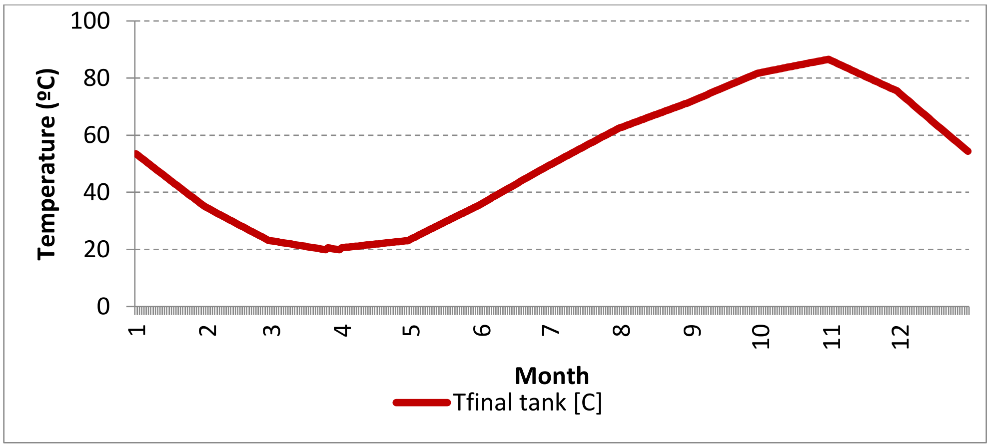
Adsorption chiller efficiency = 0.6 (60%).

Results:

Thermal demand covered by CHESS SETUP	94%



CHESS SETUP contribution to thermal demand



Temperature in thermal storage tank

Savings		CO_2
Thermal	65 %	54 %
Total	34 %	24 %

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PHOTOVOLTAIC (PV) PANELS & AIR SOURCE HEAT PUMP (ASHP)

System configuration parameters:

Photovoltaic (PV) panels: 300 m^2. Efficiency = 15%

Thermal storage volume: 200 m^3. Design temperatures in tank: Min. 20 ºC; Max. 30 ºC

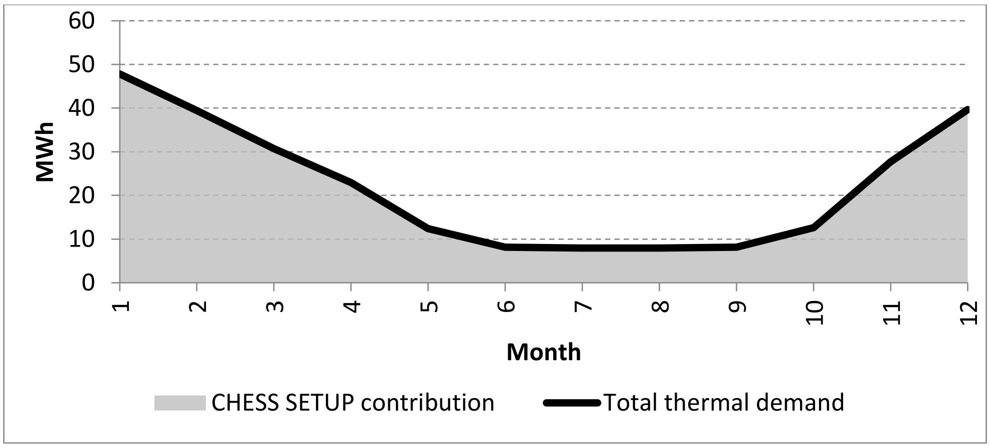
Air source heat pump: COP = 3.5. Water source heat pump: COP = 5

Back-up: Gas boiler. Efficiency = 90%

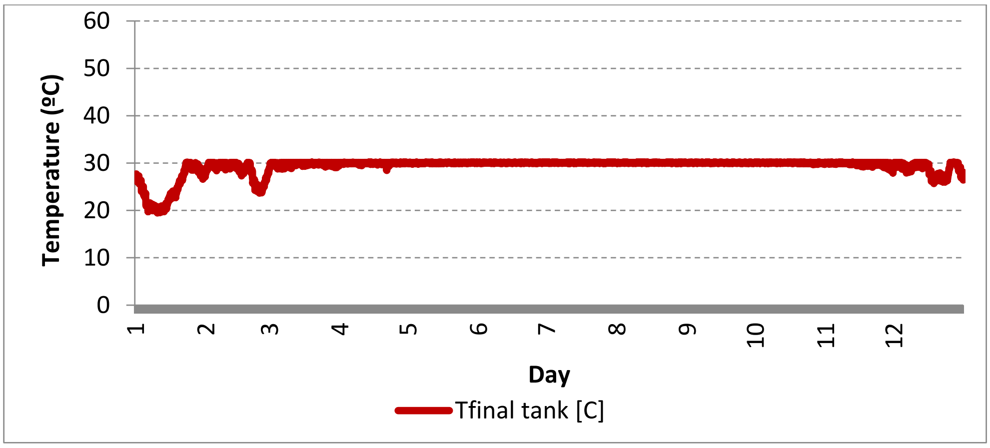
Cooling demand not considered

Results:

Thermal demand covered by CHESS SETUP	100%



CHESS SETUP contribution to thermal demand



Temperature in thermal storage tank

Savings		CO_2
Thermal	57 %	40 %
Total	42 %	32 %

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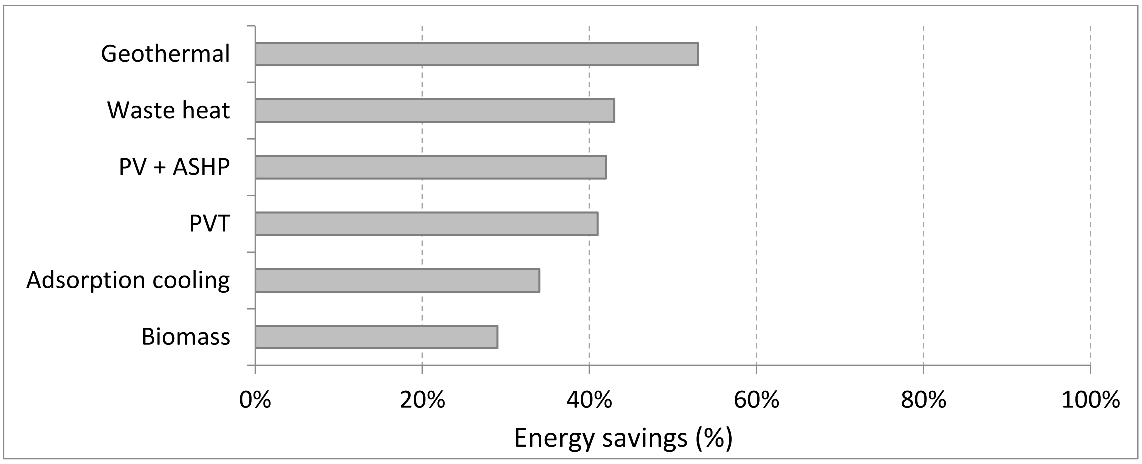
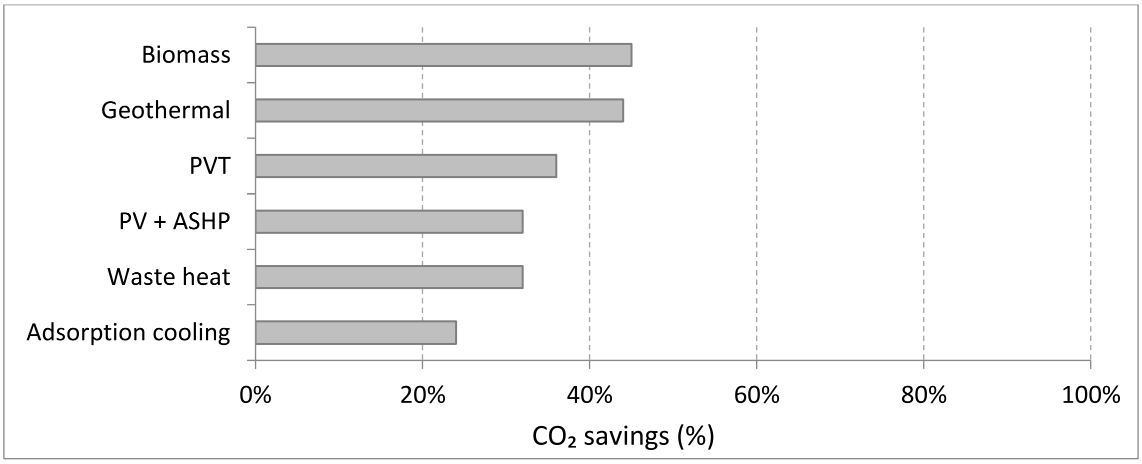
A comparison of the different options shown above is illustrated here.



Total energy savings (%)



Total CO_2 savings (%)

The graphs above show that solar hybrid panels (PVT) in conjunction with geothermal can provide the most energy savings considering the aforementioned configuration parameters. In any case, all options show over 25% potential energy savings.

Note that waste heat provides the greatest saving when only taking into account the thermal side of the demand (around 80% savings).

In terms of carbon dioxide emissions, biomass currently has a very low CO_2 emission factor which means that the option of incorporating a biomass boiler would have a very beneficial impact in this matter even when designed only to meet half of the thermal demand. However, this needs to be read in conjunction with the previous chapter on biomass and take all considerations into account.

It is important to keep in mind that variances in the operation of the building, energy demands, energy prices and CO_2 emissions factors will have a significant impact on the results shown above so each project should be studied in detail.

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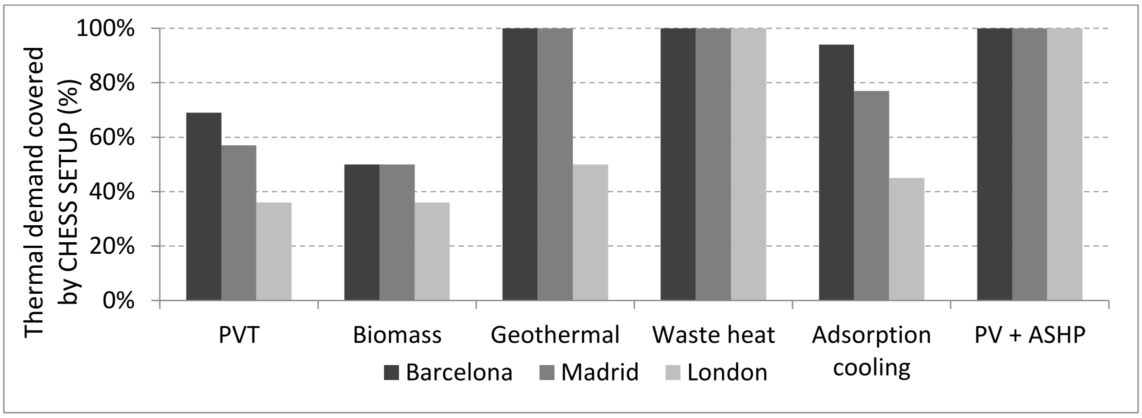
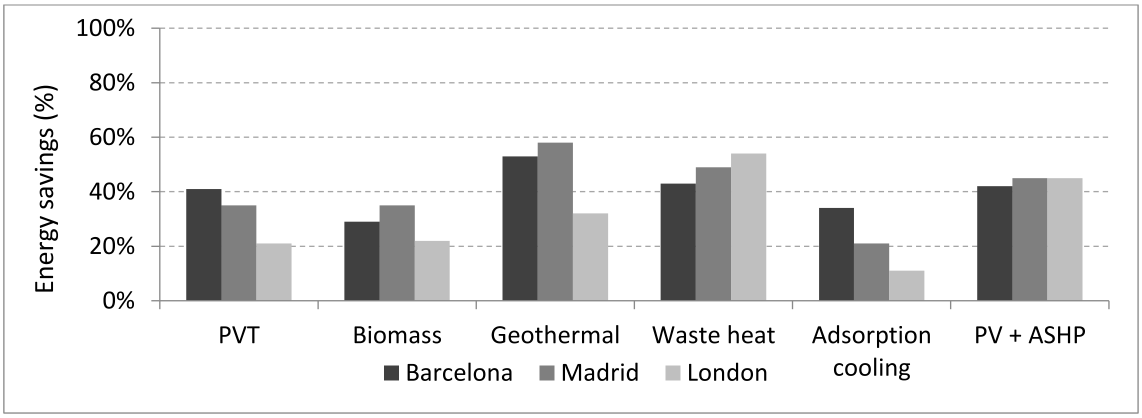
Replicability in other climates

As mentioned earlier, as well as the reference case building in Barcelona, the integration of the analyzed energy sources and technologies has been tested in London and Madrid.

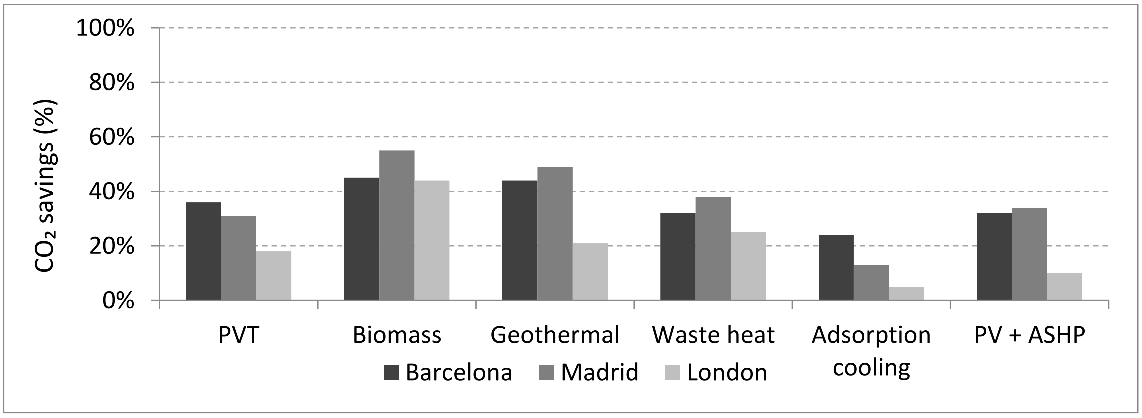
The graphs below summarize the results in terms of thermal demand covered by the CHESS SETUP, energy and CO_2 savings in the different climates. Note that the limitations in terms of the building physical space for incorporation of solar panels and thermal storage have been considered to remain unchanged from the reference case in all locations.



Thermal demand covered by the CHESS SETUP (%)



Total energy savings (%)



Total CO_2 savings (%)

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The results indicate that the CHESS SETUP with the integration of any of the technologies analyzed in this report could provide over 20% energy savings (except for the case of adsorption cooling London where this solution would not be suitable – there is no significant cooling demand anyway so this case would not be pursued further in the design).

The thermal demands covered by the CHESS SETUP system would be lower in Madrid than in Barcelona and even lower in London, clearly because of the greater energy demands in those locations and the lower solar radiation in the case of London.

In terms of CO_2 emissions, the UK has higher factors for both gas and especially electricity compared to Spain, which means the benefit of the CHESS SETUP by using heat pumps is reduced. As noted previously, this aspect and the energy costs are very important factors to take into account when considering the integration of any of these technologies.

Also, in may be the case that for very well insulated buildings, the thermal demands can vary significantly and the contribution of the CHESS SETUP and its associated savings in regions such as London may equal or improve that of the case of a not so well insulated building in Barcelona. Therefore, every project should be studied specifically.

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4. Conclusions

The potential integration of the following energy sources and technologies has been investigated in this report by analyzing its operation, availability, efficiencies, costs, market status and overall integration with the CHESS SETUP system. A summary of the key points to consider is given below.

Solar hybrid panels (PVT)

The use of photovoltaic and thermal (PVT) panels is not extended. However, this may change in the near future with as more manufacturers provide this kind of products and improve on their efficiencies and costs. In terms of implementation with the CHESS SETUP, this is ideal as the production of thermal energy at low temperatures (which can then be upgraded by a highly efficient water source heat pump) allows for greater efficiencies at the same time as producing electricity. There should be enough heating demand or physical space to install a large thermal energy storage tank that can provide inter-seasonal reliance and no thermal energy generated is dissipated

Biomass

Biomass boilers have been considered in the analysis as a back-up system of the CHESS SETUP instead of having gas boilers. Its integration will mainly depend on the location of the project and the availability of biomass. If appropriately sourced, it can provide great benefits especially regarding CO_2 savings.

Geothermal

The incorporation of geothermal energy has analysed in such way that the ground would become the energy storage element. This will therefore be subject to the properties of the ground and will involve additional previous studies about the soil properties and characteristics of the surroundings. Its integration with the CHESS SETUP is possible but needs to be sized properly in order not to 'freeze' the ground. A back-up system could be added to cope with peak winter demands if necessary. The temperature jump (ΔT) from the ground to demand may be higher in this case and therefore the efficiency of the heat pump slightly lower than in the other cases but should still be higher than an air source heat pump.

Waste heat

The possibility of having a constant waste heat source has been analysed. This scenario would be ideal to cover the thermal demand of a building as the incoming temperature could be upgraded by a water source heat pump. Its integration will depend on the availability of one or more waste heat sources, ease of connection, temperatures and schedules of operation. The building may have a boiler as a back-up anyway in case there is a failure in supply.

Absorption/adsorption cooling

In the case there is a significant cooling demand on site or nearby, the possibility of incorporating an adsorption chiller may be considered. The CHESS SETUP system would need to be configured with solar thermal panels (not PVT) in order to achieve higher temperatures that allow the adsorption chiller to run. Careful considerations need to be taken when designing a system such as this one because problems such as discontinuity in thermal production from the solar panels

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may occur. The inclusion of adsorption or absorption chillers may be more suitable if the source of heat is an excess coming from waste heat or CHP.

Combined Heat and Power (CHP)

Installing a CHP would result in an important variation to the CHESS SETUP system as the production element varies and no water source heat pump would be required to upgrade the incoming temperature from the thermal store. The incorporation of CHP does not fit properly in the CHESS SETUP system as it would become a different system on its own and has therefore not been analysed further.

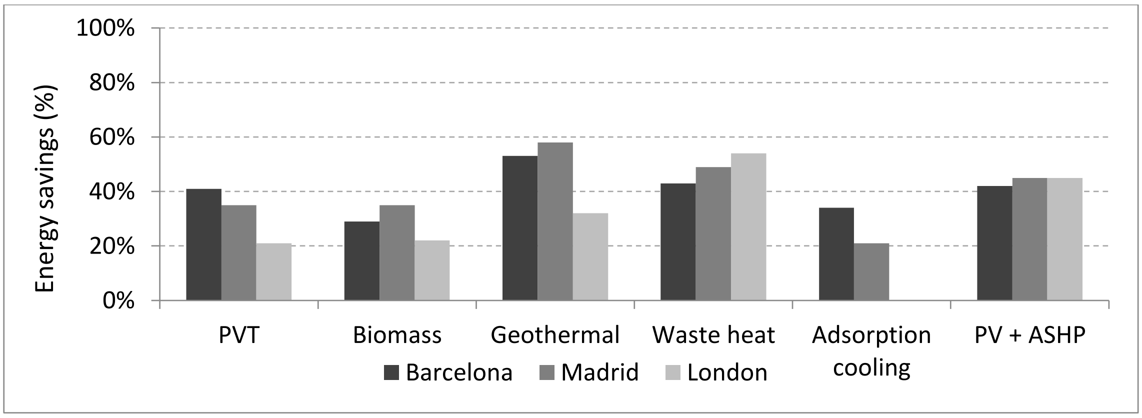
Photovoltaic panels and Air Source Heat Pump (ASHP)

This option would mean the installation of photovoltaic (PV) panels (instead of thermal only or PVT) and an air source heat pump (ASHP). By incorporating PV and ASHP, thermal energy would only be produced by the air source heat pump when required and the electricity produced by the photovoltaic panels would be used to feed this ASHP or any other electric demands of the building such as cooling, lighting and equipment.

In sites with limited possibilities for the incorporation of large thermal storage tanks and/or very low demand for heat in summer, this option may mean not having to waste any of the energy produced in summer (by the original PVT) and minimized maintenance.

Results

The results from the energy calculations on the integration of these with the CHESS SETUP show potential energy savings that are over 20% for the three different climates analyzed.



Total energy savings (%)

When considering the incorporation of the CHESS SETUP into a project and the integration of any other technologies such as the analyzed here, any variances in the operation of the building, energy demands, energy prices and CO_2 emissions factors will have a significant impact on the results shown above so each project should be studied in detail.

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