High Solar Fraction Heating and Cooling Systems with Combination of Innovative Components & Methods

SIXTH FRAMEWORK PROGRAMME

HIGHCOMBI

www.highcombi.eu

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Abbreviations

ACM: Absorption Cooling Machine

BTES: Borehole Thermal Energy Storage

COP: Coefficient of Performance

DEC: Desiccant Evaporative Cooling Device

GHE: Ground Heat Exchangers

HP: Heat Pump

RES: Renewable Energy Sources

SAC: Solar Air Conditioning (systems)

SF: Solar Fraction

SHW: Sanitary Hot Water

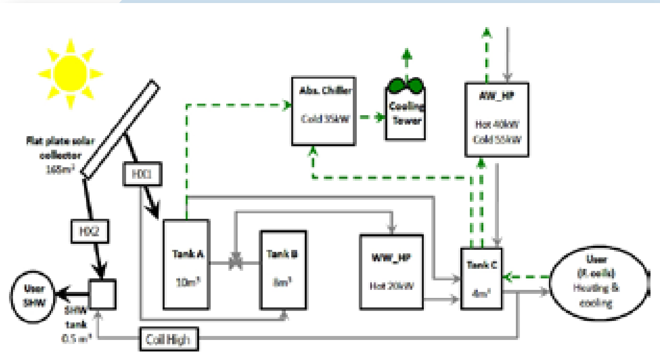
SPF_{el}: Seasonal Performance ratio (electrical)

STES: Seasonal Thermal Energy Storage

UTES: Underground Thermal Energy Storage

High Combi Project

Map of participating countries (grey colour) and demo plants (red dots).



Plant scheme of solar combi plus system with energy flows during summer
(Legend: HX = Heat Exchanger; Abs. Chiller = Absorption Chiller; AW_HP = Air-Water Heat Pump; WW_HP = Water–Water Heat Pump; SHW = Sanitary Hot Water).

View of a typical technical room.

The basic aim of the High Combi project was to develop high solar fraction systems by innovative combination of optimized solar heating, cooling and storage technologies and control strategies in order to contribute and assist the further deployment of the solar energy market. These systems can overcome the problems associated to high solar fraction systems in Southern European countries, endeavouring to increase the primary energy savings in buildings.

The main objectives of the project are summarized below.

- ✔ Identification of configurations of solar plants for heating and cooling applications.
- ✔ Computational analysis of the solar plants and optimization procedures using different combination of technologies.
- ✔ Realization of the demonstration plants.
- ✔ Development of a simple software tool for dimensioning solar systems under the same configurations.
- ✔ Monitoring and technology evaluation.
- ✔ Dissemination of the activities on national level and Europe-wide.

During the project, six demonstration plants were installed in four European countries (Greece, Italy, Spain and Austria). The project was addressed in medium and large building end-users having heating and cooling loads along the year. In Greece, the High Combi demo plant was installed in an existing office building, in the premises of the Centre for Renewable Energy Sources and Saving (CRES) in Pikermi, in Attica.

In Italy, the plant was installed in the “Idroscalo” area at the east side of Milan. “Idroscalo” is a Hydro-Park built in 1930 and today it is used as a centre for recreational activities with two million visitors a year.

In Spain, the building chosen for the demo installation was a newly designed building, in the center of Barcelona. The building embraces a healthcare center and number of social housing flats for elderly people.

In Austria two demo plants have been designed and installed in office buildings namely that of the Service center Gleisdorf and of the Feistritzwerke Gleisdorf. An additional demo plant is also installed in Austria in SOLID office building. Information about this plant is given in the project’s website.

Monitoring data of the presented solar plants was analysed, the simulation and design tools were validated and the performance of the plants was evaluated. A market analysis was carried out in order to estimate the potential penetration of these systems in the European heating and cooling market.

Solar Thermal Systems

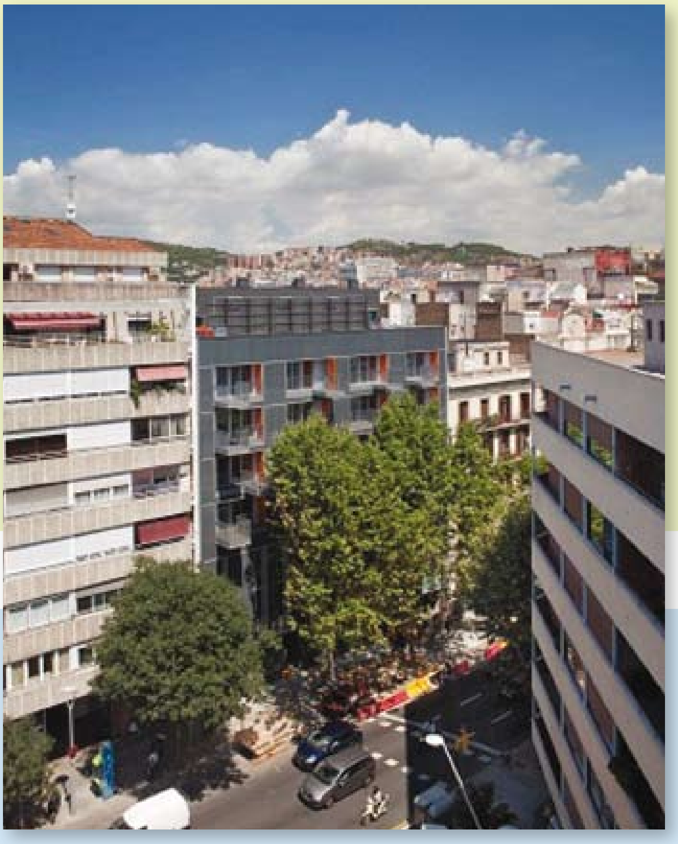
Small systems for SHW production using natural flow systems, known as ***thermosyphons***, are common practice in southern Europe. Systems combining production of SHW and space heating, known as ***solar combi*** systems, are popular in central and northern Europe. Installations with large solar collector areas and heat storage capacity can cover 50 to 80% of the total heat demand.

The heat produced by the collectors throughout the year is stored in the STES. This heat is used to provide sanitary hot water and space heating when required.

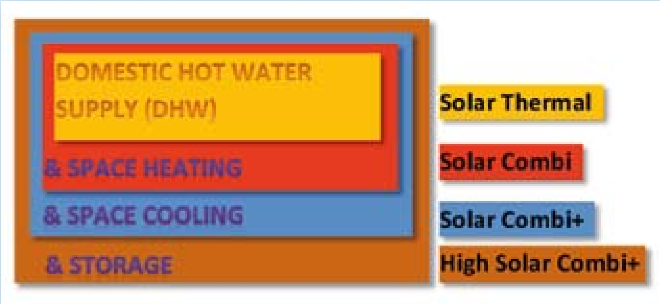
The addition of a ***solar cooling*** facility makes the system complete, covering all building's thermal and cooling demands. Since high cooling loads coincide with high solar radiation, the readily available solar energy from the existing solar collectors can be exploited by a heat driven machine.

The use of the solar collectors is thus extended to the whole year, making the system financially attractive. Furthermore, since the cooling machine is heat driven, the building's electrical loads are reduced and the problems associated with peak power demand during summer are reduced.

Depending on the size of the solar collector field, hot water storage, local climatic conditions and building loads, a ***solarcombi plus*** system may cover 10-60% of the combined space heating/cooling and SHW demand at southern, central and northern European countries.

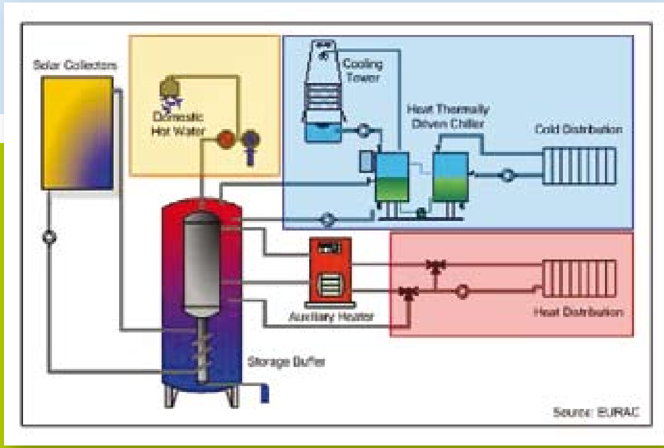


Solar combi systems in household and office sector.



Schematic illustration of various solar thermal systems.

Layout illustration of a typical solar thermal system which covers building's floor heating and SHW needs.



Schematic diagram of a SAC system.

Demo Plant: Greece

General Information

Owner:	*CRES*
Location:	*Pikermi, Attica*
Type of Building:	*Office building*
In operation since:	*2011 (December)*
Air conditioned area:	*427 m^2*

View of the office building.

View of the solar field.

Internal view of the UTES.

Description of the Application

The plant is installed in an existing office building, at the site of the Centre for Renewable Energy Sources and Saving - CRES in Athens (latitude 38° 00′ N & longitude 23° 55′ E), Greece. The building covers a total of 427 m^2 with a volume of 1296 m^3, which is typical of medium sized offices and multifamily buildings. The building was constructed in 2000 and was initially designated as laboratory. In 2008, the building was renovated and it is currently used as office.

General description of the system

The Greek plant operates since December 2011. The plant design includes solar thermal collectors, a seasonal underground thermal energy storage, a heat driven cooling machine, heat rejection units and a heat pump. In heating operation hot water is provided to the building at 7°C. During low demand periods, such as Autumn, a large amount of thermal energy is stored with the view of recovering it at the following energy demanding heating period. The heat pump, which serves as auxiliary system, is driven by solar energy resulting in increased COP. In cooling operation, the absorption machine provides chilled water to the building at 7°C. Thermal energy, by means of hot water over 65°C, drives the cooling process. The estimated solar fraction is around 85% of total thermal energy requirements of the building.

Technical Characteristics

Solar Thermal

Collector Type:	Selective Flat Plate
Collector Area:	149.5 m^2 (Gross area)
Heating Load:	12.3 MWh/a

Solar Cooling

Technology:	Closed cycle
Nominal capacity:	35 kW
System's type:	Absorption (LiBr)
Cooling Load:	19.4 MWh/a

Configuration

Heat storage:	58 m^3 (water underground thermal energy storage)
Cold storage:	N/A
Auxiliary heating system:	Heat Hump (water to water driven by solar heat)
Nominal capacity:	18 kW
COP_{heat}	7

Demo Plant - Italy

Description of the Application

The Italian High Combi demo plant has been installed at the "Idroscalo" - HydroPark. The Hydroplane Port is located on the east side of Milan and is today surrounded by a park dedicated to recreational activities with approximatetaly 2 million visitors per year. So far the building has not been in use for several years. After refurbishment it will serve activities of public interest, such as sport and other activities. The demonstration solar plant is covering heating, cooling and sanitary hot water loads.

General description of the system

The Italian High Combi plant is in operation since July, 2011. The system combines solar cooling with heat pumps, which is an interesting trend of research and commercial applications. It is a complete combination, since the water-water heat pump uses in winter hot water from the solar tank as cold source, adding energy from the electricity network in order to reach the desired temperatures. A second heat pump (air-water) is used to cover the peak loads in winter, as well as in summer.
A water-water heat-pump "in series" with the solar tank is in charge of covering heat demand in case solar energy is not available. This increases both the solar plant efficiency and the heat pump's COP. Estimated solar fraction is around 55 % of total load.

Technical Characteristics

Solar Thermal

Collector Type:	Selective flat plate collectors
Collector Area:	146m^2 (absorber), 16 large scale modules, south-west oriented, 30° slope angle
Heating Load:	59,000 kWh/y
Heat output:	64,700 kWh/y

Solar Cooling

Technology:	Closed cycle
Nominal capacity:	35 kW
System's type:	Absorption chiller
Cooling Load:	23,000 kWh/y

Configuration

Heat storage:	22.5 m^3 water: 10 m^3 + 8 m^3 solar tanks 4 m^3 buffer tank 0.5 m^3 sanitary hot water
Cold storage:	4 m^3 water
Auxiliary heating system:	Heat pumps: 20 kW water/water 40 kW air/water for peak loads

System performance

Energy production expectations:

- Cooling: 26,400 kWh/year (5 months)
- Heating: 38,300 kWh/year (7 months)

TOTAL= 64,700 kWh/year

General Information

Owner:	*Provincia di Milano*
Location:	*Idroscalo - HydroPark*
Type of Building:	*Sport facilities*
In operation since:	*July 2011*
Air conditioned area:	*700 m^2*

View of the building's interior.

View of the solar collectors on the building's roof.

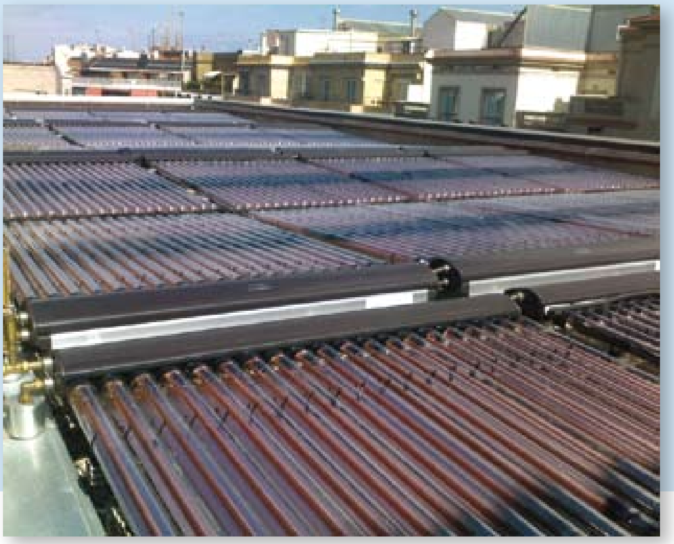
View of the High Combi plus hydraulic installation.

Demo Plant - Spain

General Information

Owner:	*PMHB, Barcelona*
Location:	*Barcelona*
Type of Building:	*Sports Center*
Auxiliary heating / cooling system:	*Condensing Gas Boilers / Compression chiller*
In operation since:	*2011 (December)*
Air conditioned area:	*3,700 m²*

Rear facade of the healthcare cente.



View of the solar field on healthcare's roof.

Description of the Application

The Spanish Plant is installed at a newly designed building, in the center of Barcelona. The building, owned by the Patronat Municipal de l'Habitage de Barcelona, comprehends a healthcare center in the three lower floors, and 32 social housing flats for elderly people in the upper floors. The building has been designed and built according to the optimization criteria of AIGUASOL, through the detailed simulation and the proposal of different measures (including the optimal size of insulation, the glasses to be used and the size of the balconies).

General description of the system

The installed system consists of 200 m^2 heat pipe evacuated tube collectors, a stratified storage tank, an absorption chiller, a compression chiller and a condensation boiler. The option to install geothermal heat exchangers was disregarded, due to substantially higher investment costs that could not be justified when energy price is taken in account. Additionally, the heat demand in winter is low and could be easily covered by the solar collectors.
The optimization process led to an optimal driving temperature for the absorption chiller (75-80ꞮC), for the optimal solar collectors inclination (25o) and for the specific heat storage ratio (35 l/m^2).
The main components of the Spanish Combi + plant are:

- ✔ Evacuated heat pipe tubes
- ✔ Water as fluid in the primary circuit,
- ✔ Absorption chiller for 70 kW cooling
- ✔ Wet cooling tower
- ✔ Radiant floor for heating and cooling
- ✔ Dehumidification

Technical Characteristics

Solar Thermal

Collector Type:	Evacuated tube heat pipe
Collector Area:	200 m^2
Accumulation:	9 m^3
Absorption:	70 kW

System performance

Energy production expectations:

- Cooling: 60,418 kWh/year
- Heating:11,664 kWh/year
- SHW: 49,487 kWh/year

TOTAL=161,874 kWh/year

Energy savings

- Cooling: 12 c€/kWh (EER = 3.8)
- Heating: 6 c€/kWh (Eff = 0.95)
- Elect. consumption: 15,078 kWh
- Gas consumption: 24,287 kWh =3,266€/year

TOTAL = 3,266 €/year

Demo Plant - Austria I

Description of the Application

Within the framework of the renovation of the old Town Hall (1,321 m²) and the construction of a new Service Centre (office building with 1,212 m²), a Solar Combi Plus installation was realised in 2008. The system provides both buildings with heating and cooling energy as well as sanitary hot water.

General description of the system

Space cooling energy is generated by means of two different solar thermal cooling technologies - with an ACM and with a DEC. The DEC provides the hygienic air flow within the Service Center and the ACM covers the cooling load of both buildings. Heat rejection is done by means of an open wet cooling tower. Cooling energy distribution occurs over the cold water storage with fan coils in the Town Hall and with chilled ceilings in the Service Center.

Two different oriented **collector fields** are integrated in the system. One field is situated at the roof of the Service Center and the other one is situated on four so called "solar trees". The generated heat is stored in one heat storage via an external plate heat exchanger and a stratifier unit. A district heating access serves as **backup**.

Space **heating** is done via radiators and floor heating in the Town Hall and via ceiling elements in the Service Center.

Technical Characteristics

Solar Thermal

Collector Type:	Gluatmugl-HT and -GV
Collector Area:	302 m²
Collector gain (Oct10-Sep11):	304 kWh/m² (measured)
Heat output:	

Solar Cooling - Chiller Characteristics

Technology:	Closed cycle
Nominal capacity:	35 kW
System's type:	Absorption
Cooling Load: (Oct10-Sep11)	28,748 kWh (measured)

Solar Cooling - ACM Characteristics

Technology:	Open cycle
Nominal capacity:	6,250 m³/h (35 kW)
System's type:	Silicagel sorption wheel
Cooling Load: (Oct10-Sep11)	19,649 kWh (measured)
Heat storage:	4,600 l water
Cold storage:	1,000 l water
Auxiliary heating system:	District heating

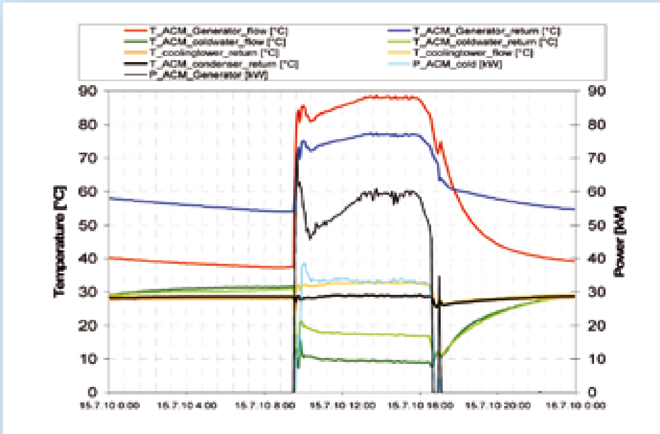
System performance

	Oct 08-Sept 09	Oct 09-Sept 10
SPFel (DEC system is not considered) (useful energy/electricity effort)	19.1	29.7

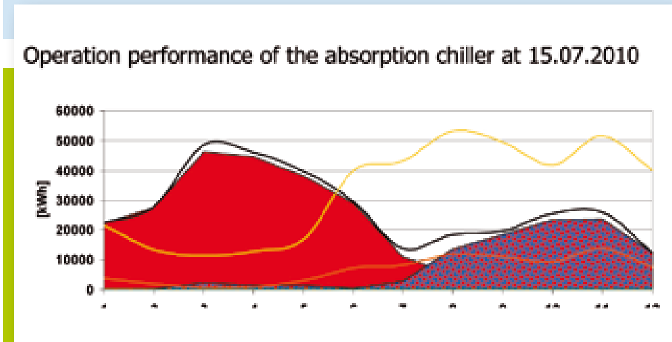
General Information

Owner:	*Municipality of Gleisdorf*
Location:	*Gleisdorf*
Type of Building:	*Town Hall Offices*
Auxiliary source:	*Natural Gas*
In operation since:	*2008 (July)*
Air conditioned area:	*2,533 m2*

View of the solar field in Austria I.



Operation performance of the absorption chiller at 15.07.2010.



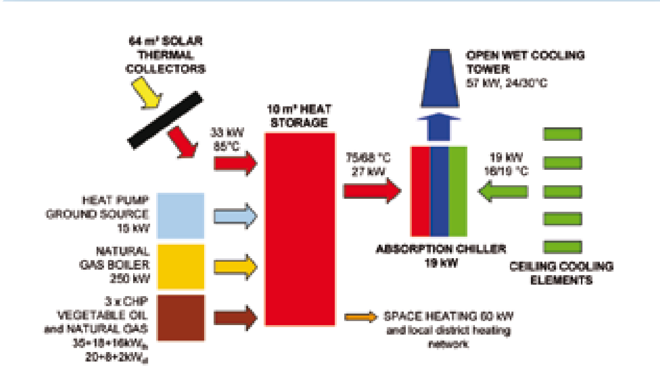
Solar Energy Source Management (Oct 2008 - Sept 2009).

Demo Plant - Austria II

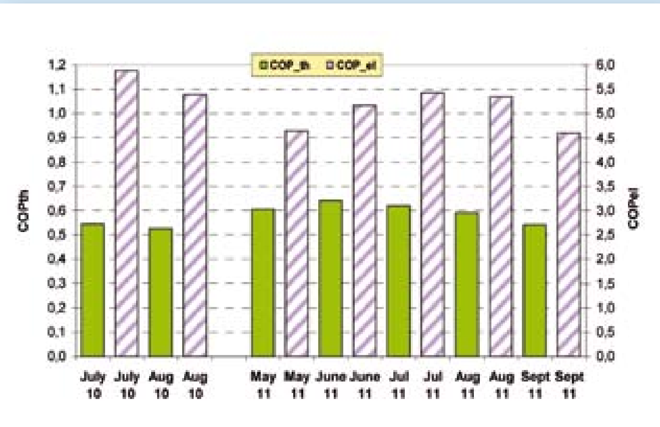
General Information

Owner:	*Feistritzwerke STEWEAG GmbH*
Location:	*Gleisdorf*
Type of Building:	*Offices*
Auxiliary source:	*Natural Gas, Rapeseed Oil CHP*
In operation since:	*2010 (July)*
Air conditioned area:	*1,000 m²*

View of the STEWEAG GmbH office building.



Schematic illustration of the energy flows (Shankey diagram).



Average COP thermal and COP electrical per month over an annual time period (2010 - 1011).

Description of the Application

The 1,000m² office building of the Feistritzwerke STEWEAG GmbH (a regional energy and municipal water supplier) is located in Gleisdorf and was equipped with a solar thermal heating and cooling system in June 2010. Air ventilation is provided via manual window openings.

General description of the system

Solar thermal energy is produced by a 64 m² collector field and is stored in five 2 m³ heat storage tanks. One of these tanks is equipped with a stratifier unit and is switched in series to the other four tanks. That high temperature tank can be operated independently of the other four tanks.

The generator heat of the **absorption chiller** is taken out of the high temperature tank. The produced cold water is transported directly to the chilled ceilings in the office rooms - without any cold water storage in order to avoid an extra cold water pump to reduce the electricity effort. A **dynamic cooling power control** configuration is achieved for the chiller to produce the equal actual required cooling load of the building. This is realised by controlling the flow rates and temperatures in the hydraulic circuits of the chillers' periphery.

Heat rejection is realised with a wet, open cooling tower combined with an electrolytic water preparation device with the advantage of reduced electricity consumption.

Space heating occurs with the ceiling elements and with the existing radiators. During the heating season three CHP's, a condensing natural gas boiler and a heat pump serve as **backup**. Except the Feistritzwerke office building, also a local district heating net is supplied with heat.

Technical Characteristics

Solar Thermal

Collector Type:	Gluatmugl HT
Collector Area:	64m²
Collector gain (Oct10-Sep11):	493.2 kWh/m² (measured)

Solar Cooling - Chiller Characteristics

Technology:	Closed cycle
Nominal capacity:	19 kW
System's type:	Absorption
Cooling Load: (Oct10-Sep11)	13,354 kWh (measured)

Configuration

Heat storage:	5x2 m³ water
Cold storage:	none
Auxiliary heating system:	Vegetable oil driven CHP

System performance

	Oct 09 - Sept 10
SPF_{el} *(useful energy/ electricity effort)*	29,9

Software Tool

Description of Software Program

The software tool was developed in the High-Combi project, showing the potential of solar thermal energy to cover a high fraction of the heating, cooling and SHW consumption of buildings. The objective of the software program is to contribute in the optimum system's operation. In the main screen display the scheme of the simulated systems is presented.

In the High Combi project, three main system concepts had been analysed.

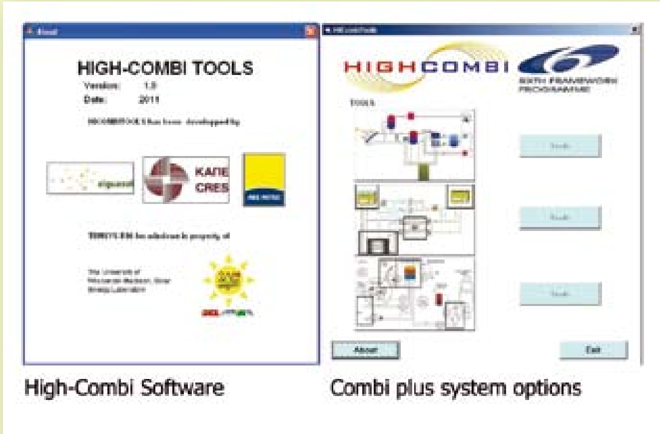
- A solarcombi-plus system,
- A solarcombi-plus system with seasonal storage through borehole thermal energy storage,
- A solarcombi-plus system with seasonal underground water thermal energy storage.

The software includes an overall energy analysis of each component, input and output of the system in a visualised user friendly way, cost analysis, comparison of the solar plant with a reference one (gas boiler and electric chiller). The results of the simulation present the economic, energetic and environmental analysis. In the economic analysis of the software tool, it is possible to estimate the necessary subsidy needed to make the investment sustainable.

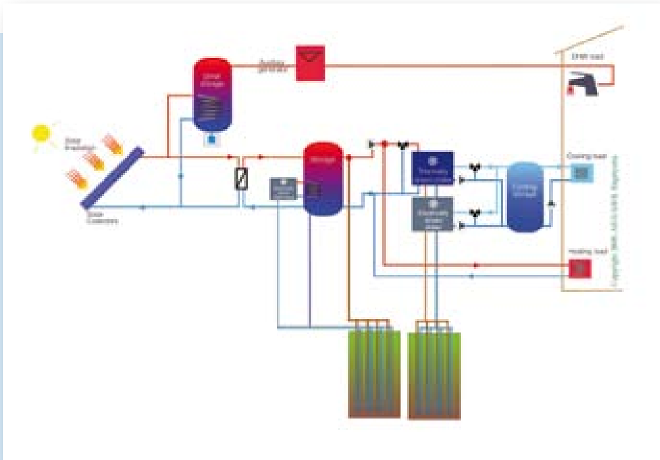
The software menu consists of five display sheets with different information included, according to particular configuration for each country's plant.

- ✔ Main
- ✔ General Data (simulation parameters, weather data etc.)
- ✔ Solar collector field
- ✔ System Demands
- ✔ Seasonal storage tank
- ✔ Absorption chiller (Cooling)
- ✔ Auxiliary System
- ✔ Outputs
- ✔ Results

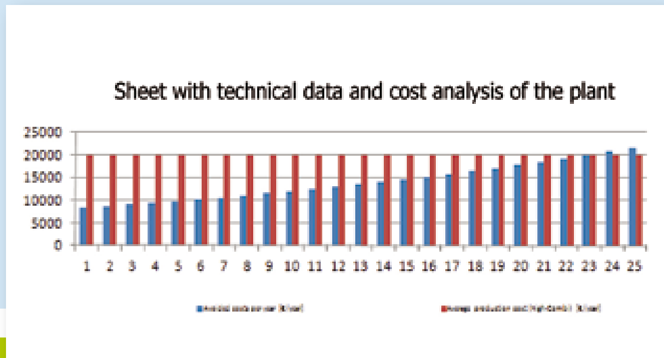
The software tool is available at the project website.



Screenshot of the high combi software program.



Schematic layout of a high combi plus system.



Indicative graph: Avoided cost vs average production cost.

Maintenance Guidelines

A smooth operation and a proper maintenance work is indispensable to guarantee a successfully operation performance of solar heating and cooling systems. The whole solar heating and cooling systems typically operates self-contained. An automatic control system (building management system) makes that possible. Nevertheless it is necessary from time to time to check the functionality of some main components and to do some maintenance work in order to keep the system running reliable. The manufacturers hand out specific operation and maintenance instructions which are typically for each main component (controller, chiller, cooling tower, water treatment device, pumps, expansion vessel, etc.).

Once the design and construction phases have been concluded properly, solar thermal plants require little maintenance in order to operate efficiently for their lifetime (estimated to be about 20 years) and the actions required are low cost. Apart from regular maintenance, most of the necessary actions during solar plant's operation are periodic inspections. They are listed in the table below, together with an indication as to their frequency.

Maintenance or periodic inspection	Frequency	Comments clarifications
Condition of collector array	Once a year	Visual inspection of possible internal or external degradations (broken glass, loose-jointed frames and connections etc). Remove and replace the broken or damaged parts.
Transfer fluid testing	Twice a year	Check the antifreeze solution percentage by measuring its density and the pH level (pH level should not fall below 7).
Pressure of the primary circuit should be constant	Twice a year	The inspection should be carried out when there is no incident radiation (e.g. in the evening time).
Temperature difference created by the collectors during sunny hours should be near the design value (e.g. about 20°C)	Twice a year	A higher value indicates a flow reduction due to obstacles or pumping problems. Lower values indicate either a too high flow or efficiency problems.
Primary circuit pump is off when there is no solar radiation	Twice a year	If not, there is some problem either with the sensors or the controller.
Presence of air in the primary circuit (noise)	Once a year	Remove trapped air - refill circuit at correct pressure if needed.
Clearness of collector glass surface	Once a year	Glass surface of the collectors needs to be cleaned when dirty and it has not rained for a long time.
Condition of energy meter	Twice a year	At least 2 kWh/m^2 per day, measured in a sunny day with normal heating load.

Present & Future Aspects

A combination of solar heating and cooling systems (Solar Combi Plus), if possible with thermal storage usage (High Solar Combi Plus), is an ideal solution, extending the use of the solar system throughout the year. Although a limited number of applications have been realized, on-going research and demonstration efforts are striving to achieve high solar fractions, thus enabling future market growth. Solar combi-plus systems may play an important role in the near future and support European and national efforts to meet the ambitious energy saving targets.

Almost all EU countries are considering special support programmes and stimulation schemes for a larger market deployment of solar thermal technologies. Solar air-conditioning installations will be supported by substantial investment funds in order to overcome the existing cost barriers and prove high quality performance and a high level of reliability.

On the other hand, in some other countries the support programmes are frequently changing because of short-term political decisions. For further information on up to date support programs for solar thermal installations, you have to contact the energy agency of your region (see back cover page of the brochure).

The following aspects have been identified in order to be further investigated:

- ✔ Use of GHE around the STES.
- ✔ Use of low cost thermal insulation materials.
- ✔ Use of an adsorption HP as the auxiliary heating and cooling source. This combination may lead to a 100% renewable energy coverage of the heating/cooling demands with a smaller and cheaper plant.
- ✔ Examination of similar systems in other countries.
- ✔ Optimization procedure with even more variables such as the control system, the solar collectors and STES combined with GHE.

Have you Say

Greece

The combination of solar heating and cooling technologies is rapidly evolving in recent years, setting new goals and offering new perspectives for the development of advanced heat pump systems.

The Greek High Combi project brings forward innovative ideas by implementing the daily use of the new technology in CRES premises. Furthermore, the project supports and promotes solar heating and cooling technologies and facilitates the penetration of renewable energy sources in everyday life, in line with the EU objectives for sustainable development and environmental protection.

Giorgos Sirpis, Head of Technical Support & Procurement Department

Italy

The Province of Milan governs the largest metropolitan area in Italy and is located in the middle of one of the most highly populated regions of Europe. Almost four million people live and work in the district, all within an area of less then 2,000 square kilometres. The Province of Milan Energy Sector deals with energy demand side management, rational use of energy and the development of renewable energy sources.

The key point of High Combi project lies in the use of solar energy for summer cooling. Due to the fact that the demand for “fresh” occurs in the period in which there is greater availability of solar energy, the principle of High Combi is to use the sun itself to produce “cold”. The basic idea is then to couple solar technologies with absorption chillers for cold production.

The goal of Province of Milan is ambitious: to create a “Zero Energy” facility-building system that minimizes the energy leakage of the building envelope and exploits as much as possible the use of solar energy thanks to an optimized combination of the best technologies for medium and large size buildings. The ultimate goal is to disseminate cutting-edge and proven technology solutions, now attractive on the market.

Spain

The activity that the Patronat Municipal de l’Habitatge develops as Social Housing real state developer has always been guided by the Concern about the environmental impact of construction and serious commitment to reduce it. In fact, more than a decade ago we started to introduce criteria of sustainable construction and energy efficiency in all our developments with the conviction that, a little increase in cost, can provide a better quality of life for all users in the city. Through this commitment we could make buildings that have received high marks energy, such as the promotion of Cibeles, which participates in the European project High Combi.

Antoni Sorolla, housing delegate, Town Hall of Barcelona

Austria

The Austrian HighCombi demonstration plants for solar cooling and heating showed clearly that the overall system design including the building, the proper installation and a very well fine tuned controlling according to the real needs of the inhabitants is essential for a successful operation and the achievement of significant primary energy savings. Main conclusion: Essentially, it is a system concept without hot auxiliary back-up based on fossil fuels. If necessary, a cold back-up based on compression chiller should be used. At least one year of monitoring based commissioning phase is recommended to enable optimized operation. Finally, in both plants remarkable primary energy savings in cooling months of more than 50% could be reached.

Consortium

Project Coordinator
CRES - Centre for Renewable Energy Sources & Saving, Solar Thermal Systems Department / Greece

AEE INTEC - Institute for Sustainable Technologies / Austria

AIGUASOL - Sistemes Avannats d'energia solar termica / Spain

FRAUNHOFER-ISE - Fraunhofer-Institut Solare Energiesysteme / Germany

NOA - National Observatory of Athens / Greece

PMHB - Patronat Municipal de l'Habitatge, Ajuntament de Barcelona / Spain

POLIMI - Politecnico di Milano / Italy

Provincia di Milano / Italy

S.O.L.I.D. - Solarinstallation und design GmbH / Austria

SOLE SA / Greece

SOLITES - Steinbeis Innovation GmbH / Germany

UOR - University of Oradea / Romania

HIGH COMBI

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ΚΑΠΕ
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