



Contract No: TREN/07/FP6EN/S07.68923/038659 HIGH-COMBI

# HIGH-COMBI

**HIGH SOLAR FRACTION HEATING AND COOLING SYSTEMS  
WITH COMBINATION OF INNOVATIVE COMPONENTS AND  
METHODS**

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**Thematic Priority: Sustainable Energy Systems**

**Workpackage WP 3, Deliverable D10**

***"BASIC DESIGN OF THE SOLAR HEATING AND  
COOLING DEMO PLANTS TO BE CONSTRUCTED"***

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# 1. Objective

The objective of this document is to describe appropriate configuration (optimum combination of technological performance and economy) that has been identified for each demo plant considered in the High-Combi project:

- Two office building plants for Austria
- One office building for Greece
- One tourist facility for Italy
- One residential building for elderly people for Spain

This results come after having implemented and performed multiple simulations for the total system concept including crucial parameter variations (dimensions of components, load scenarios, climatic conditions etc) and optimisation procedures.

## 2. Austria

In Austria two demonstration plants are built in office buildings in Gleisdorf (close to the city of Graz) within the EU project HighCombi.

### 2.1 Demonstration plant AUT 1 - Service Center and Town Hall Gleisdorf

The system configuration of the solar heating and cooling system is shown in 2-1; **Error! No se encuentra el origen de la referencia.** The provision of heat is effected at one side by the solar thermal system and on the other side by a small local district heating network powered by natural gas which serves as back up. The generated heat is stored in a hot tank all over the year. The needed heat for space heating, domestic hot water preparation and for driving the cooling installations is always taken from this central tank.

Space heating is done via radiators and floor heating in the old town hall and via ceiling elements in the new built Service Center. Space cooling occurs via the same ceiling elements in the Service Center and via fan coils in the town hall.

In the town hall air ventilation is done manually via window opening. A central air conditioning device is responsible for the air ventilation in the Service Center. This unit is performed as a desiccant evaporative cooling (DEC) device with a certain cooling capacity. In winter an effective heat recovery can be achieved due to the heat recovery wheel and the sorption wheel. In both summer and winter the ventilation heat losses are almost completely covered by the DEC device.

Cold water is produced by an absorption cooling machine and stored in a cold water tank. Recooling is done by an open wet cooling tower.

In the following subchapters detailed information to the applied components is given.

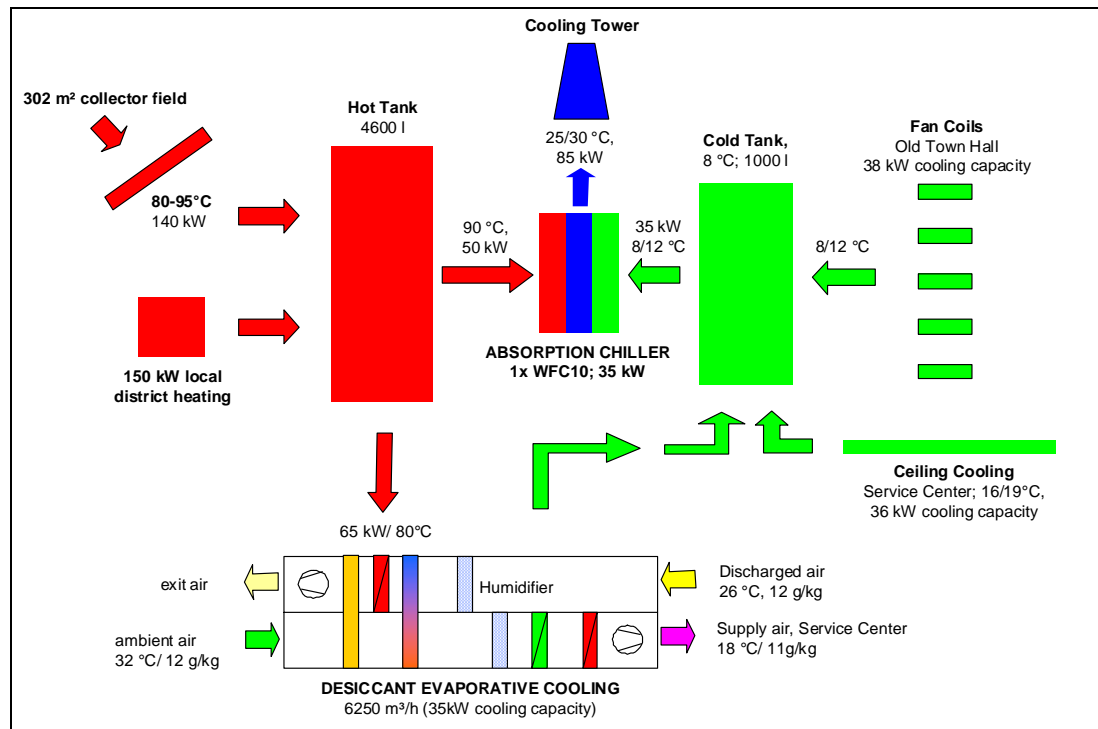


Fig. 2-1: System configuration of the Service Center and Town Hall demonstration plant

### 2.1.1 Solar thermal system

The solar thermal system consists of two collector fields. One is situated at the roof of the Service Center and is oriented  $30^\circ\text{W}$  with a  $134\text{m}^2$  gross collector area and an inclination of  $22^\circ$ . The other one is situated on four so called “solar trees” next to the building and is oriented  $30^\circ\text{E}$  with  $168\text{m}^2$  gross collector area, with an inclination of  $30^\circ$ . The collectors are high temperature flat plate collectors “Gluatmugl HT” with a teflon foil integrated to reduce convection heat losses. The generated heat is put into the heat storage via an external plate heat exchanger; the whole storage volume is available for the solar thermal system.

### 2.1.2 Heat back up

The district heating access with a capacity of  $190\text{kW}$  is able to load the top 40% of the heat storage. In summer time district heating should not be necessary to drive solar cooling. This local district heating network is currently powered by natural gas, in close future it shall be replaced by a biomass boiler.

### 2.1.3 Heat storage

The size of the heat storage was unfortunately already given by the available space in the technical room with  $4.6\text{ m}^3$  because the planning phase of the building was already finished as the project started and so revisions were not possible any more. The solar heat input into the storage is done by a stratifier pipe, all other flow and return pipes

are connected at the right height of the storage to achieve a proper stratification. The nominal temperatures in the store are 95°C in summer and 65°C in winter time.

#### **2.1.4 Space heating**

The nominal space heating load of the new built Service Center amounts to 31 kW and for the old Town Hall to 94 kW, in total about 125 kW space heating load. In the Town Hall space heating is done via radiators (temperature difference 70/50°C, nominal installed capacity: 99 kW), floor heating (temperature difference 40/30°C, 24 kW) and in the Service Center via ceiling elements (temperature difference 37/27°C, 22 kW). Room temperature set point is 22°C. The flow temperature of the space heating circuit is controlled based on the nominal heating curve according to the actual ambient temperature.

Beside the static space heating systems there are some heat register for the ventilation system and other applications existing with 65 kW nominal heat capacity in total and based on a nominal temperature difference of 60/35°C.

#### **2.1.5 Space cooling**

Space cooling load of the Service Center is 24 kW and of the Town Hall 38 kW. Cold distribution is done via fan coils (temperature difference 10/20°C) in the rooms of the Town Hall and via ceiling cooling elements (temperature difference 16/20°C) in the Service Center.

Further cooling devices are some cooling registers in the ventilation system with a nominal cooling power of about 12 kW at a nominal temperature difference of 10/20°C.

#### **2.1.6 Central mechanical ventilation unit – Dessicant Evaporative Cooling (DEC)**

The ventilation system supplies the office rooms of the Service Center with conditioned air with a supply air set point temperature of 18°C (at 32°C ambient temperature with 12 g/kg humidity), the nominal volume flow is 6250 m<sup>3</sup>/h. The configuration of the DEC device is shown in the bottom part of 2.1. The power of the regeneration heat register in the discharged air line between the sorption wheel and the heat recovery wheel is 65 kW and the nominal temperature difference is 80/55°C. The nominal cooling capacity of the DEC amounts to about 30 kW.

#### **2.1.7 Cold production**

An absorption chiller with a nominal coefficient of performance of 0.7 and a cooling capacity of 35 kW produces cold water with a temperature of 7°C. The generator power efforts 50 kW and the recooling capacity is 85 kW.

The produced cold water is stored in a 1000 litre cold water storage which is more or less a hydraulic switch between the cooling machine and the cold distribution circuit.

### 2.1.8 Water treatment

Treated water is needed for refilling the recooling circuit of the wet cooling tower and the humidifiers in the DEC unit. The electrical capacity of the whole water treatment device is 1600 W (reverse osmosis with high pressure pump, UV- disinfection with circulation pump and decarbonisation unit)

### 2.1.9 Dimensions of the main components

Finally the dimensions of the main components are listed up compactly in Table 1:

Table 1: Components of the first Austrian demonstration plant “Town Hall and Service Center Gleisdorf”

Solar collector	302 m <sup>2</sup> gross collector area “Gluatmugl HT” by Ökotech/SOLID	Nominal power of 150 kW <sub>th</sub> at operating temperature of about 90 °C
Back up heater	190 kW	Local district heating, powered by natural gas
Heat storage	4.6 m <sup>3</sup> water tank	Integrated stratifier pipes for charging with solar heat
Cold storage	1 m <sup>3</sup> water tank	
Space heating load	125 kW	
Space cooling load	62 kW	
DEC	30 kW <sub>th</sub> cooling capacity; 10 kW electrical capacity	6250 m <sup>3</sup> /h nominal air flow rate
Cold production	35 kW; COP <sub>th</sub> =0.7	Absorption chiller
Recooling	100 kW <sub>th</sub> cooling capacity 2.5 kW <sub>el</sub> electrical capacity for fan and circulation pump	Wet, open cooling tower
Water treatment	1.6 kW electrical; 30 l/h fresh water capacity	UV disinfection, decarbonising, reverse osmosis filter, biocide injection, adding corrosion blocker

## 2.2 Demonstration plant AUT 2 – Office Building Feistritzwerke Gleisdorf

This office building is an existing building which was renovated around 1995. Some technical installations already exist in this building which shall be used in the new heating and cooling concept. Mainly five heat storages with 2 m<sup>3</sup> volume each and several heating systems like a condensing natural gas boiler and two combined heat and power plants (CHP) powered by vegetable oil shall be integrated.

The final system configuration of this second Austrian demonstration plant is shown in 2-2. Solar thermal energy is stored in five 2 m<sup>3</sup> heat storage tanks. One of these tanks is working as a high temperature tank which can be operated independent of the other four tanks, which are connected in parallel to each other and which are used only for surplus heat generated by the solar collectors. In summer time cold is generated exclusively with solar energy, only during the heating season the power plants driven with vegetable oil and the condensing natural gas boiler and are serving as backup.

The absorption chiller is mainly driven with solar heat taken out of the heat storage. The cold water generated by the chiller is transported directly to the cold distribution system without any cold storage in between in order to avoid an extra circulating pump. The office rooms are cooled via plaster board ceiling cooling elements.

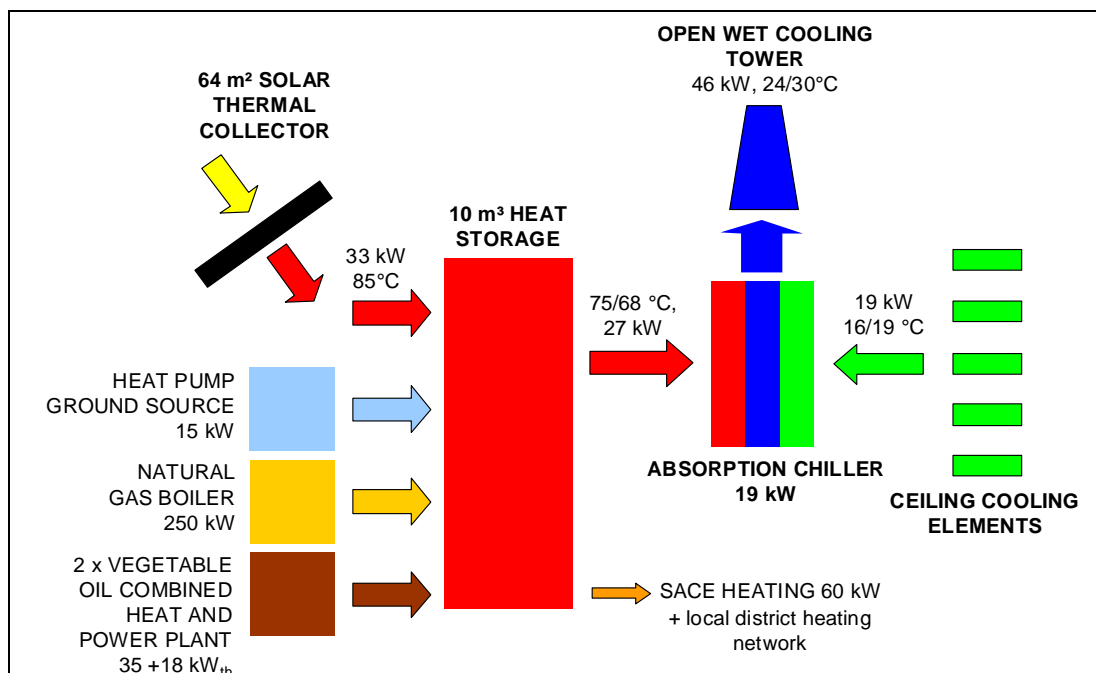


Fig. 2-2: System configuration of the demonstration plant “Feistritzwerke Office Building”

### 2.2.1 Solar thermal system

The solar thermal collectors are situated on the roof of a neighbour building next to the office building with 64 m<sup>2</sup> gross collector area, oriented 34°E. The collectors are high temperature flat plate collectors “Gluatmugl HT” with a teflon foil integrated to

reduce convection heat losses. The generated heat is charged via an external plate heat exchanger into the heat storage. In principle the whole storage volume is available for the solar thermal heating system, but first the high temperature tank is heated to set temperature and then further surplus heat is used to charge the remaining four tanks.

### **2.2.2 Heat back up**

Heat back up is only active during the heating period. In summer time a solar fraction of one hundred percent is the goal. Nevertheless, as heat back up several heat producers are available. One is an already existing condensing natural gas boiler (250 kW) and the other ones are two CHP's powered by vegetable oil as fuel (35 kW<sub>th</sub> and 18 kW<sub>th</sub>). The back up heat is can be stored in the heat tanks as well. If the flow temperature out of the heat storage does not reach the required temperature during the heating period, first the CHP's and a small prototype high temperature heat pump (15 kW<sub>th</sub>) will start heating and as the last the condensing natural gas boiler will be switched on.

### **2.2.3 Heat storage**

Four of the five heat storages with 2 m<sup>3</sup> volume each are connected in parallel and the fifth tank is connected in series to the others and used as a "first priority tank". The total heat capacity of 10 m<sup>3</sup> water tanks can be charged up to 95 °C, if the irradiation is sufficient. Because there won't be built in stratifier units in those existing storages, the solar sided flow and return pipes are connected in different height levels of the storages controlled by switching valves and depending on the temperatures.

### **2.2.4 Space heating**

The space heating load of the office building is 50 kW. With measured data from the office building the simulated space heating load could be verified. Heating occurs via radiators and ceiling heating elements (the same elements are also used for cooling). The nominal temperature differences are 60/40°C for the radiators and 35/25°C for the ceiling heating elements. The flow temperature is depending on the ambient temperature, room temperatures can be controlled for each room.

### **2.2.5 Space cooling**

The cooling load of the office building amounts about 24 kW. This cooling load was not calculated in the standard static way, because this typically results in unnecessary high nominal capacity of the absorption chiller. Based on dynamic building simulation with TRNSYS the cooling load was decreased so far, until the room temperatures could be kept at around 24°C most of the time and only in some short but very hot periods 26°C were reached. Conventional design would have resulted in a nominal cooling capacity of about 40 kW.

Chosen cooling elements for cold distribution are plaster board ceiling elements in all office rooms.

### 2.2.6 Ventilation

There is no mechanical ventilation system intended for this building because all office rooms have windows. Ventilation is done manually by window opening.

### 2.2.7 Cold production

Cold water is produced by an absorption chiller with a nominal cooling capacity of  $19 \text{ kW}_{\text{th}}$  with a nominal thermal coefficient of performance of  $\text{COP}_{\text{th}} = 0.7$ . The generator power efforts  $27 \text{ kW}$  heat and the recooling capacity is  $46 \text{ kW}$ . The produced cold water is directly pumped to the cold distribution network. The cooling power of the absorption chiller shall be controlled according to the cold demand by speed controlled fan of the cooling tower and speed controlled generator and recooling pumps as well.

### 2.2.8 Water treatment

For the refilling of the water losses of the wet cooling tower cycle a new developed water treatment system has been installed and will be tested in this installation first time.

### 2.2.9 Dimensions of the main components

Finally, the dimensions of the main components are listed up compactly in Table 1:

Table 2: Components of the second Austrian demonstration plant “Office Building of the utility Feistritzwerke in Gleisdorf”

Solar thermal system	64 m <sup>2</sup> gross collector area “Gluatmugl HT” by Ökotech/SOLID	Nominal power of $33 \text{ kW}_{\text{th}}$ at operating temperature of about 90 °C
Back up	250 kW natural gas boiler 35 and 18 kW vegetable oil powerd CHP plant 15 kW prototype high temperature heat pump	Only during heating period active
Heat storage	10 m <sup>3</sup>	4 x 2 m <sup>3</sup> parallel + 2m <sup>3</sup> in series
Cold storage	-	
Space heating load	60 kW	Nominal
Space cooling load	24 kW	nominal
Ventilation	Manually window opening	
Cold production	19 kW; 0.7 COP	Absorption chiller
Recooling	46 kW thermal	Wet, open cooling tower
Water treatment	New developed prototype	

## 3. Greece

### 3.1 General Info

The plant design includes the solar thermal collectors (95 m<sup>2</sup>), the cylindrical underground thermal energy storage (58 m<sup>3</sup>), the absorption cooling machine (35 kW), the wet cooling tower and the ground heat exchangers (650 m). Through optimization procedures the system aims at high solar fraction (SF) over 85%.

In common solar combi-plus systems, there is still some mismatch between the availability of solar energy and the loads, especially during the intermediate “low load” seasons in spring and autumn. Moreover, consecutive winter days with low solar radiation, impose a real limit on the system’s solar fraction for space heating. Therefore, even a solar combi-plus system struggles to reach a high solar fraction (e.g. over 80% in terms of total solar fraction and over 70% in terms of space heating fraction).

In this application, an underground thermal energy storage (UTES) stores part of the excess solar energy and uses it when needed. During autumn and spring, a large amount of thermal energy is stored, with the view to be recovered in the following heating (winter) or cooling (summer) period. The UTES energy performance is improved by a heat pump (HP) in winter and by the ground heat exchangers (GHX) in summer.

An innovative HP is used as a back-up system for both heating and cooling operation. In heating period, heat from the UTES drives the HP, thus the 45 °C lower operational limit of the storage for heating is further decreased. Thus, higher heat capacity is achieved and consequently, more energy is stored in the same volume. Additionally, due to the high driving temperature, the innovative HP (awarded the 2009 National Energy Award) operates with a COP of about 8, which is substantially higher than that of a conventional HP. Apart from the higher exploitation of the stored solar energy, the solar collectors’ efficiency increases as well, due to the lower supply temperature from the UTES.

The GHX are thermally coupled with the UTES and they play a dual role: They serve as a heat sink for dissipating heat from the absorption chiller and they reduce the heat losses from the UTES to the ground. Thus, the cooling tower of the absorption chiller dissipates less heat to the environment, reducing not only its parasitic electrical energy consumption, but also its water consumption.

Regarding the energy source utilization, priority is given to the heat derived from the solar field, since its operation requires low primary energy consumption. This refers only to the electricity required to drive the pumps for circulating the medium in the circuits.

### 3.2 Plant operations

In heating mode, the solar system is designed to supply the building with hot water of 45 °C. Priority is given to the heat coming from the solar field or/and the UTES. The

HP connected in series, subtracts energy (evaporator) only from the UTES and raises the supply temperature to the building (condenser) to the required level, if necessary.

Depending on the building's heating demand, the availability of solar radiation as well as the water temperature inside the UTES, a control system selects the optimum heat source or a combination of them. The possible operating modes are:

- Solar collectors
- Underground thermal energy storage
- Solar collectors & Heat pump
- Underground thermal energy storage & Heat pump

In cooling mode, the solar system is designed to supply the building with chilled water of 7 °C. Priority is given to the absorption chiller, due to its low electrical energy consumption. The HP is connected in series and reduces the supply temperature to the building (evaporator) to the required level, if necessary.

The absorption chiller is driven either by the heat output from the solar collectors or by the UTES at a "high" temperature (70-85°C), and provides useful cooling by extracting heat from the building. The absorption process is continued only if the sum of the heat extracted from the building plus the heat for driving the absorption chiller is rejected. Part of this heat is dissipated to the earth via the GHX, whereas the remaining heat is dissipated to the environment via the wet cooling tower. Similarly, the heat pump dissipates heat to both heat sinks.

Depending on the building's cooling demand, the availability of solar radiation and the water temperature inside the UTES, a control system selects the optimum heat source or a combination of them. The possible operating modes are:

- Solar collectors – Absorption chiller
- Underground thermal energy storage – Absorption chiller
- Solar collectors – Absorption chiller & Heat pump
- Underground thermal energy storage – Absorption chiller & Heat pump

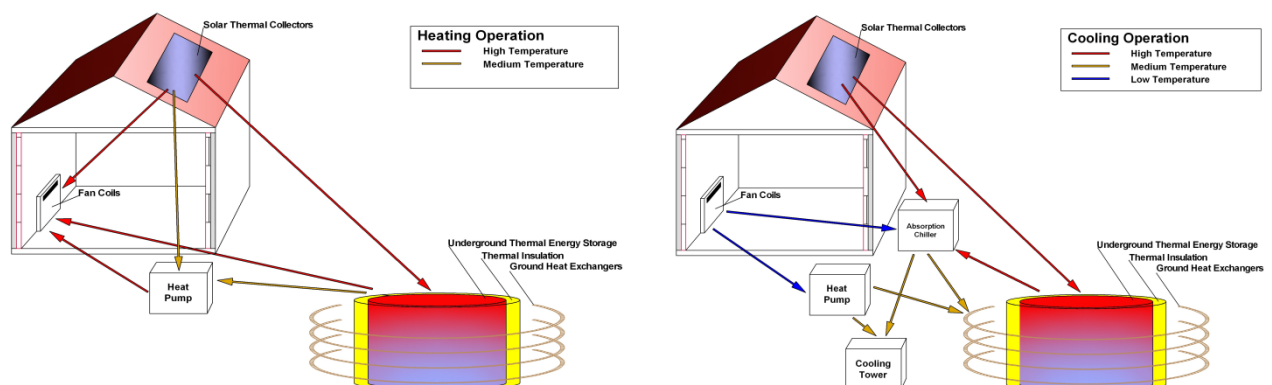


Fig. 3-1 :Schematic of plant operations for heating (left) and cooling (right)

During the intermediate seasons (autumn and spring), when heating and cooling loads are relatively low, the excess solar energy is stored in the UTES, reaching a water temperature of about 95 °C. The combined effect of the UTES good thermal insulation and the surrounding high ground temperature, reduce thermal losses from the storage.

### 3.3 Main components

#### **Building**

The plant is installed at an existing office building, at the site of the Centre for Renewable Energy Sources and Saving (CRES) in Athens, Greece. The building covers a total of 426.6 m<sup>2</sup> with a volume of 1296.4 m<sup>3</sup>, which is typical of medium sized office and multifamily buildings (Figure 2). The building was constructed in 2000, together with other 3 similar buildings that were initially designated as laboratories. In 2008 the building was renovated and is currently used as an office building, with natural ventilation and equipped with a heat pump connected to fan coils.



Fig. 3-2: Views of the building.

The building thermal simulations were performed using the transient building thermal simulations (TRNSYS) software to calculate energy demand for space heating and cooling, and peak heating and cooling loads for a five day working period (08:00-18:00) with a total occupancy of 37 people.

The annual energy demand per unit floor area for maintaining the desirable indoor thermal comfort conditions, was estimated at 10.4 kWh/m<sup>2</sup> for heating (9.7 kWh/m<sup>2</sup> sensible and 0.7 kWh/m<sup>2</sup> latent) during the winter period (October-April), and 37.9 kWh/m<sup>2</sup> for cooling (34.4 kWh/m<sup>2</sup> sensible and 3.5 kWh/m<sup>2</sup> latent) during the summer period (May-September). The calculated peak space heating and cooling loads were estimated at 31.7 kW and 33.2 kW, respectively. Simulations were also performed for the worst case scenario, i.e. no internal heat gains in winter and maximum internal heat gains in summer (e.g. all installed lights in use, all equipment, all occupants during building operation hours). The calculated energy demand per unit floor area (kWh/m<sup>2</sup>) for the entire building was estimated at 28.9 kWh/m<sup>2</sup> for heating (17.8 kWh/m<sup>2</sup> sensible and 11.3 kWh/m<sup>2</sup> latent) and 45.4 kWh/m<sup>2</sup> for cooling (41.9 kWh/m<sup>2</sup> sensible and 3.5 kWh/m<sup>2</sup> latent).

#### **Solar Field**

The solar field consists of 35 flat plate collectors with selective surface. They are connected in 5 parallel series covering a total gross area of 95 m<sup>2</sup> (151.2 total installed). They are south-west orientated, with 30° slope and 26° azimuth angle.

### **Underground Thermal Energy Storage**

The UTES has a volume of 58 m<sup>3</sup>. The tank is cylindrical, with 4 m diameter and 4.6 m height with the upper part of the tank being approximately 0.4 m below the earth surface. The dimensions as well as the position of the tank inside the earth were subject to physical constraints, since underground water can be found at 8 m depth.

### **Absorption Chiller**

The type of the absorption chiller is SOLE Climasol XZR-35 with LiBr as the working medium. The cooling capacity under nominal conditions is 35 kW operating with a thermal coefficient of performance of 0.6. Heat either from the solar collectors or the UTES drives the chiller with temperatures over 65 °C.

### **Ground heat exchangers**

The Ground Heat Exchangers (GHX) consist of ten uninsulated pipes forming ten horizontal spirals around the tank. They cover the whole height of the tank and their total length is approximately 650 m. Viewing the tank from the side, the first spiral pipe starts at the bottom of the tank. The vertical distance between two consecutive spiral pipes is 0.5 m, so the second spiral pipe is 0.5 m over the first. Viewing now the tank from the top, the closest point between the spiral and the tank is 0.55 m and this is exactly the point where the water coming from the chiller enters. Each spiral pipe makes three turnings with 0.55 m constant separation distance (step) and the water exits at the outer part of the spiral. The direction of the water is designated for better stratification of the ground temperature. Given the clay synthesis, the heat rejection rate is estimated at 12 W per m of pipe, or 7.8 kW in total.

### **Cooling tower**

The Cooling tower is connected in parallel to the GHX in order to reject most of the waste heat during the cooling process. The cooling tower is counter flow with the air flowing opposite to the water flow. Air enters at the bottom of the tower, beneath the fill media, and is then drawn up vertically by a fan. The water is sprayed through pressurized nozzles and flows downward through the fill, opposite to the air flow.

### **Heat pump**

An innovative HP (CIAT S.A.) acts as the auxiliary system. Due to the high driving temperature, the innovative HP (2008 National Energy Award) operates with a COP of about 8, which is substantially higher than that of a conventional HP. The key features are the refrigerant R410A, the high efficiency compressor, the counter/parallel flow twin external heat exchanger and the high capacity internal heat exchanger.

## 4. Italy

The demonstration plant in Italy will be installed at the Idroscalo – HydroPark (see figure below). The latter, built in 1930 as Hydroplanes port at the east side of Milan, is today a centre for recreational activities with 2 millions visitors a year.



Fig. 4-1 : General view of Idroscalo

The building hosts areas dedicated to various activities like fitness, medical room, bar and multifunctional room.

The demonstration plant will provide part of heating, cooling and sanitary hot water, substituting the standard technology with the high solar fraction heating and cooling concept.

The demonstration project will aim to show to the general public that it is possible to heat and cool buildings using solar systems and on the other hand give the chance to test the innovative system configuration. This demonstration plant will be constructed using conventional solar thermal collectors (selective flat plate or evacuated tube) and a low temperature heat driven technology (based on absorption process). The system will follow the same approach of the other demo plants for what the configuration concerns, aiming at an optimised combination of heating and cooling, thus maximising the solar fraction.

### 4.1 Solar thermal system

The solar field consists of 140 m<sup>2</sup> of collectors. The collectors' type and field configuration is not yet decided. The following figure gives a possible view of the collectors on the roof of the building.

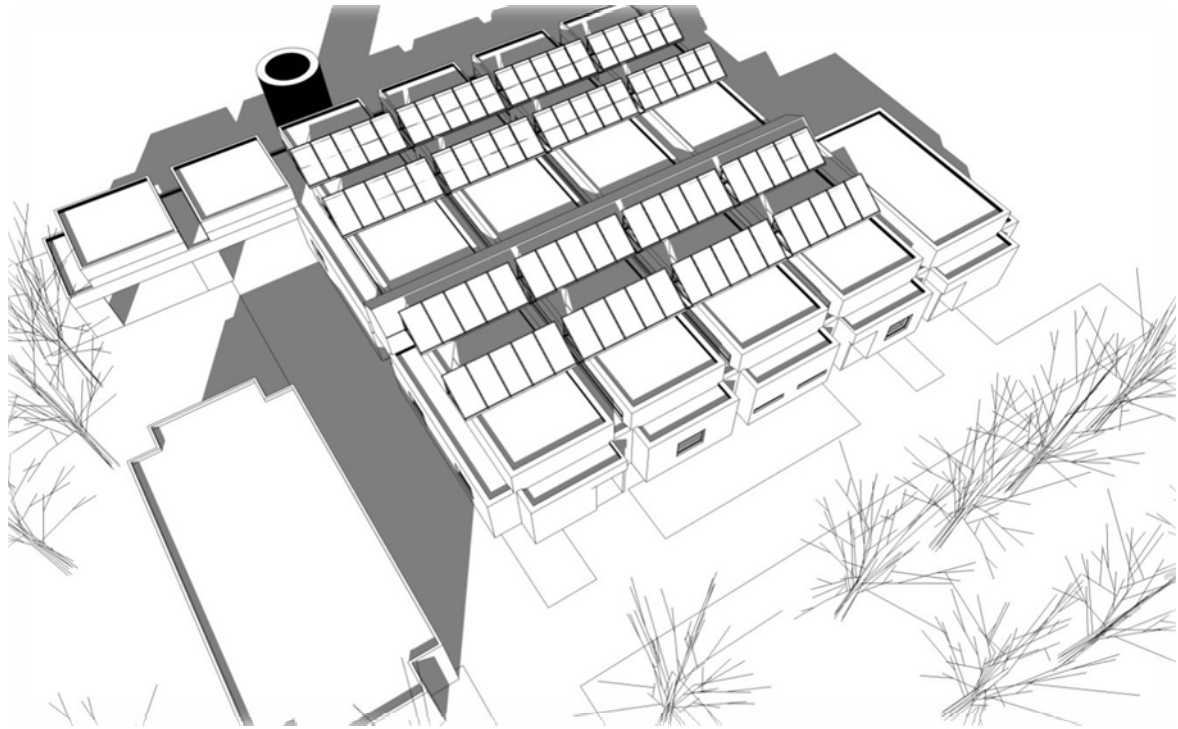


Fig. 4-2: Possible view of the collectors on the roof of the building. Source: Graduate thesis of BOSCARRELL- BRAVI (2008)

## 4.2 Heat back up

### Winter operation:

The main back-up system for the winter operation of this plant is a water to water compression heat pump with a nominal power of 20 kW. The innovation is the connection of this heat pump with the solar system. Thus, the cold source (evaporator side) of the pump is the pre-heated solar tanks water. This specific (Climaveneta) can accept evaporator side temperatures up to 22 °C, thus increasing its COP. Technical data of the heat pump are available in the file “Pompa di calore Climaveneta” (in Italian).

### Summer (and winter) operation:

The back up system in summer operation is an air to water heat pump (cooling power of 55 kW at an ambient temperature of 35 °C). This heat pump is also a back up for winter since it can deliver 40 kW with an ambient temperature of -5 °C. Technical data of the air to water heat pump are not yet available.

## 4.3 Heat storage

As it can be seen in the scheme, the plant tanks are the following:

1. A 500 l tank for the sanitary water preparation (will probably be increased to 800 l).

2. Two tanks (called “A” and “B”) of 10.000 l each for heating and cooling needs.
3. One tank of 2.000 l called “Buffer” tank. This last tank becomes a cold storage in summer period.

## 4.4 Space heating and cooling

Space heating and cooling will be basically provided via fan-coils and air handling unit. Small radiators will be used in the toilets.

The load has been estimated through dynamic simulations according to the foreseen building characteristics and results are give below. However, the final building plan will differ from the foreseen one. Thermal loads will therefore be different compared to the ones mentioned below.

Table 3: Heating and cooling loads

Heating load	31,3 kW	
Cooling load	Latent	11,0
	Sensible	28,9
	Total	39.9

## 4.5 Cold production

The type of the single effect absorption chiller is YAZAKI WFC-SC 10 with a cooling capacity of 35,2 kW.

Table 4: Summarized technical data of the chiller (Nominal Conditions)

Chiller Characteristics		Comments
Type	Absorption (H <sub>2</sub> OLiBr)	YAZAKI WFC-SC 10
Capacity	35,2 kW	
COP	0,7	Coefficient of Performance
T <sub>chilled</sub>	7-12,5 °C	Temperatures of the chilled water
T <sub>cooling</sub>	31-35°C	Temperatures of the cooling water
T <sub>hot</sub>	88-83 °C	Temperatures of the hot water
F <sub>chilled</sub>	5,5 m <sup>3</sup> /hr	Flow rate of the chilled water
F <sub>cooling</sub>	18,4 m <sup>3</sup> /hr	Flow rate of the cooling water
F <sub>hot</sub>	8,6 m <sup>3</sup> /hr	Flow rate of the hot water
Auxiliary Power	210 W	(chiller only)

A heat cooling tower with a nominal power of about 100kW will be implemented. Technical data of the cooling tower are not yet available.

## 4.6 Domestic hot water

On the basis of the final destination of use for the building a DHW demand estimation was made considering a daily profile and a weekly profile. The DHW will be always prepared considering its priority on the heating and cooling demand. It's prepared in a boiler that will have approximately a volume of 800 lt. This tank will be equipped with an internal heat exchanger placed at the bottom of it that will be fed with hot water from the heat source or from the back up consisting in a heat pump. The maximum hot water temperature delivered by the heat pump should be 55°C. If the temperature of the tank will be below the 45°C and there isn't availability of power from the solar source a system of three way valves allows to use hot water from the heat pump.

It's foreseen that the DHW demand will be relatively scarce in comparison with the solar collector surface used in the highcombi system. Therefore, it could be inferred that in the summer season and in spring and autumn the coverage of the demand will be approximately close to 100%. The DHW demand foreseen a rotation of 10 people 2 times a day in the changing room, after the athletic preparation activity in the fitness room. For every person was estimated a DHW consumption equivalent to a shower (25 lt. at 45°C.). At the end the estimated DHW consume was 500 lt/d from Monday to Saturday.

## 4.7 Pumps

The type and technical data of the pumps is not available yet. However, the principle for their dimensioning is explained below.

The flow rate of the solar field should be as low as possible in order to save parasitic energy. This is relatively easy to achieve for heating and DHW operation and common hourly flow values are about 12 l per m<sup>2</sup> of collector. However, this flow rate causes Delta T of about 30 to 40 °C at peak incident radiation conditions. Such flow rates are not appropriate for the cooling mode of operation, since the absorption cooler requires much lower delta T (as low as 5 °C). Consequently, both pumps and pipes should allow high flow rates i.e. of about 50 l per m<sup>2</sup> of collector and hour. If technically possible, the optimum dimensioning would be for high flow, but allowing a low flow operation (using the pumps inverter or velocity selection) outside the cooling season.

## 4.8 Summary of main components size

Table 5: Components of the Italian demo plant

Solar thermal system	140 m <sup>2</sup> aperture collector area
Back up	air to water heat pump: 40 kW <sub>th</sub> ; 55 kW <sub>fr</sub> water to water heat pump: 20 kW <sub>th</sub>
Heat storage	2 x 10.000 l (main storages) 1 x 2.000 l (buffer) 1 x 800 l (DHW)
Cold storage	1 x 2.000 l (the same buffer storage used as heat sotrage in winter)
Space heating load	31,3 kW
Space cooling load	11 kW latent + 28,9 kW sensible
DHW load	500 l/d (45 °C)
Cold production	35 kW; 0.7 COP absorption chiller
Recooling	100 kW thermal wey cooling tower

## 5. Spain

### 5.1 Background. Initial Building, BUI1

In the research phase of High-Combi project, different configurations of optimized solar heating, cooling and storage technologies had to be examined and optimized by detailed simulations. One of the most important conclusions of this phase was that, depending on the usage of the building, some configurations made sense and some others not. This was the reason to simulate the real building behaviour and, once the demand was characterized, design the most suitable scheme of the High-Combi system to be finally installed.

Initially, the demo plant for Spain had to be placed in a multi-storey residential building in Terrassa (close to Barcelona, but in a dryer and colder area). The first results on the demand (cooling, heating and DHW), for BUI1, were the following:

Table 6. Annual demand values for Terrassa building, BUI1.

BUI1		Cooling	Heating	DHW
Demand	kWh/m <sup>2</sup>	22	12	30

The scheme to be installed, SCH1, taking into account the state of the art of solar cooling and seasonal storage technologies, and the profile of the demand, was to be a scheme in which solar energy could regenerate the heat extracted from the ground. Although cooling demand was important, it was lower than heating and, therefore, injecting heat to the ground made sense, since in some periods of the year, a big amount of heat was extracted from it.

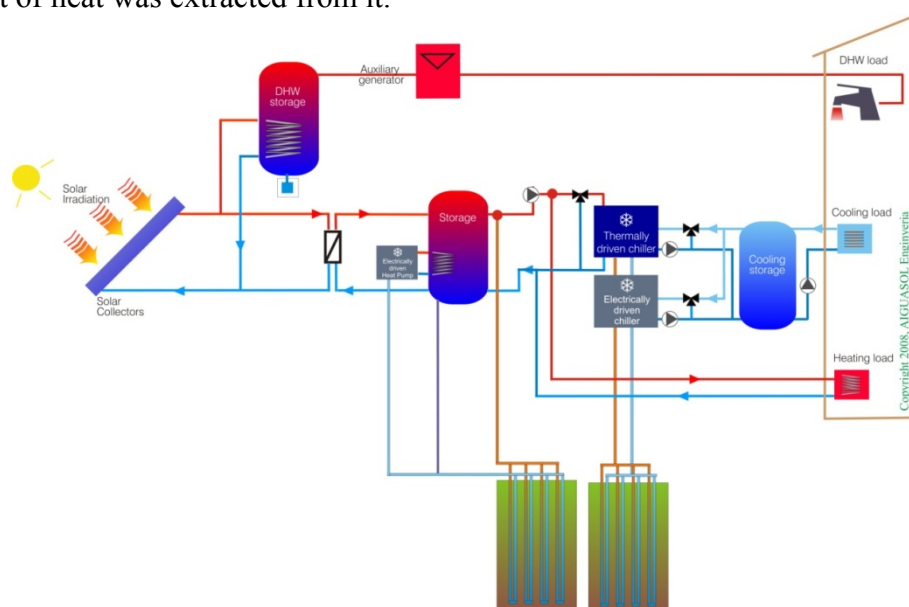


Fig. 5-1 High-Combi scheme SCH1 for BUI1

The detailed design consisted in a solar thermal system that fed two storage tanks (high/low temperature) which, at the same time, supplied energy either to heating

space, domestic hot water or cooling requirements (through the absorption machine). In case there was no demand, and the tanks were full of energy, the excess energy was sent to the ground heat exchangers, which were divided into two groups, one that acted somehow as BTES (borehole thermal energy storage) and the other that was used to dissipate energy (more separation between boreholes). Two geothermal heat pumps (to be able to act simultaneously) were used as a back-up of the heating and cooling system. A condensation boiler was placed as backup for DHW.

## 5.2 Design process

### 5.2.1 Change of Building, BUI2

However, before starting the project, the building in Terrassa BUI1, was cancelled because of administrative problems. So a new building was necessary to be found. Finally, a building BUI2, placed in the centre of Barcelona, with a social housing space for elderly people and a Healthcare Centre, was chosen.

New location and usage would, for sure, change the previously calculated demand and new simulations would be required in order to evaluate the new demand.

Table 7. Annual demand for Barcelona building, BUI2.

BUI2	Cooling	Heating	DHW	
Demand	kWh/m <sup>2</sup>	28.4	9.6	14.1

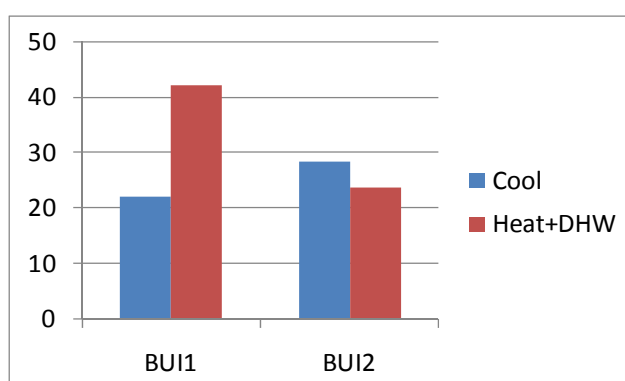


Fig. 5-2 Cooling and (heating + DHW) demands in BUI1 and BUI2.

These new results made us think twice about the initial configuration; heating demand of the new High-Combi building was really low, mainly due to a hotter location and new usage. Would initial configuration fit properly to this demand?

Moreover, in the new building, we did not have as much space in the roof as we had in the previous one. Although filling all the roof with the necessary evacuated tubes (around 250-280 m<sup>2</sup>) was possible, the local administration did not allow to fill all the roof with a solar thermal structure, because of visual impact. Therefore, the maximum occupancy of the roof (taking into account this administrative considerations) was intended, and the final result was the use of 200 m<sup>2</sup> of evacuated tube collectors.

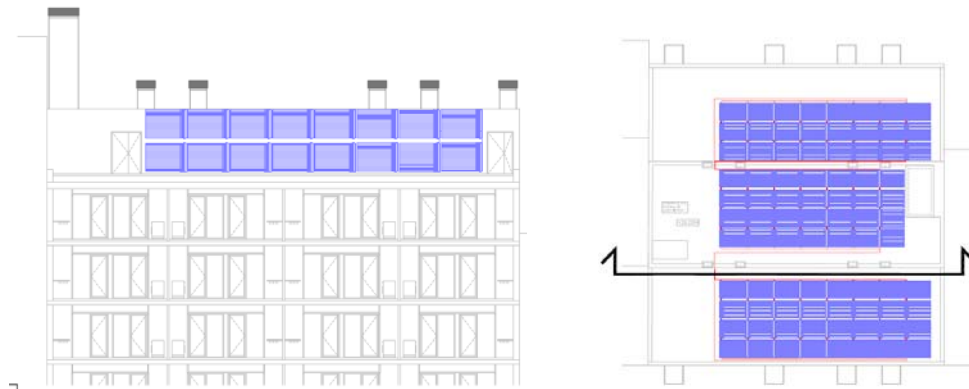


Fig. 5-3 Frontal and upper view of the solar collectors

Dynamic simulations with TRANSOL, showed that an excess of charge of the ground during spring and low heat extraction in winter (caused by the low heating demand), made the ground temperature increase from 20°C in the beginnings of the year to 25°C in the end. It means that this operation behaviour could not be sustainable with the years because that would involve a reduction in the EER of the geothermal heat pumps in summer, which also contributed in rising ground temperature.

### 5.2.2 Change of System, SCH2

Consequently, we analysed the potential solutions for this problem, and seeing the profile of the demands, we thought that a new scheme for solar cooling (without geothermal semi-seasonal storage) could fulfil the requirements. A new system was proposed. High-Combi SCH2 consisted in a solar thermal system that fed an stratified storage tank which supplied energy either to heating space, domestic hot water or cooling requirements (through the absorption machine) simultaneously. A compression chiller and condensations boilers were placed as backup for cooling and heating demand respectively.

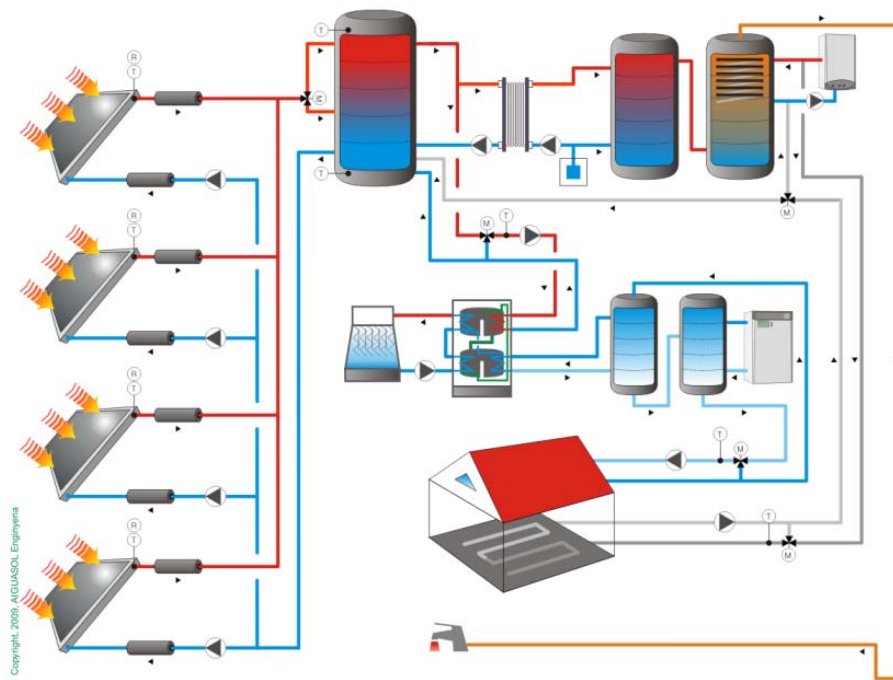


Fig. 5-4 High-Combi scheme SCH2 for Barcelona

Furthermore, dynamic simulations with TRANSOL were made to compare SCH1 with SCH2 for the same new demand profile, BUI2, in order to analyse which would be the optimal configuration scheme for the BUI2 demand profile.

	SCH1		SCH2	
Winter		<b>Demand</b> DHW 9.1 Cooling 0.0 Heating 9.6 <b>Consumption</b> Electricity 1.5 Gas 1.5		<b>Demand</b> DHW 9.1 Cooling 0.0 Heating 9.6 <b>Consumption</b> Electricity 0.0 Gas 6.2
Summer		<b>Demand</b> DHW 4.9 Cooling 28.4 Heating 0.0 <b>Consumption</b> Electricity 3.9 Gas 0.5		<b>Demand</b> DHW 4.9 Cooling 28.4 Heating 0.0 <b>Consumption</b> Electricity 3.7 Gas 0.2

Fig. 5-5. High-Combi schemes SCH1 and SCH2 results for Barcelona, BUI2.

Table 8. High-Combi schemes SCH1 and SCH2 results for Barcelona, BUI2..

BUI2		SCH1	SCH2	diff
Electricity	kWh/m <sup>2</sup>	5.4	3.7	-32%
Gas	kWh/m <sup>2</sup>	2.0	6.4	218%
Prim. Energy	kWh/m <sup>2</sup>	15.7	15.9	2%
FS	%	70%	70%	-1%
Invest. Cost	€/m <sup>2</sup>	210	162	-23%
Energy price	c€/kWh	0.67	0.51	-24%

Despite primary energy consumption and fractional savings did not differ significantly between both options, investment costs were appreciably higher in SCH1 due to boreholes' investment. This additional cost could not be justified when we took in account the energy price. Additionally, the heat seasonally accumulated could only be used to raise the COP of the heat pumps in winter, when the heat demand was very low, and easily covered by solar energy production.

### 5.2.3 Optimisation process. Final design

We used the TRNSYS1 models developed for the new version of the TRANSOL software (TRANSOL 3.0), which incorporates solar cooling and solar combi plus schemes, so as to optimise the different parameters of the system.

The optimisation process analysed the three basic groups of parameters that can be optimised in a solar cooling system: solar collector field, storage systems, absorption cooling subsystem.

The first step was to optimise the behaviour of the solar collector field, under different criteria. The necessary use of evacuated tube collectors, for visual impact requirements, reduced the possibilities of the optimisation process. Therefore, since the azimuth of the field was also established because of the building shape, we could simply optimise the inclination of the absorber. Five inclinations were tested (10,15,20, 25 and 30°). The fourth option gave the best results as for total production.

After the solar collector field was optimised, we decided to optimise the parameters of the absorption cooling machine, making some tests in the driving temperatures of the machine. The trade-off that had to be found was between collector efficiency (lower at higher temperatures) and absorption machine COP (higher at higher temperatures). The amplitude of the delta T (supply-return) was also important. The final result showed that the optimal driving temperatures were 80-75°C.

The last optimisation step was the storage (heat and cold). Because of the high cooling demand, all the analyses done with high specific heat storage ratios (>60 l/m<sup>2</sup>) gave rather bad results. Therefore, we tested quite low accumulation and we saw that the behaviour improved significantly. The optimal accumulation proved to be at 35 l/m<sup>2</sup>.

In order to deal with stagnation and over-temperature problems in the collectors, we design a balanced combination of different strategies as huge expansion vessels and water as primary circuit fluid.

### 5.3 Dimensions of the main components

Finally, the dimensions of the main components are listed up compactly in Table 1:

Table 9: Components of the Spanish plant

Solar thermal system	200 m <sup>2</sup> evacuated tube collectors (water)	100 kW (1000 W/m <sup>2</sup> irradiation)
Back up	321 kW natural gas boiler	Only during heating period active
Heat storage	8 m <sup>3</sup>	Pink tank
Cold storage	2.5	Hydraulic switch
Space heating load	250 kW	
Space cooling load	200 kW	
Ventilation	Manually window opening	
Cold production	70 kW; 0.7 COP	Absorption chiller
Recooling	200 kW thermal; 1.5 kW electrical ?	Wet, open
Water treatment	0.5 kW electrical; 30 l/h fresh water	decarbonising, biocide, adding corrosion blocker