Climasol

Solar air conditioning guide

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I

INTRODUCTION

The demand for air conditioning in tertiary sector is increasing due to a demand for improved comfort, but also because of the higher temperatures that have occurred during the last decade. At the same time, passive or semi-active techniques, used for centuries to keep comfortable indoor conditions, seem to have been forgotten in a lot of new buildings.

This more and more extensive use of electrically driven compression cooling equipment is responsible for an increasing peak demand of electrical power in summer, which reaches the capacity limit in several cases. Emission of greenhouse gases is increased, by the energy production or by leakage of the cooling fluids, intensifying the vicious circle of the climate change.

As it is shown in the first part of this publication, a large choice of passive solutions is available, either for new buildings at the conception stage or for already existing ones, to improve the indoor conditions without any air conditioning system, or at least to drastically reduce the summer cooling needs.

At the same time, solar radiation is available. And the solar cooling technologies presented in this document have proved, for some of them during more than ten years, their efficiency and reliability. These technologies use harmless cooling fluids (water generally), and much less primary energy than the classical systems. Therefore, why not using solar energy for the purpose of keeping indoor conditions during summer in a comfortable range ?

I.1 - Why solar cooling ?

Throughout the years various methods for heat prevention and reducing indoor temperatures in the summer have been used. In the Mediterranean area, for example, buildings are painted in light colours in order to reflect a portion of the solar radiation, especially during the summer. The alternative cooling strategies are based on various passive and low energy cooling technologies for protection of the buildings via design measures or special components to moderate the solar or thermal gains, or to reject the excess heat to the ambient environment. All these techniques aim to reduce summer cooling loads and electricity demand for air conditioning.

During the summer the demand for electricity increases because of the extensive use of heating ventilation air conditioning (HVAC) systems, which increase the peak electric load, causing major problems in the electric supply. The energy shortage is worse during 'dry' years because of the inability of the hydroelectric power stations to function and cover part of the peak load.

The use of solar energy to drive cooling cycles for space conditioning of most buildings is an attractive concept, since the cooling load coincides generally with solar energy availability and therefore cooling requirements of a building are roughly in phase with the solar incidence.

Solar cooling systems have the advantage of using absolutely harmless working fluids such as water, or solutions of certain salts. They are energy efficient and environmentally safe. They can be used, either as stand-alone systems or with conventional air conditioning, to improve the indoor air quality of all types of buildings. The main goal is to utilize "zero emission" technologies to reduce energy consumption and CO_2 emissions.

I.2 - Are the solar cooling technologies attractive ?

Although a large potential market exists for solar cooling technology, existing solar cooling systems are not directly economically competitive with electricity-driven or gas-fired HVAC, mainly because of the high investment cost of solar cooling systems and the low prices of conventional fuels.

Lowering the cost of the different components (solar collectors, chillers...) and improving their performance will change the situation dramatically, even though it is still difficult to predict the date when these solar technologies will reach economical maturity.

The comparison of a solar technology with one of conventional energy sources can only be made if the environmental and societal costs (with externalities, distribution costs and indirect costs) are included in each case. The unpredictability of conventional fuel prices over long periods should also be taken into account.

In general we can note for the solar energy technologies that:

- their cost is decreasing as they enter mass production
- they are already technically mature to meet the consumer's needs
- they are much friendlier than the conventional air conditioning systems

With all this, there is a strong need both for some kind of investment incentive and also for an energy tax that would help reflect the full environmental costs of conventional fuels. In a lot of countries, the available subsidies provide a more economically attractive solution.

I.3 - How to go for a solar cooling installation ?

You are convinced that, to cut the vicious circle of the climate change, we need a more conscious environmental approach to our energy consumption ? That the reduction of the cooling needs by passive or bioclimatic techniques is the first step of this approach ? And that, if a cooling system is still needed, the friendly solar cooling technologies could be a good solution ? This publication is for you.

The first part of this publication presents the main passive or semi-active techniques for reducing summer cooling loads.
Different technologies of solar assisted cooling systems are then described : absorption, adsorption or desiccant systems.
The brochure contains also a large list of commercial installations in operation, with ten show cases in different countries, climate contexts, use and range of applied techniques.
And, last but not least, advices to go further in your solar air conditioning project.

2

REDUCING SUMMER COOLING LOADS

Thanks to solar energy cooling systems it is possible to cool buildings yet avoid any environmental impact. However, whilst solar energy, that is the source of energy they use, is free, given the same amount of cooling power generated, such systems are more expensive than air conditioning plants using traditional compression cooling systems.

Therefore, if deciding to install a solar energy cooling system, one should carefully analyze the features of the building to be cooled and adopt all the measures needed to reduce energy requirements. The purpose of this chapter is to summarize the principles, strategies and techniques for reducing summer cooling loads.

The advice contained in this document covers both buildings still to be designed, for which it is possible to opt for far more innovative approaches and solutions, and existing ones for which there are, anyway, many intervention strategies.

2.1 - General principles

In summer cooling systems, the cooling power of the chillers is assessed on the grounds of the summer cooling load, that is the sum of all cooling loads, both internal and external, which goes to affect the thermal balance between the closed environment and whatever is to be found outside it (not only the external environment as such but also all the neighbouring environments which are not air-conditioned). In summer the amount of heat to be removed depends on a number of factors some of which, like solar radiation incidence, vary depending on the time of the day.

The factors having the greatest impact on summer cooling loads are as follows:

- effects of solar radiation through clear transparent surfaces;
- effects of heat transfer through clear and opaque structures;
- effects of thermal inertia of building structures;
- internal thermal loads, both sensible and latent, due to the presence of both people and heat-generating sources (lighting, different kinds of machine, etc.);
- heat gain, both sensible and latent, due to infiltration and airing of room.

The flow chart of Figure1 shows that the summer cooling load is greatly influenced by the features of the architectural elements defining the building envelope.

A cooling system planned for summer months must be able to remove both sensible and latent heat from the building.

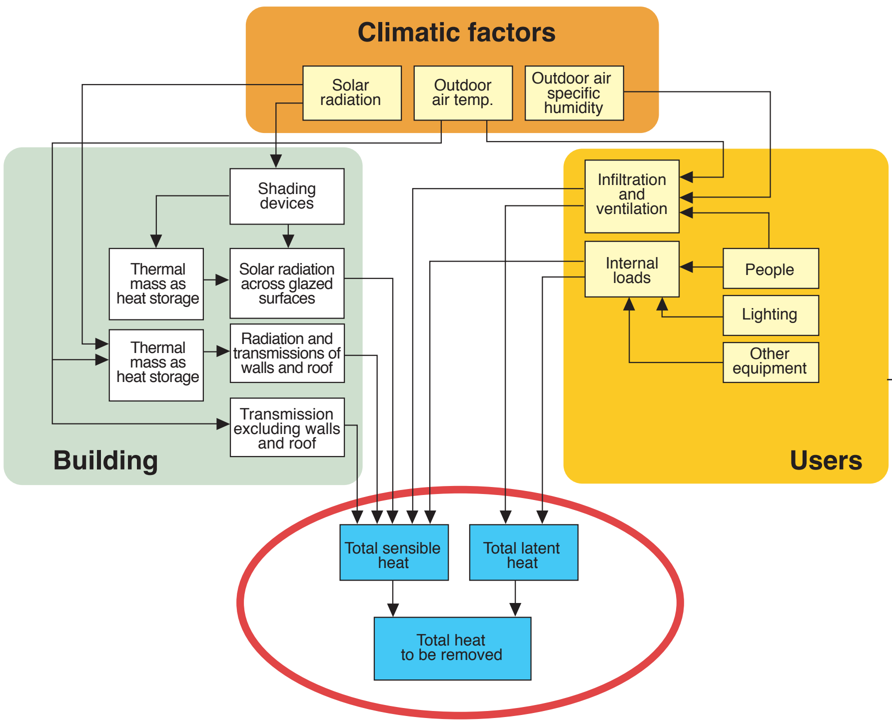


Figure 1
Flow chart of the calculation procedure for the assessment of a building's summer cooling loads.

Sensible heat and latent heat

Sensible heat, which usually prevails over latent heat, is the sum of the heat loads which result only in an increase in temperature; it comes from outside the building as a result of solar radiation of the difference in temperature between the outside and the inside of the building (transmission of heat by conduction through the structure) and also because of the so-called internal loads, such as – for instance - people and any source of heat (lighting, equipment, engines, etc.).

Latent heat, instead, is the sum of the heat loads which go to increase the amount of vapour to be found in the air and, as a result, of humidity, without increasing temperature; ambient latent heat results of steam emitted by people (through breathing and perspiration) and other vapour-producing sources (cooling, drying of laundry, etc.).
When ventilating a room, the air coming from the outside brings sensible heat, as its temperature is higher than ambient temperature, and latent heat, given its vapour content.

Figure 2
Offices of Chamber of Commerce in Freiburg (D): correct example of application of techniques to reduce summer thermal loads (sun protection and ventilation of roof), shading devices and green roof.

2.2 - Strategies

The summer cooling loads of a building and, therefore, the energy requirements of the cooling system, may be reduced by adopting "bioclimatic" strategies (Figure 3).
Reduction of heat loads, by foreseeing in the design stage:
- sun protection for windows, walls and surface cover, by using artificial or natural screening devices (Figure 4, 5);
- major thermal inertia coupled with nocturnal ventilation;
- adequate ventilation.

Reduction of outside temperature by intervening on the external setting in close proximity to the building by:
- increasing relative air humidity with of ponds, fountains and vegetation;
- shading through planting schemes (trees, pergolas, etc.);
- reducing external sun-glare (creation of green areas);
- choosing light-coloured for exterior walls.

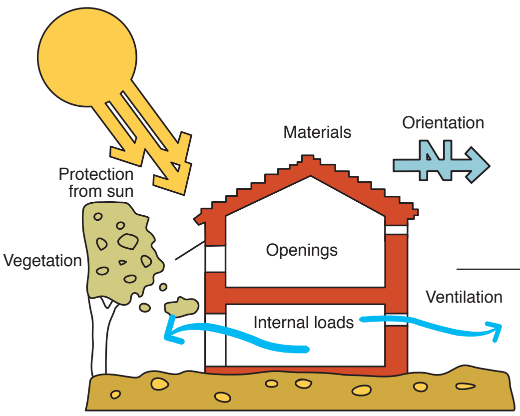


Figure 3
A reduction of the summer cooling loads may be obtained, in the planning stage, by having recourse to bioclimatic strategies

Figure 4
Vertical shadings devices in an office building in Dresden (D)

PROTECTION FROM SUN

In summer, solar radiation penetrates the transparent surfaces of the envelope (doors and windows) causing an immediate energy gain which must be removed by the cooling system. The impact of solar radiation may be reduced by having recourse to different kinds of shading devices:
- vertical shading devices (for east or west-facing orientations) or horizontal (for south-facing orientations) (Figure 7);
- fixed or adjustable external sunscreens;
- external awnings (rolling blinds or Venetian blinds);
- internal curtains (Venetian blinds or fabric);
- special glazing.

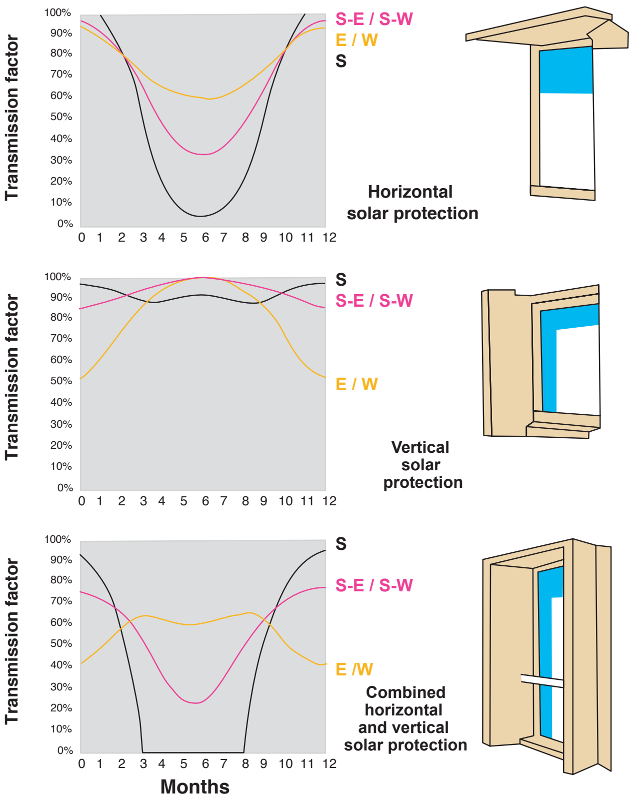
External shading devices prove to be the most effective as they prevent solar radiation from beating on transparent surfaces.

Figure 5 *Protection from the sun with horizontal overhangs and external awnings in an office building in Dresden (D)*

Figure 6
Horizontal overhang with integrated PV modules (solar houses in Freiburg (D))

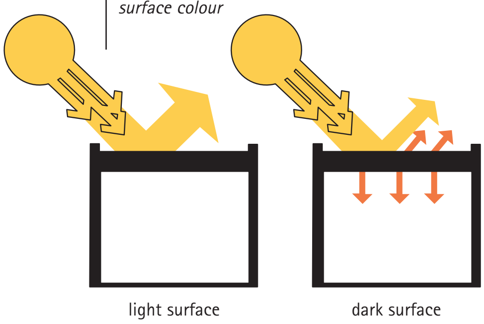
Effectiveness of different solar protection systems, depending on:
- the geometry of the solar protection
- the orientation of the façade
- the period of the year

Figure 7



Graphs in Figure 7 show the effectiveness of some solar protection systems.
Solar protection is also important for opaque surfaces and above all the roof covering which is the envelope surface most affected by solar radiation.
Should it be impossible to resort to true and proper screening devices it might be advisable to choose the most suitable external surface colour scheme with colours having a low absorption coefficient.

Figure 8
Thermal impact of solar radiation in relation to surface colour



THERMAL MASS CONTROL

The thermal inertia of a building has a major impact on the transfer of heat to the inside ambient.
A building characterized by a major thermal mass takes longer to heat and allows for the distribution of the heat entering through light-coloured walls over a longer period of time.
As a matter of fact, the structures accumulate direct radiation from the outside and release it to the inside ambient a few hours later.
In buildings having high thermal inertia, therefore, cooling system peaks are lower.

VENTILATION

In summer, ventilation is one of the easiest ways to ensure the thermal comfort of occupants of a building. There are two possible strategies. The first one also has a direct impact on the psychological well-being of the occupants and consists in moving the air inside the building by stirring it with ceiling fans or the like or by getting the air to circulate, possibly thanks to the help of air from the outside (provided this is not warmer than air inside the building).
The second approach, directed at cooling the building, consists in insistently airing the rooms provided the external air is cooler than the air to be found inside the building: this way the structures cool-off thus prolonging occupant comfort also during the hottest hours of the day.
In both instances the goal may be achieved either mechanically or by means of an airflow which is conveyed naturally through the building.
This entails having:
- rooms with a double orientation (at least two walls facing externally in two opposite directions);
- walls with openings subject to low noise pollution (to allow for the opening of air-intakes).

Controlling the three elements: thermal inertia, solar protection and ventilation bring about a marked decrease in average internal temperatures in summer.

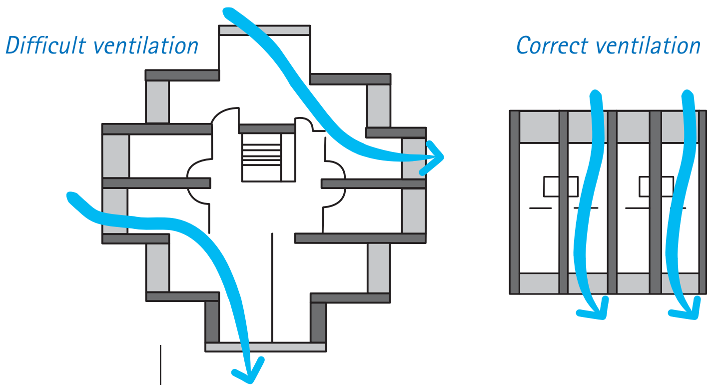


Figure 9
Natural ventilation also depends on the layout of buildings. Rooms with a double orientation with at least two walls facing externally but in opposite directions make for easier ventilation.

2.3 - Techniques for the reduction of summer cooling loads

If buildings are carefully planned taking into account the building design parameters discussed above, the need for summer air conditioning is drastically reduced.
Although some of the techniques discussed can be efficiently applied to buildings still in the design stage, many interventions aimed at the reduction of the summer cooling loads may be implemented also in existing buildings at a reasonable cost.

NATURAL TECHNIQUES AND PASSIVE COOLING

Passive cooling techniques may be subdivided into two major groups:
- those protecting the building through project solutions limiting solar heat gains and internal gains;
- those contributing to remove summer heat from the air-conditioned ambient by conveying it towards other ambients (water, air, ground, etc.).

The planning criteria to be adopted are clearly set out in the "Natural and Low Energy Cooling in Buildings" brochure (see bibliography).

REDUCTION OF SUMMER COOLING LOADS IN EXISTING BUILDINGS

The technologies considered in the previous paragraphs can drastically reduce the summer thermal loads of a building both as peak power as well as energy consumption, by:

- improving of the operational management of the building-plant system;
- reducing of the internal thermal loads;
- carrying out structural interventions on the building envelope;
- intervening on the air conditioning plant.

The reduction of the loads depends on many factors: technical features of the envelope, orientation, building mass, latitude, climatic conditions, etc. A computer simulation has been run considering an hypothetic office plan located, in Rome (Lat. 43°N), characterized by a medium weight structure and a single external façade with 80 % glazing. The simulation has considered different orientations of the module and various energy saving measures. The results have shown that significant savings (up to 45 %) are possible by adopting quite simple passive cooling solutions. These results, because specific to a building, shouldn't though be taken as general values.

	Description of interventions	Cost	Savings
Operational management	Regulation of internal temperature in each space	null	0% - 6%
	Increase of ambient temperature (i.e. 27 °C instead of 25 °C)	null	4% - 8%
	Increase of ambient relative humidity (i.e. 60-55% instead of 50%)	null	1% - 5%
	Correct utilization of the lighting plant and electrical appliances	null	3% - 7%
	Correct management of external windows and shutters	null	0% - 5%
Reduction of internal thermal loads	Regulation of the lighting plant system (variation of intensity, sensor people detectors, etc.) with incandescent lights	low	4% - 6%
	Regulation of the lighting plant system (variation of intensity, sensor people detectors, etc.) with fluorescent lights	low	2% - 4%
	Utilization of low-energy lighting appliances (i.e. fluorescent lights instead of incandescent lamps)	medium	10% - 13%
Interventions on the building envelope	Internal shading devices	low	2% - 5%
	External shading devices	medium	8% - 19%
	Application of vertical (0,6 m) overhangs	high	2% - 18%
	Application of horizontal (1,5 m) overhangs	high	1% - 9%
	Application of horizontal (0,6 m) overhangs	high	2% - 8%
	Application of reflective double glazing	high	4% - 7%
	Application of reflective film	medium	3% - 11%
	Painting of external walls with light colours with low absorption	low	1% - 8%
	Insulation coating of perimeter walls	high	0,6% - 1%
	Application of ventilated cavity wall	high	0,2% - 0,6%
	Roof insulation	medium	3% - 6%
	Application of shading devices on the roof covering	high	2% - 8%
	Realization of ventilated roofs	high	4% - 15%
Intervention on plant system	Installation of a heat recovery unit from extracted air	high	2% - 4%
	Implementation of free-cooling and night purge	medium	4% - 8%
	Installation of efficient regulation systems	high	2% - 8%
	Installation of radiant terminals (cold ceilings, cold beams, etc.)	high	2% - 8%

Table 1: Technical and operational management intervention for thermal load reduction on summer season, related with the costs and energy savings.

3

SOLAR AIR CONDITIONING TECHNICAL OVERVIEW

In solar assisted air conditioning systems, solar heat is required to drive the cooling process. The most common technologies used in combination with solar heat are shown in the following table. Thus, solar assisted air conditioning systems operated so far may be classified into:

- closed systems: these are thermally driven chillers which provide chilled water, that is either used in air handling units to supply conditioned air (cooled, dehumidified) or that is distributed via a chilled water network to the designated rooms to operate decentralized room installations, e.g. fan coils. Market available machines for this purpose are absorption chillers (most common) and adsorption chillers (a few hundred machines worldwide, but of rising interest in solar assisted air conditioning);

- open systems, allowing complete air conditioning by supplying cooled and dehumidified air according to the comfort conditions. The "refrigerant" is always water, since it is in direct contact with the atmosphere. Most common systems are desiccant cooling systems using a rotating dehumidification wheel with solid sorbent.

Method	Closed cycle		Open cycle	
Refrigerant cycle	Closed refrigerant cycle		Refrigerant (water) is in contact with the atmosphere	
Principle	Chilled water		Dehumidification of air and evaporative cooling	
Phase of sorbent	solid	liquid	solid	liquid
				
Typical material pairs	water - silica gel	water - lithium bromide ammonia - water	water - silica gel, water - lithium chloride	water - calcium chloride, water - lithium chloride
Market available technology	Adsorption chiller	Absorption chiller	Desiccant cooling	Close to market introduction
Typical cooling capacity (kW cold)	50 – 430 kW	15 kW – 5 MW	20 kW – 350 kW (per module)	
Typical COP	0.5 – 0.7	0.6 – 0.75 (single effect)	0.5 – >1	> 1
Driving temperature	60 – 90 °C	80 – 110 °C	45 – 95 °C	45 – 70 °C
Solar collectors	Vacuum tubes, flat plate collectors	Vacuum tubes	Flat plate collectors, solar air collectors	Flat plate collectors, solar air collectors

Table 2: Overview of the most common solar assisted air conditioning technologies.

3.1 - Thermally driven chillers

Thermally driven chillers may be characterized by three temperature levels:
- a high temperature level at which the driving temperature of the process is provided;
- a low temperature level at which the chilling process is operated;
- a medium temperature level at which both the heat rejected from the chilled water cycle and the driving heat have to be removed. For this heat removal, in most cases, a wet-cooling tower is used.

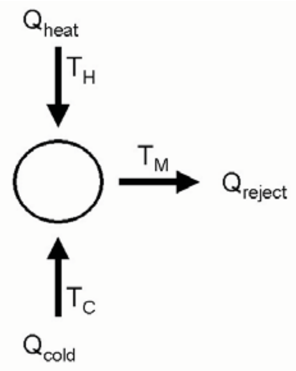


Figure 10
Basic scheme of the process: Q_{cold} is the heat rejected from the chilled water in the evaporator of the chiller (chilling power), Q_{heat} is the required heat in the generation part to drive the process, and the amount of Q_{reject}, the sum of Q_{cold} and Q_{heat}, has to be removed at a medium temperature level TM. Q_{heat} is deliverd either by the solar system or by backup heat sources, e.g. by district heat or by a gas burner.

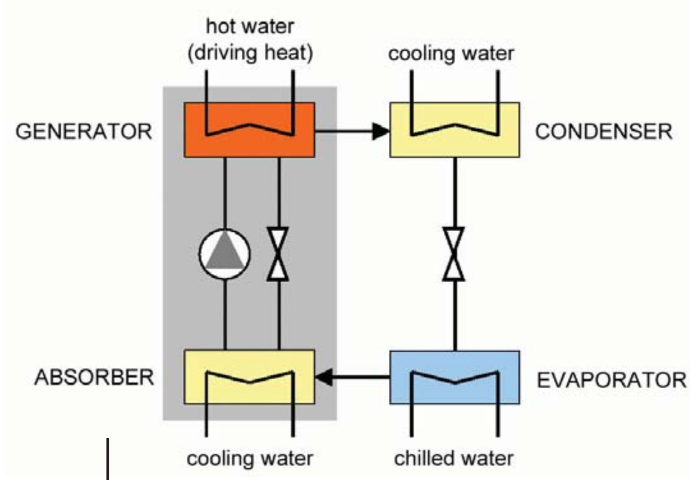


Figure 11
Schematic drawing of an absorption chiller

A key figure describing the efficiency of a thermally driven chiller is the thermal Coefficient Of Performance (COP), defined as the fraction of heat rejected from the chilled water cycle ('delivered cold') and the required driving heat, i.e. $COP_{thermal} = Q_{cold} / Q_{heat}$. This is different to the COP_{conv} of a conventional electrically driven compression chiller, defined by $COP_{conv} = Q_{cold} / E_{electric}$, with $E_{electric}$ representing the electricity consumption of the chiller.

This definition of the $COP_{thermal}$ does not include any additional electric power consumption. A realistic comparison of different technologies thus requires the consideration of the total energy input for heat as well as for pumps, fans, etc. It has to be noted that the smaller the COP, the more heat input is required and the more heat has to be removed by the cooling tower. Vice versa, a high COP value is of advantage in reducing both heat input and electric power for the pumps in the heating cycle and in the re-cooling cycle.
The required chilled water temperature depends on the installed cooling system in the rooms. In case that a dehumidification of the air is required, e.g. falling below the saturation point of the room temperature by using fan coils, chilled water temperatures in the range of 6°C-9°C are required. For the removal of sensible cooling loads only, as it is achieved with cooled supply air or with room installations such as chilled ceilings etc., a chilled water temperature of 12°C-15°C is sufficient, allowing to operate the chiller with higher performance.

ABSORPTION CHILLERS

Absorption chillers are the most distributed chillers worldwide. A thermal compression of the refrigerant is achieved by using a liquid refrigerant/sorbent solution and a heat source, thereby replacing the electric power consumption of a mechanical compressor. For chilled water above 0°C, as it is used in air conditioning, typically a liquid H_2O/LiBr solution is applied with water as refrigerant. Most systems use an internal solution pump, but consuming little electric power only. In the operation of an H_2O/LiBr absorption chiller, a crystallisation of the solution has to be avoided by an internal control of the heat rejection temperature in the machine.
The main components of an absorption chiller are shown in the figure following.

The cooling effect is based on the evaporation of the refrigerant (water) in the evaporator at very low pressures. The vaporised refrigerant is absorbed in the absorber, thereby diluting the H_2O/LiBr solution. To make the absorption process efficient, the process has to be cooled. The solution is continuously pumped into the generator, where the regeneration of the solution is achieved by applying driving heat (e.g. hot water). The refrigerant leaving the generator by this process condenses through the application of cooling water in the condenser and circulates by means of an expansion valve again into the evaporator.
Typical chilling capacities of absorption chillers are several hundred kW. Mainly, they are supplied with district heat, waste heat or heat from co-generation. The required heat source temperature is usually above 80°C for single-effect machines and the COP is in the range from 0.6 to 0.8. Double-effect machines with two generator stages require driving temperature of above 140°C, but the COP's may achieve values up to 1.2.

Figure 12
Absorption chiller – Rethimno village hotel - Crete

A few absorption chillers with capacities below 50 kW are available. In solar assisted air conditioning systems with absorption chillers, often these small units are implemented. A machine type, developed newly for small capacities, enables part-load operation with reduced chilling power already at heat source temperatures of 65°C and with a COP of still approximately 0.7, which is promising in combination with solar heat. This indicates that there is still potential for performance improvements of absorption chillers.

ADSORPTION CHILLERS

Here, instead of a liquid solution, solid sorption materials are applied. Market available systems use water as refrigerant and silica gel as sorbent.
The machines consist of two sorbent compartments (denoted as 1 and 2 in the figure below), one evaporator and one condenser. While the sorbent in the first compartment is regenerated using hot water from the external heat source, e.g. the solar collector, the sorbent in the compartment 2 (adsorber) adsorbs the water vapour entering from the evaporator; this compartment has to be cooled in order to enable a continuous adsorption. The water in the evaporator is transferred into the gas phase being heated from the external water cycle; here actually the useful cooling is produced. If the cooling capacity reduces to a certain value due to the loading of the sorbent in the adsorber, the chambers are switched over in their function. To date, only a few Asian manufacturers produce adsorption chillers.

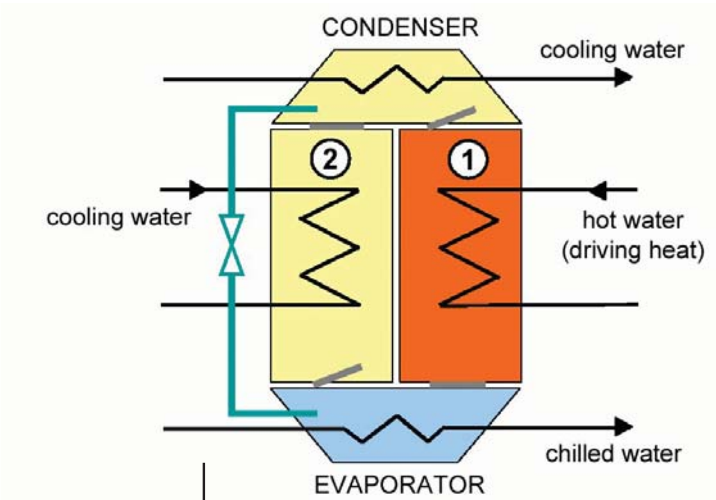


Figure 13
Schematic drawing of an adsorption chiller

Under typical operation conditions with a temperature of the driving heat of about 80°C, the systems achieve a COP of about 0.6, but operation is possible even at heat source temperatures of approx. 60°C. The capacity of the chillers ranges from 50 kW to 500 kW chilling power.

The simple mechanical construction of adsorption chillers and their expected robustness is an advantage.
No danger of crystallisation is given and thus no limitation in the heat rejection temperatures are existing. An internal solution pump does not exist and hence only a minimum of electricity is consumed. A disadvantage is the comparatively large volume and weight. Furthermore, due to the small number of produced items, the price of adsorption chillers is currently high. A large potential for improvements of the heat exchangers in the adsorber compartments is expected; thus, a considerable decrease in volume and weight can be assumed in future generations of adsorption chillers.

Figure 14
Adsorption chiller - Sarantis - Greece

3.2 - Desiccant cooling systems

Desiccant cooling systems are basically open cycle systems, using water as refrigerant in direct contact with air. The thermally driven cooling cycle is a combination of evaporative cooling with air dehumidification by a desiccant, i.e. a hygroscopic material. For this purpose, liquid or solid materials can be employed. The term 'open' is used to indicate that the refrigerant is discarded from the system after providing the cooling effect and new refrigerant is supplied in its place in an open-ended loop. Therefore only water is possible as refrigerant since a direct contact to the atmosphere exists. The common technology applied today uses rotating desiccant wheels, equipped either with silica gel or lithium-chloride as sorption material.

SOLID DESICCANT COOLING WITH ROTATING WHEELS

The main components of a solar assisted desiccant cooling system is shown in the figure below. The basic process in providing conditioned air may be described as follows.

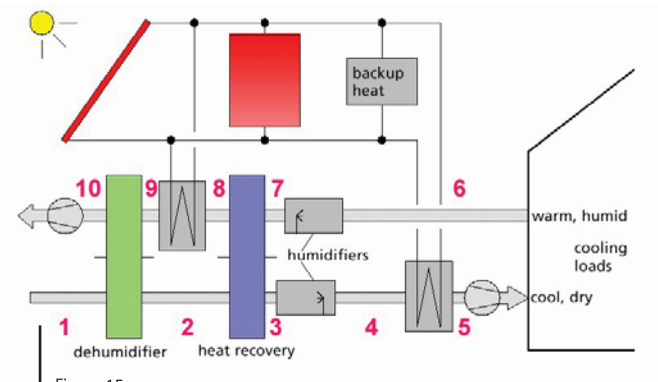


Figure 15
Schematic drawing of a desiccant cooling system

A: Cooling case

Warm and humid ambient air enters the slowly rotating desiccant wheel and is dehumidified by adsorption of water (1-2). Since the air is heated up by the adsorption heat, a heat recovery wheel is passed (2-3), resulting in a significant pre-cooling of the supply air stream. Subsequently, the air is humidified and further cooled by a controlled humidifier (3-4), according to the desired temperature and humidity of the supply air stream. The exhaust air stream of the rooms is humidified (6-7) close to the saturation point to exploit the full cooling potential in order to allow an effective heat recovery (7-8).
Finally, the sorption wheel has to be regenerated (9-10) by applying heat in a comparatively low temperature range from 50°C-75°C, to allow a continuous operation of the dehumidification process.

B: Heating case

In periods with low heating demand, heat recovery from the exhaust air stream and enthalpy exchange by using a fast rotating mode of the desiccant wheel may be sufficient. In case of increasing heating demand, heat from the solar thermal collectors and, if necessary, from a backup heat source (4-5) is applied.

Flat-plate solar thermal collectors can be normally applied as heating system in solar assisted desiccant cooling systems. The solar system may consist of collectors using water as fluid and a hot water storage, to increase the utilisation of the solar system. This configuration requires an additional water/air heat exchanger, to connect the solar system to the air system. An alternative solution, leading to lower investment cost, is the direct supply of regeneration heat by means of solar air collectors.

Special design of the desiccant cycle is needed in case of extreme outdoor conditions such as e.g. coastal areas of the Mediterranean region.
Here, due to the high humidity of ambient air, a standard configuration of the desiccant cooling cycle is not able to reduce the humidity down to a level that is low enough to employ direct evaporative cooling. More complex designs of the desiccant air handling unit employing for instance another enthalpy wheel or additional air coolers supplied by chilled water can overcome this problem.

LIQUID DESICCANT COOLING

A new development, close to market introduction, are desiccant cooling systems using a liquid Water/Lithium-Chloride solution as sorption material. This type of systems shows several advantages like higher air dehumidification at the same driving temperature range than solid desiccant cooling systems, and the possibility of high energy storage by storing the concentrated solution. This technology is a promising future option for a further increase in exploitation of solar thermal systems for air conditioning.

Figure 16
Liquid desiccant cooling system, installed at the new "Solar Building Innovation Center (SOBIC)" at Freiburg (D).

3.3 - Solar collectors

The market available solar thermal collectors are shown in the following table. High temperature systems such as tracked parabolic troughs are not considered here.
In solar assisted air conditioning systems, the difference in the operation of the solar collectors compared to solar thermal collector systems for hot water production is the high temperature level, at which the useful heat has to be provided. For thermally driven chillers, the driving temperature is mainly above 80°C, lowest values are 60°C. For desiccant cooling systems, the driving temperature is above 55°C up to 90°C. Due to the high volume flow rates in the heat supply cycle, an ideal stratification in the hot water storage is difficult and the return temperature to the solar collector is relatively high as well. This causes some restrictions in the selection of the collector type.
Consequently, standard flat-plate collectors and solar air collectors may be implemented with most benefit in solar assisted desiccant systems. In configurations using an adsorption chiller or a single-effect absorption chiller, the use of selectively coated flat-plate collectors is limited to areas with high irradiation availability.
For other areas and for chillers requiring higher driving temperatures, high efficient collectors are to be implemented, e.g. evacuated tube collectors. From the fixed-mounted collector systems, highest temperatures may be achieved with evacuated tube collectors using optical concentration. This is an interesting option for solar assisted air conditioning system using high efficient absorption chillers (2- effect).

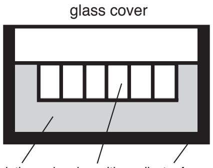
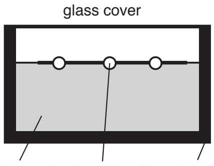
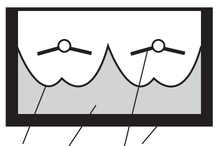
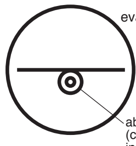
Collector type	Solar air collector	Flat-plate collector	Stationary parabolic compound collector	Vacuum tube collector (VTC)
Short cut	SAC	FPC	CPC	EHP, EDF, SYC: ETC
				
				
Principle	Direct heating of air	Heating of a liquid (water, water-glycol)	Heating of a liquid (water, water-glycol); radiation concentration without tracking	Evacuated glass tube for reduction of thermal losses EHP: evacuated tube with heat pipe EDF: evacuated tube with direct flow SYC: Sydney-type evacuated tube with concentrator reflector
Main application area	Pre-heating of ventilation air	Domestic hot water preparation	Domestic and industrial hot water preparation	Domestic and industrial hot water preparation
Prevalent application in solar assisted air conditioning	Open cooling systems, e.g. desiccant cooling systems	Desiccant cooling systems, Thermally driven chillers (single-stage) with selective absorbers	Thermally driven chillers (single-stage)	Thermally driven chillers (single-stage) Thermally driven chillers (double-stage): SYC

Table 3

3.4 - Precautions with cooling towers and air-handling units

Traditional air handling units with air supply generally use humidification systems and a wet cooling tower has to be installed in sorption systems.
The two technologies can present a risk of legionella development if the installation has not a serious and sustainable maintenance plan.

This issue is not therefore particular to solar cooling systems and standard safety/maintenance rules make it possible to avoid the risk. In each country, special standard technical conditions must be taken into consideration in the design process of solar cooling systems.

3.5 - Investment and running cost

Most of today realised projects are of research or demonstration nature and still much additional design and planning effort are necessary. The technical effort in the implementation of a solar assisted air conditioning system is higher as compared to the implementation of a conventional system. This results from the complete additional solar thermal installation on the one hand, and from the increased requirements on the re-cooling installations, since the thermally driven chillers usually need higher amounts of heat to be re-cooled. Furthermore, some of the component costs are still high, since the production of particular components, e.g. adsorption chillers, is currently far below the level of large scale industrial production.

As a summary, the investment costs of the systems are considerably above the investment costs of conventional system solutions. This is less valid for desiccant cooling systems, as the dominating cost for the ventilation system are required in both the solar assisted system and the conventional system and the additional cost of the collector system is partwise compensated through the absence of a chiller, as it is required in the conventional system configuration.

On the other hand, the running costs of solar assisted air conditioning systems are expected to be considerably below the running costs of a conventional system. This is especially the case if in a given building the peak electricity power is caused by the conventional compression chiller and a special fee is due to peak consumption.

Although a precise statement on the economic situation of a solar assisted air conditioning system depends on the specific system, in general the annual cost, i.e., the complete cost including investment (capital cost), operation and maintenance costs etc., of a solar assisted air conditioning system are currently above the annual cost of a conventional system.

For desiccant cooling systems, it is expected that with a moderate decrease in component costs (nearly within the range of negotiations with distributors), these types of solar assisted air conditioning systems may be already cost competitive in some applications, with conventional solutions.

For systems using thermally driven chillers, more actions are necessary to improve the cost performance. Although remarkable future cost reductions of the adsorption chillers and of evacuated tube collectors are expected, additional efforts in an increase of the technical performance (COP) of the chillers are required. A raised experience of manufacturers, planners and installers of these types of systems may additionally result in a decrease of cost for planning, installation and control. With these measures, the systems may achieve step by step a cost range close to conventional systems, but always saving considerable amounts of primary energy and thus contributing to the goals in reducing environmentally hazardous emissions.

N°	Location (Country) *
	Type of building Technology – Cooling capacity (kW cold) Collector type – Gross collector area - In operation since

* The installations marked with the stars are presented with more details in the following pages.

Collector type
VTC : Vacuum Tube Collector
FPC : Flat Plate Collector
CPC : Compound Parabolic Collector
SAC: Solar Air Collector

Technology
Ab: Absorption
Ad: Adsorption
DEC: Desiccant cooling

1 Wolfferts
Köln (D)
Offices
AB - 70 kWc
VTC - 196 m² - 1995

2 Ott & Spies *
Langenau (D)
Offices
AB - 35 kWc
VTC - 45 m² - 1997

3 Bundespresseamt
Berlin (D)
Offices
AB - 70 kWc
VTC - 348 m² - 2000

4 University hospital
Freiburg (D) *
Laboratory
AD - 70 kWc
VTC - 230 m² - 1999

5 IHK *
Freiburg (D)
Meeting room
DEC - 60 kWc
SAC - 100 m² - 2001

6 Fraunhofer Umsicht
Oberhausen (D)
Offices, laboratories
AB - 58 kWc
VTC - 108 m² - 2001

7 Bundesverkehrmini sterium, Berlin (D)
Chilled water network
AB - 70 kWc
FPC - 229 m² - 2000

8 ZAE Bayern
Garching (D)
Offices, laboratory
AB - 7 kWc
VTC - 30 m² - 1999

9 Zander
Stuttgart (D)
Offices, slab cooling
AB - 143 kWc
VTC - 300 m² - 2000

10 Technologiezentrum
Köthen (D)
Offices
AB - 15 kWc
VTC - 100 m² - 2000

11 Stadtwerke
Remscheid (D)
Offices
AD - 105 kWc
FPC - 170 m² - 1999

12 Bautzener Str
Dresden. (D)
Offices
AD - 71 kWc
FPC - 156 m² - 1996

13 Götz
Würzburg (D)
Offices
AD - 70 kWc
FPC - 80 m² - 1996

14 LfU
Augsburg (D)
Offices, seminar room
AD - 245 kWc
FPC - 2000 m² - 2000

15 Malteser-Krankenhaus
Kamenz (D)
Hospital
AD - 105 kWc
TIM-FPC - 140 m² - 2000

16 Ecotec
Bremen (D)
Offices
AD - 70 kWc
VTC - 175 m² - 2000

17 Stadtwerke
Bückeburg (D)
Seminar room, foyer
DEC - 30 kWc
SAC - 115 m² - 1998

18 ILK
Dresden (D)
Meeting room
DEC - 18 kWc
FPC - 20 m² - 1996

19 Gründerzentrum
Riesa (D)
Meeting room
DEC - 18 kWc
FPC - 23 m² - 1997

20 Fachhochschule
Stuttgart (D)
Exhibition room
DEC - 18 kWc
SAC - 20 m² - 1999

21 Mayer
Alt-Hengstett (D)
Factory
DEC - 108 kWc
SAC - 100 m² - 2000

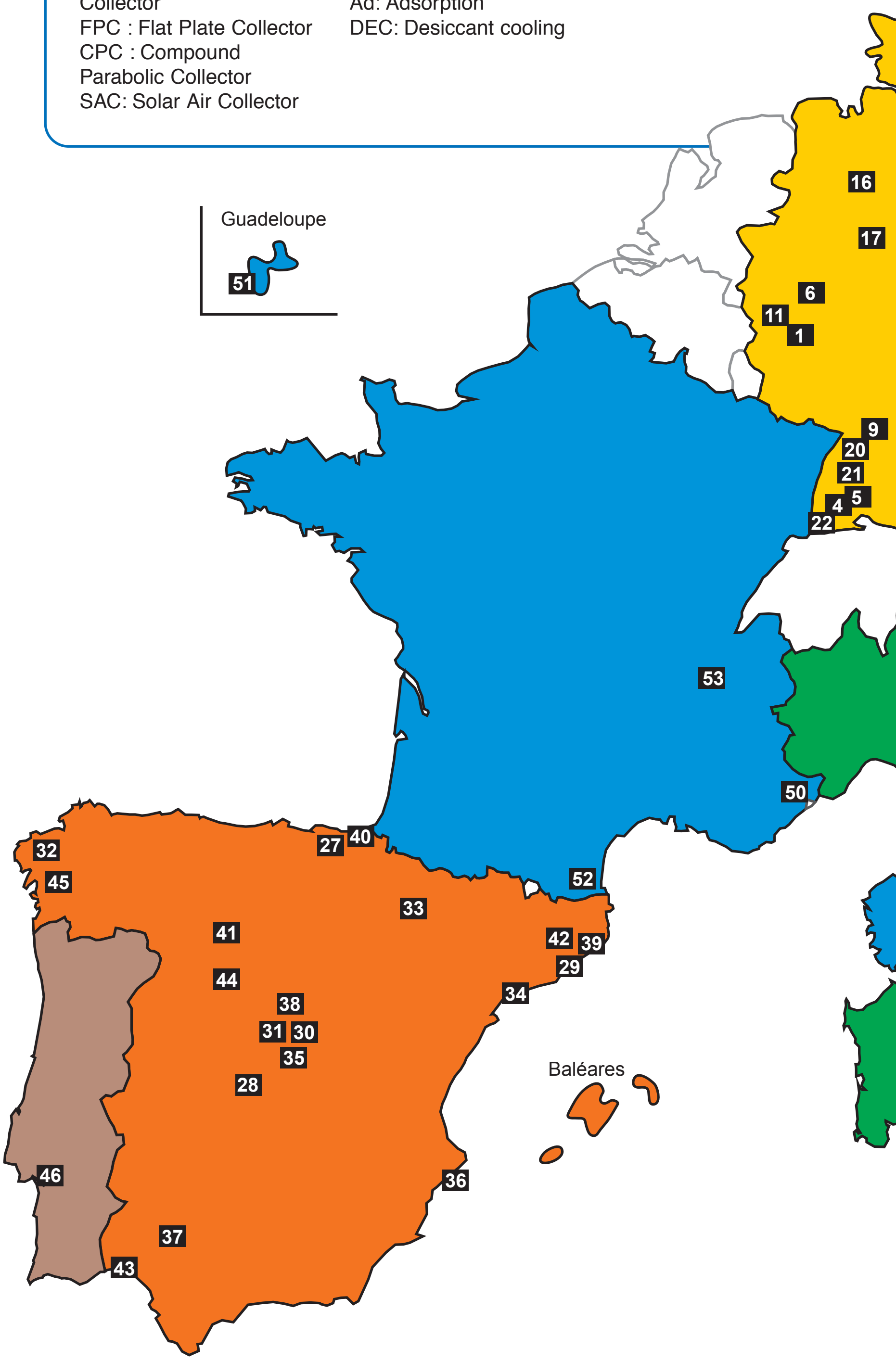
22 Fraunhofer ISE
Freiburg (D)
Test plant
DEC - 24 kWc
SAC+FPC - 40 m² - 2000

23 NCSR "Demokritos"
Solar lab Athens (GR)
Offices and laboratories
AB - 35 kWc
FPC - 160 m² - 2003

24 Sarantis SA *
Viotia (GR)
Industry (warehouse)
AD - 700 kWc
FPC - 2700 m² - 1999

25 Rethymno Village *
Hotel - Crete (GR)
Hotel
AB - 105 kWc
FPC - 450 m² - 2000

26 Lentzakis S.A.
Crete (GR)
Hotel
AB - 105 kWc
FPC - 450 m² - 2002



PLANTS

Here are plants in operation in "commercial" buildings (factories, offices, hotels ... , without the R&D installations) identified in the countries participating in the Climasol project.

27 Clara Campoamor Centre, Barakaldo (E)
Social and cultural centre
AB - 229 kWc
FPC - 163 m² - 2004

28 Education Department Toledo (E)
Offices
AB - 252 kWc
VTC - 1095 m² - 2004

29 Fábrica del Sol Barcelona (E)
Offices
AB - 105 kWc
VTC - 175 m² - 2004

30 Fundación Metrópoli Alcobendas (E)
Offices
AB - 105 kWc
VTC - 105 m² - 2004

31 Daoiz y Velarde Sports Centre Madrid (E)
Sports Centre
AB - 170 kWc
VTC - 740 m² - 2003

32 Inditex Arteixo (E) *
Offices, stores
AB - 170 kWc
FPC - 1626 m² - 2003

33 Old Peoples' Home Fustiñana (E)
Old Peoples' Home
AB - 105 kWc
VTC - 149 m² - 2003

34 University Rovira i Virgili - Tarragona (E)
Offices
AB - 35 kWc
VTC - 140 m² - 2003

35 Head Offices Viessmann Pinto (E)
Offices
AB - 105 kWc
FPC+VTC - 123 m² - 2001

36 Belroy Palace Hotel Benidorm (E)
Hotel
AB - 125 kWc
VTC - 345 m² - 1992

37 School of Engineers Sevilla (E)
Laboratory
AB - 35 kWc
FPC - 158 m² - 2001

38 University Carlos III Leganés (E)
Laboratory
AB - 35 kWc
FPC+VTC - 128 m² - 2000

39 Pompeu i Fabra Library Mataró (E)
Library
DEC - 55 kWc
SAC - 105 m² - 2002

40 Laia Hotel Derio (E)
Hotel
AB - 105 kWc
FPC - 173 m² - 2002

41 Cartif Valladolid (E)
Offices and laboratory
AB - 35 kWc
FPC+VTC - 99 m² - 2002

42 Siemens Corneliá del Vallés (E)
Offices
AB - 105 kWc
CPC - 214 m² - 2003

43 Inta El Arenosillo (E)
Laboratory
AB - 10 kWc
FPC+VTC - 53 m² - 1994

44 Fontedoso El Oso (E)
Industry
AB - 105 kWc
FPC - 528 m² - 2003

45 Stella-Feuga Santiago de Compostela (E)
Offices
AB - 115 kWc
FPC - 63 m² - 2003

46 Ineti, Lisbon (P) *
Offices
DEC - 36 kWc
CPC - 48 m² - 1999

47 Agenzia per lo Sviluppo - Trento (I) *
Offices, exhibition area
AB - 108 kWc
FPC - 265 m² - 2004

48 Ökopark Hartberg Styria (A) *
Offices, seminar rooms
DEC - 30 kWc
VTC - 12 m² - 2000

49 Vineyard Peitler Leutschach Styria (A)
Wine bottle storage
AB - 10 kWc
FPC - 100 m² - 2003

50 CSTB Sophia Antipolis (F)
Laboratories
AB - 35 kWc
VTC - 58 m² - 2003

51 DIREN Guadeloupe (F)
Offices
AB - 35 kWc
VTC - 100 m² - 2003

52 GICB Banyuls (F) *
Wine bottle storage
AB - 52 kWc
VTC - 215 m² - 1991

53 ASDER Chambéry (F)
Seminar room
DEC - 7 kWc
FPC - 16 m² - 2004

Ott & Spiess Langenau

NUMBER ON THE MAP: 2

COUNTRY
Germany

LOCATION
Langenau, Federal State of Baden Württemberg

BUILDING
Offices

COOLING CAPACITY
35 kWc

TECHNOLOGY
Absorption chiller

COLLECTOR TYPE
Evacuated tubes, direct flow

GROSS COLLECTOR AREA
45 m²

IN OPERATION SINCE
1997

Description :

In the new building of the company Ott & Spiess, an office area of 415 m² is cooled by chilled ceilings and by displacement ventilation with an air flow volume rate of 2 600 m³/h. The offices are located at the round-shaped south/southwest facade of the building to use passive solar gains in the heating period.
The chilled water is provided by an absorption chiller. The implemented thermal heating/cooling system is located in a partly glazed area to allow a demonstration of the system to visitors.
The solar thermal collector system, equipped with a hot water buffer storage of 2 m³, provides heat for both, driving the absorption chiller in the cooling season and for heating in winter. Additional heat in case of low solar gains or low storage temperature is obtained from a CHP unit for combined heat/electricity production (19.5 kW thermal power, 8 kW electrical power). If the heat demand still exceeds the capacity of the solar system or of the CHP unit, additionally a gas burner of 50 kW thermal power is started.
The chilled water from the common water/lithium-bromide absorption chiller is stored in a buffer of 1 m³ storage capacity. Due to the application in chilled ceilings and in the ventilation system, the chilled water is provided at a temperature of 13°C. A wet cooling tower re-cools the water to be used in the cooling circle in the condenser and in the absorber of the chiller.
In 1999, the annual Coefficient of Performance COP (useful cold / driving heat) of the chiller was 0.56. Approximately 9 % of the total heat input into the building for cooling and heating was provided by the solar system.

Investment and Financial Data :

Total investment cost: 285 000 €, and without chilled ceilings and floor heating: 176 000 €.

The project was subsidised by the Federal Ministry of Education and Research.

Energy and Environmental Data :

Due to the limited power of the CHP unit, the thermal power of this unit does not conflict with the gains from the solar system. With this system design, a high utilisation of both, the solar thermal system as well as of the CHP can be achieved, avoiding peak-electricity consumption during the cooling season. Savings in primary energy and related CO_2 emissions are expected as well.

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University Hospital Freiburg

NUMBER ON THE MAP: 4

COUNTRY
Germany

LOCATION
Freiburg, Federal State of Baden Württemberg

BUILDING
Laboratories

COOLING CAPACITY
70 kWc

TECHNOLOGY
Adsorption chiller

COLLECTOR TYPE
Evacuated tubes, direct flow

GROSS COLLECTOR AREA
230 m^2

IN OPERATION SINCE
1999

Description :

The hospital of the University Freiburg, 'Klinikum Freiburg', operates several laboratory facilities. One separate laboratory building is equipped with a solar assisted air conditioning system. The total cooled area of the building is approximately 550 m^2.
Two ventilation systems with variable volume flow rates (10 550 m^3/h and 6 350 m^3/h nominal) are implemented, using cross-flow heat exchangers for heat recovery in the heating season. During the cooling season, the supply air is cooled by means of heat exchangers with chilled water, provided by an adsorption chiller. The supply air temperature is set to 18°C.
The heat provided by the solar thermal collector system is used in summer to drive the adsorption chiller as well as to heat the ventilated supply air in winter. A hot water storage of 6 m^3 and a chilled water storage of 2 m^3 is integrated into the plant. In case of non-sufficient solar radiation and low hot water storage temperatures, additional heat from district heat (steam network of the hospital) is applied. A closed wet cooling tower re-cooles the water to be used in the cooling circles of the condenser and during the adsorption phase.
After adjustments in the chiller control due to the specific operation of the chiller, the evaluation of monitored data from 2002 reveals daily values of the thermal Coefficient of Performance COP (useful cold / driving heat) for several days in the cooling season around the expected value of 0.60. An annual net collector efficiency of 32 % was achieved.

Investment and Financial Data :

Total investment cost of the system: 352 000 € (without monitoring cost).
The installation was subsidised by the Federal Ministry of Economy and Work and by the company Sulzer Infra. The cumulated support was 262 000 €.
The annual operation and maintenance cost are approximately 12 000 €.

Energy and Environmental Data :

With this system concept, a steady-going utilisation of the existing steam-network is supported, avoiding peak-loads in both, steam and electricity consumption during high cooling loads which are coupled with high solar gains. Primary energy savings and thus the avoidance of CO_2 emissions are expected. Only environmentally friendly materials are employed in the adsorption chiller.

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IHK (chamber of commerce) Freiburg

NUMBER ON THE MAP: 5

COUNTRY
Germany

LOCATION
Freiburg, Federal State of Baden Württemberg

BUILDING
Offices, cooled:
2 meeting rooms

COOLING CAPACITY
60 kWc

TECHNOLOGY
Desiccant cooling system solar autonomous

COLLECTOR TYPE
Flat plate solar air collector

GROSS COLLECTOR AREA
100 m^2

IN OPERATION SINCE
2001

Description :

At the chamber of commerce (IHK Südlicher Oberrhein) in Freiburg, the first thermally solar autonomous driven desiccant cooling system in Germany is operated for cooling the areas of two meeting rooms in summer and for pre-heating the rooms in winter respectively.
The area of the small meeting room is 65 m^2, the area of the large meeting room is 148 m^2. The total capacity of the rooms is approximately 120 persons, the total volume of the rooms is 815 m^3. The facades are fully glazed, but provided with external and internal shading devices. The air flow volume of the desiccant cooling system is variable from 2 500 m^3/h to 10 200 m^3/h. No backup system for cooling is installed, since the cooling loads correlate quite well with the solar gains. In winter, a backup heating system is used to obtain the required supply air temperature.
In order to reduce the cost for collector support construction, the collectors are mounted roof-parallel at the 15° tilted roof area. Due to the concept using solar air collectors and due to the high correlation between solar gains and cooling load, a heat storage is not implemented.
As a consequence of the solar autonomous operation in summer, deviations from the comfort area as defined in DIN 1946, part 2, have occurred within the expected range for a small time fraction of system operation.

Investment and Financial Data :

Due to the cost-saving installation of the solar air collectors, the specific collector cost including the support structure are 210 €/m^2 gross area, equivalent to 10 % of the total investment cost of the system (210 000 €).
The specific cost of the air conditioning unit are approximately 9.50 €/m^3 nominal air flow volume (without installation cost).
The project was supported by the EC (NNE5-1999-531).

Energy and Environmental Data :

Environmental and primary energy savings are estimated by comparing the heat and electricity consumption figures of the solar driven desiccant cooling system to the consumption figures of a conventional air handling unit with heat supply in winter provided by a gas boiler, and with an electrically driven compression chiller for cooling the supply air in summer.
In this estimation, the annual primary energy savings are estimated to 30 000 kWh and the savings in CO_2 emissions are approximately 8 800 kg per year.

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Gr. Sarantis S.A., Viotia

NUMBER ON THE MAP: 24

COUNTRY
Greece

LOCATION
Oinofyta, Viotia

BUILDING
Warehouse of cosmetic Company Gr. Sarantis S.A.

COOLING CAPACITY
700 kWc

TECHNOLOGY
Adsorption

COLLECTOR TYPE
Selective flat plate solar collectors

GROSS COLLECTOR AREA
2 700 m^2

IN OPERATION SINCE
1999

Description :

This project is called "PHOTONIO" and is related with the installation of central air conditioning system using solar energy for the heating or cooling of the new buildings and warehouses of the cosmetic company Sarantis S.A.. The air-conditioned space is 22 000 m^2 (130 000 m^3). A park of 2 700 m^2 selective flat plate solar collectors was manufactured in Greece by SOLE S.A. and installed for this purpose.

Investment and Financial Data :

Total cost of the investment: 1 305 943 €, 50 % funded by National Operational Programme for Energy (of the Greek Ministry of Development)
The project has been awarded by "Energy Globe Award 2001"as the world's third best investment for sustainable energy in the year 2001 and by CRES (Centre for Renewable Energy Sources) in Greece as the best energy saving investment in Greece for the year 1999.

Energy and Environmental Data :

The total cooling needs of the building are about 2 700 000 kWh annually. The solar collectors supply two adsorption chillers with hot water of temperature 70-75 °C and they operate with a coefficient performance of 60%. The two adsorption coolers use the hot water as source of energy and produce cool water of temperature 8-10 °C. The adsorption chillers don't need movable parts and use minimum electric energy for the operation of the vacuum pumps (1.5 kW). The useful power is 350 kW for each one and 700 kW for the total. For the coverage of the peak load three conventional electric coolers of 350 kW each have been installed. During the winter period the solar collectors often produce hot water about 55°C, which is circulated directly to the fan coil units in the building. The same boilers replace the collector field in case of overcast. The cold water (during the summer period) and the hot water (during the winter period) is directed to the local air conditioning units where they cool or heat respectively the ambient air as needed.

Technical results:
Reporting period: 12 months
Solar energy output: 1 719 000 kWh, Cooling: 1 090 000 kWh, Heating: 629 000 kWh, Total energy load: 614 000 kWh, Solar coverage: 66%
CO_2 reduction: 5 124 596 kg/year

Contact :

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“Rethimno Village” Hotel, Crete

NUMBER ON THE MAP: 25

COUNTRY
Greece

LOCATION
Crete, Rethimno

BUILDING
Hotel

COOLING CAPACITY
105 kWc

TECHNOLOGY
Absorption

COLLECTOR TYPE
Flat plate solar collectors-selective surfaces

GROSS COLLECTOR AREA
448 m^2

IN OPERATION SINCE
2000

Description :

The “Rethimno Village” hotel is located in Rethimno Crete, in southern Greece. It caters mainly for tourism; with a bed capacity of 170 beds, and it has a 100% occupancy rate in the summer and a 45% occupancy rate in the winter.
This installation uses flat plate collectors (selective surfaces, 448 m^2) for central air conditioning (cooling and heating) and also 199 m^2 polypropylene collectors provide hot water for the heating of the swimming pool. The design, supply and installation of this system was done by SOLE S.A.
Total air conditioned area: 3 000 m^2

Investment and Financial Data :

Total cost of investment: 264 123 €
The project was subsidized up to 50 % by National Operational Programme for Energy (of the Greek Ministry of Development)
The project has been awarded by CRES (Centre for Renewable Energy Sources) in Greece as the best energy saving investment in Greece for the year 2000.

Energy and Environmental Data :

The solar collectors supply an absorption chiller with hot water of temperature 70-75 °C which operates with a coefficient performance of 60%. The absorption chiller uses the hot water as source of energy and produces cool water of temperature 8-10°C. The cooling medium is also water (instead of Freon or Ammonia).
The absorption chiller uses minimum electric energy for the operation of the vacuum pump (0.5 kW).
The useful power is 105 kW. Also a boiler (gas) of 600 kW substitutes the collectors' field when there is cloudiness or whenever there is need for air conditioning during the night. During the winter period the solar collectors produce hot water of 55°C, which is circulated directly to the fan coil units in the building. The same boiler replaces the collectors' field in case of overcast. The cold water (during the summer period) and the hot water (during the winter period) is directed to the local air conditioning units where they cool or heat respectively the ambient air within physical procedures.

Annual results
Solar energy output: 650 743 KWh, Total energy load: 1 498 247 KWh, Solar coverage: 43 %
Primary energy savings: 650 743 kWh/year
CO_2 reduction: 1 094 972 kg/year

Contact :

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SOLE S.A. (design, supply, installation)
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Head Offices of Inditex
Arteixo - A Coruña

NUMBER ON THE MAP: 32

COUNTRY
Spain

LOCATION
Arteixo – A Coruña

BUILDING
Offices and Stores

COOLING CAPACITY
170 kWc

TECHNOLOGY
Absorption chiller
($LiBr-H_2O$)

COLLECTOR TYPE
Flat Plate Collector
with selective cover

GROSS COLLECTOR AREA
1 626 m^2

IN OPERATION SINCE
2003

Description :

The building where the solar heat collectors are located is the main building of Inditex. This building is used mainly for offices, with a part for stores. It consists of two stories, of 10 000 m^2 each. The upper floor is used for designing all items related to ZARA (clothes and accessories) and is completely open-plan, with a height of 4.10 metres. Climate control is by means of three 4-pipe air handling units, controlled by ambient temperature sensors with a constant temperature of 23°C.
The ground floor has more divisions, and we therefore combined air handling units with fan-coils. There is also a 4-pipe installation, so that each person can regulate the temperature according to their needs; the building is used from 8 am to 10 pm, Monday to Friday and has an average occupation of 500 people in the two stories.

The system initially had two electric heat pumps and an electric cooler to ensure year-round hot water at 55°C and cold water at 7°C, with a return of 45°C and 12°C.

With the solar installation the heat is accumulated in two 30 000 litre tanks. When the temperature in the tanks exceeds 55°C, the control gives the order to the solar system to send water to the hot water collector, which prevents the heat pumps from starting up. In summer, because the demand for heat is low, once the temperature in the tanks reaches 80°C the back water is sent from the system to the absorption machine and after cooling is introduced into the cold water collector, and as a result the electric cooler works less.

Investment and Financial Data :

Total investment: 900 000 €
Subsidised by the Galician Regional Ministry for Industry and Trade (100 000 €) and the IDAE Spanish (Institute for Energy Diversification and Saving) (300 000 €).

Energy and Environmental Data :

This solar facility will save a total of 565 060 kWh/year, 15 % of the total energy required, with a consequent reduction in emissions of 282 t in CO_2 and other pollutant gases.

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Ineti
Lisbon

NUMBER ON THE MAP: 46

COUNTRY
Portugal

LOCATION
Lisbon

BUILDING
Offices

COOLING CAPACITY
36 kWc

TECHNOLOGY
Desiccant Evaporative Cooling Unit and Heat Pump

COLLECTOR TYPE
Compound Parabolic Collector (CPC)

GROSS COLLECTOR AREA
48 m^2

IN OPERATION SINCE
1999

Description :

It is the building of Renewable Energy Department of INETI, where applied research activities are being performed in the Solar thermal, PV, Biomass, Wind and Ocean fields. It has mechanical and chemical laboratories as well as the room offices of its personnel.
The 12 offices located in the first floor are exclusively air conditioned with a DEC system incorporating a heat pump and assisted by 24 CPC solar collectors (gross area 48 m^2, aperture area 46 m^2) located in the flat cover of the building.
The office windows represent 70 % of wall area in contact with exterior, they are facing SW, (28ºW), meaning that there is a peak for cooling during last hours of the afternoon.
The limited size of the air distribution system obliged the incorporation of a heat pump in the design of the Solar Assisted Desiccant Evaporative technology.
The climate is a Mediterranean one. The system has been designed for the following conditions, maximum air flow is 5 000 m^3/h (only outside air), with a summer (outer air) temperature of 32º C, relative moisture of 40.4 % and absolute moisture of 12 g/kg. In the rooms, the confort conditions are, a temperature of 24º C and a relative moisture of 50 %.
The system has been well accepted by the users of the office rooms, because comfort has been a first priority all the time. In consequence the degree of satisfaction is high.

Investment and Financial Data :

The system has been bought in the framework of an European project to be used in a real application but with demonstration purposes. Thus, it has been acquired with a very complete set of sensors with control, monitoring and demonstration capabilities, contributing to the very expensive final system.
The replication cost of this system, like it is - solar field, air handling unit, backup, control and monitoring systems – is around 75 000 €

Energy and Environmental Data :

This point is directly connected with energy savings resulting from solar energy contribution, which is, in the present configuration, very low value.
The system has been working according to the initial design configuration, which incorporates, as already said a heat pump for cooling assistance in summer. The size of the distribution ducts limited the air flowrate and obliged to reduce its temperature (imposing the heat pump), to cover the cooling needs. However, the condensor of this one, provides almost all heat needed for desiccant wheel material regeneration, making superflus the solar contribution in most cases in summer.

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Agenzia per lo Sviluppo Pergine Trento

NUMBER ON THE MAP: 47

COUNTRY
Italy

LOCATION
Pergine Valsugana-Trento

BUILDING
Business Innovation Centre

COOLING CAPACITY
108 kWc

TECHNOLOGY
Absorption chiller (LiBr – H_2O) single effect

COLLECTOR TYPE
Flat Plate Collector with selective cover

GROSS COLLECTOR AREA
265 m^2

IN OPERATION SINCE
2004

Description :

The building is located within the artisan/industrial area under development in the Municipality of Pergine, 11 km away from Trento. This two-storey office building, a new construction of 9814,5 m^3, is near to recently renovated warehouses. The offices are therefore serviced with HVAC equipment, plus a fire prevention water system and DHW.
The solar collector (30° - South) produces in winter DHW at 45°C with Δt = 55 °C, whereas in summer it can produce DHW at 90 °C, with the same Δt. The nominal winter thermal loads will be of the order of 230 kW and the district heating system has been sized for this capacity. Whereas in the winter situation the sum of the thermal loads of each single space corresponds to the overall building load, during the summer period, as known, the global loads result inferior to the algebraic sum (each space is valued during its most critical hour according to its solar exposure, but the overall building will have a unique critical hour which not necessarily corresponds to the maximum thermal load of all spaces).
Thus the sum of the summer loads (excluding thermal heat recovery) is of 188 kW, having a maximum contemporary load of 170 kW. Under these conditions solar collectors supply 145 kW. With this above thermal power the absorber can produce 108 kW. When under cloudy sky conditions the thermal load (in absence of solar radiation) drops from 170 kW to 120 kW.
The compression refrigeration machine is thus selected to cover this capacity. Under summer nominal conditions the compression and absorption refrigerating group provide respectively 120 kW and 108 kW, for a total of 228 kW, with a margin of 58 kW (34 %) on for the peak load (estimated for July 20th at 32°C).

Investment and Financial Data :

Total investment: 540 000 €
The province of Trento (Italy) co-financed 32 % of the overall costs of the plant

Energy and Environmental Data :

Primary Energy saving during winter = 258 000 MJ
Primary Energy saving during summer = 176 000 MJ
This solar facility will save a total of 434 000 MJ or 120 556 kWh/year, with a consequent reduction in emissions of 28 t in CO_2 and other pollutant gases.
The system is designed to generate 70 % of the cooling needed by the building with the only use of the solar collectors during the summer peak radiation months. The remaining 30 % of cooling is provided by an electrical compression chiller installed in parallel with the absorption system.

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Research building "Ökopark Hartberg"

NUMBER ON THE MAP: 48

COUNTRY
Austria

LOCATION
Hartberg, in Styria

BUILDING
Research house

TECHNOLOGY
Desiccant cooling

COOLING CAPACITY
30 kWc

COLLECTOR TYPE
Vacuum Tube Collector

GROSS COLLECTOR AREA
12 m^2

IN OPERATION SINCE
2000

Description :

The research building in the Ökopark Hartberg is the first Austrian solar assisted DEC ("desiccative and evaporative cooling") system pilot plant powered by renewable energy which was installed to demonstrate the DEC technology in Austria.
The building is used for seminars and conferences and there is also an office infrastructure. There are two floors (each about 140 m^2) with a glass facade in the South (in the lower part there are 11 vacuum tube collectors).
The experience from summer 2001 showed that the adiabatic air conditioning is sufficient for 50 to 70 % of the summer days, only on days with higher humidity, heat is needed for the sorption based air conditioning. The heat for the "sorptive cooling" is produced by solar collectors of 12 m^2 and a biomass pellet boiler as backup system. There is a heat water storage facility of 2 000 liters water for cooling and heating.

Investment and Financial Data :

Total investment, excluding VAT: 105 000 €, subsidies: 60 %
The project was financed by the government of Styria and the Ökoplan GmbH in Hartberg. The Joanneum Research in Graz is in charge of the project management and the planning.

Energy and Environmental Data :

annual COP: 0.6 (annual cooling load/annual regeneration heat), COP adiabatic mode: 3 - 5, supply air flow: 6 000 m^3/h, total of the cooling load: 20 kW (dry: 17 130 W, humid: 3 320 W), total of the heating load: 24 kW, maximal cooling capacity of the DEC system: 30 400 W, maximal cooling capacity in the building: 21 800 W

Referring to the environment, the use of solar heat and heat from biomass are reducing CO_2 emissions which would be caused through fossil fuels. A small contribution to the indirect global warming potential is caused by the energy consumption needed for the ventilators and the sorptive and heat wheel.

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GICB (wine cellar) Banyuls/Mer

NUMBER ON THE MAP: 52

COUNTRY
France

LOCATION
Banyuls/Mer

BUILDING
Wine cellar

TECHNOLOGY
Absorption chiller (LiBr)

COOLING CAPACITY
52 kWc

COLLECTOR TYPE
Vacuum Tube Collector

GROSS COLLECTOR AREA
215 m2

IN OPERATION SINCE
1991

Description :

In 1989, the Banyuls Wine Producers Grouping (G.I.C.B) built a wine cellar to age wine in bottles. This wine cellar has a total useful area of 3 500 m^2, with a 15 000 m^3 capacity on three levels (two of them are half-buried. The storage capacity is nearly of 3 millions of bottles. Wine cellar managers wished to install in this cellar a solar cooling system because such a device could fit as well the cooling demand as their environmental respect

The cooling system is made of :
- 130 m^2 of evacuated tube collectors (useful area) Cortec Giordano on the roof, oriented in South/South-West
- a technical premises situated in Level -2 and owning :
  - a buffer storage tank of 1 000 litres,
  - a single effect indirect absorption chiller YAZAKI type WFC 15, with a nominal cooling power of 52 kW,
  - several circulating pumps for the different loops and a general electrical managing chest,
- a open loop cooling tower with a nominal power of 180 kW, installed in the Northern front,
- three air conditioning units (one per level) having a filter, a cold exchanger for chilled water (+ an heat exchanger for the Ground Floor one) and a centrifugal fan with a 25 000 m^3/h flow

Investment and Financial Data :

The installation made in 1991 had a cost of 294 500 € without tax, corresponding to an overcost of nearly 150 000 € in comparison with a traditionnal compression system. This investment permits to do an annual saving of nearly 40 % on the energy consumption of the GICB

Energy and Environmental Data :

Typical measurements of the real conditions working from June to September :
- Average energy taken from the primary loop = 298 kWh/jour
- Average energy taken from the generator loop = 256 kWh/jour
- Average energy taken from the evaporator loop = 145 kWh/jour
- Absorption chiller COP = 0.57.

This system, using free energy, participate in addition, doubly to the environment protection :
- by the CFC et HCFC giving up. These refrigeration fluid are used in traditional cooling systems and probably participate to the greenhouse effect increase and to ozone layer destruction.
- by the lack of CO_2 production which contributes as well to the greenhouse effect increase.

This kind of absorption chiller has the asset to be a totally quiet machine (because there are no moving parts), and thanks to this feature, to have a lifetime much more longer rather than traditional electric chillers (working with pumps).

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5

MANAGING A PROJECT

Solar assisted air conditioning is a new and growing technology, compared to other fields of solar energy application. The novelty of this technology is reflected by the fact that most of today's realized projects are of demonstration nature and still a lot of additional design and planning effort is required in the implementation phase of such a project. Various technical solutions are possible, depending on the type and use of the building, on boundary conditions like e.g. existing technical infrastructure, and on other like e.g. climate conditions. This chapter is presenting a decision scheme for the different solar air conditioning technologies, basic rules for design and sizing, and good reasons to begin a project by a serious feasibility study.

5.1 - Choosing a technology

A simplified decision scheme for air conditioning technologies, applicable with solar thermal systems, is presented in the Figure 17.

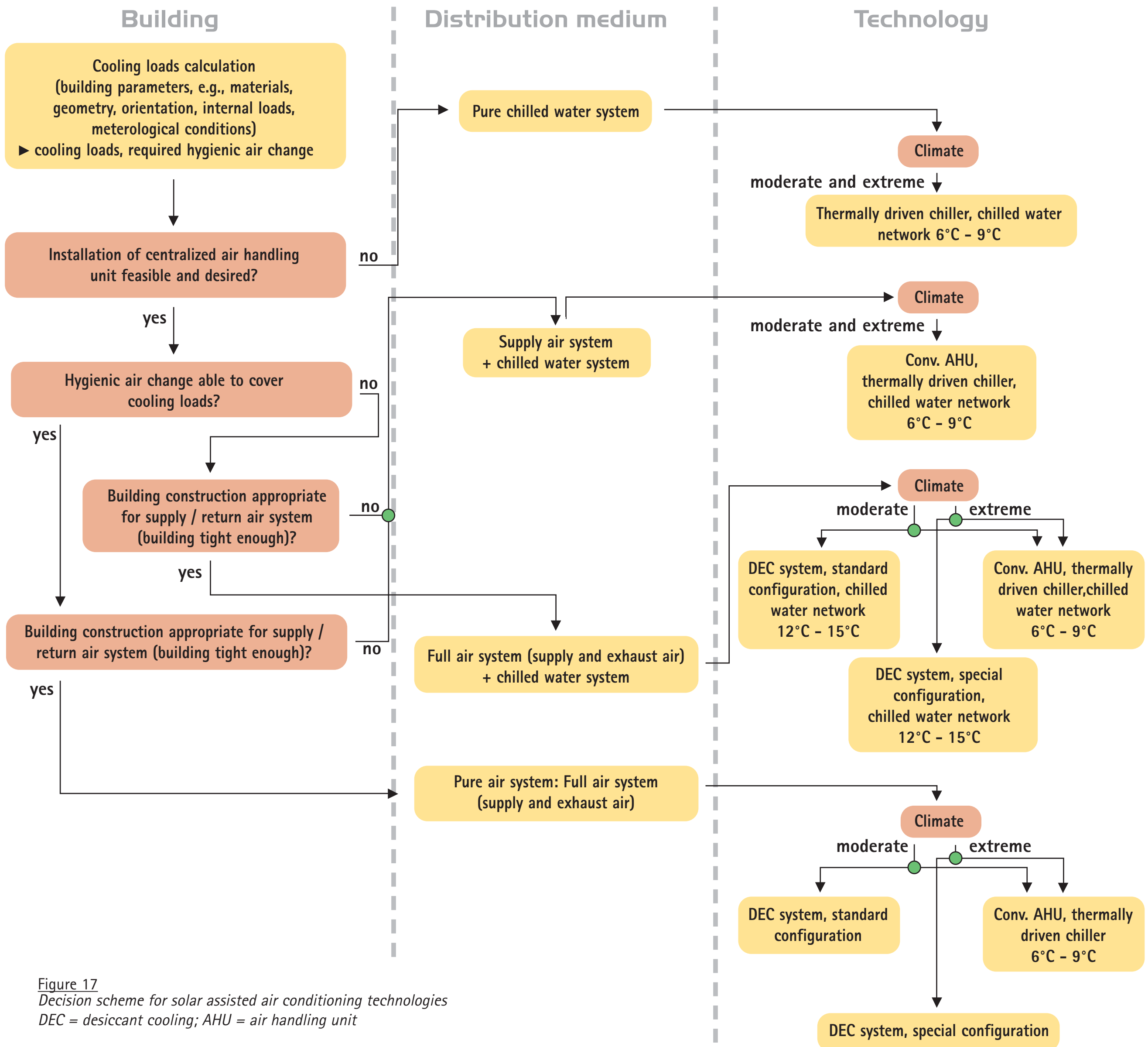

Figure 17
Decision scheme for solar assisted air conditioning technologies
DEC = desiccant cooling; AHU = air handling unit

A basic assumption is that both, temperature and humidity of indoor are to be controlled. Finally, each decision results in a solution which includes use of solar thermal energy for conditioning of indoor air. The starting point always is a calculation of cooling loads based on the design case. Depending on the cooling loads and also according to the desire of the users/owner, either a pure air system, a pure water system or hybrid air/water systems are possible for extraction of heat and humidity out of the building. The basic technical decision is whether or not the hygienic air change is sufficient to cover also cooling loads (sensible + latent). This will typically be the case in rooms/buildings with a requirement of high ventilation rates, such as e.g. lecture rooms.

However, a supply/return air system makes only sense in a rather tight building, since otherwise the leakages through the building shell is to high. In cases of supply/return air systems both thermally driven technologies are applicable, i.e., desiccant systems as well as thermally driven chillers. In all other cases only thermally driven chillers can be used in order to employ solar thermal energy as driving energy source. The lowest required temperature level of chilled water is determined by the question whether air dehumidification is realized by conventional technique, i.e., cooling the air below the dew point or whether air dehumidification is realized by a desiccant process. In the latter case the temperature of chilled water - if needed at all - can be higher since it has to cover only sensible loads. Application of desiccant technique in extreme climates, i.e., climatic conditions with high humidity values of the ambient air, special configurations of the desiccant cycle are necessary in order to be able to employ this technology.

More items of the design which cannot be covered in this presentation are for instance:

- Necessity of a backup system for the cold production or to allow solar autonomous operation of the solar assisted air conditioning system;
- Flexibility in comfort conditions, e.g. to allow certain deviations from the desired air states;
- Economical issues;
- Availability of water for humidification of supply air or for cooling towers;
- Comfort habits for room installations: fan coils have lowest investment cost, but allow dehumidification only when connected to a drainage system; chilled ceilings and other gravity cooling systems require for high investment cost, but provide high comfort.

It is not indicated here, which type of thermally driven chiller is applied. In case of a desiccant system is required with an additionally chiller to cover peak-loads, the required chiller may be an electric driven compression chiller for economical reasons.

5.2 - Basic rules for design and sizing

From basic considerations and from experiences gained in demonstration projects, a set of general 'thumb' rules for the design and sizing of a solar assisted air conditioning system has already been extracted:

- A thermally driven cooling system with a comparatively low $COP_{thermal}$ and a fossil fuel heat source as a backup, requires a high solar fraction in order to achieve significant primary energy savings. This has to be guaranteed by a properly design of the system, e.g. a sufficient large solar collector area, sufficient large storages and other measures in order to maximize the use of solar heat.
- Alternatively, a conventional chiller as backup system may be used. In this concept, each unit of cold provided by the solar thermally driven chiller reduces the cold to be delivered by the conventional unit. This design allows some primary energy savings even at low values of solar fraction. The solar system then serves mainly to reduce the electrical energy consumption.
- When a heat backup using fuels is applied, any replacement of fossil fuels by fuels from renewable sources such as biomass will decrease the primary energy consumption of the thermally driven system.
- Solar thermally autonomous systems do not require any other cold source and therefore always work at the limit with a 100% solar fraction.
- Systems with a thermally driven chiller with a high $COP_{thermal}$ may be designed with a smaller solar fraction even if a fossil fuel heat backup source is applied. The reason is that the heat from the fossil fuel burner is also converted at a high $COP_{thermal}$, competitive with a conventional system from a primary energy point of view.
- In any case, the use of the solar collector should be maximized by supplying heat also to other loads such as the building heating system and/or hot water production.

Additional recommendations on the design of solar assisted air conditioning systems may be found in the Guidelines for planners, installers and other professionals at the homepage of the EU project SACE – Solar Air Conditioning in Europe (http://www.ocp.tudelft.nl/ev/res/sace.htm) and in the book "Solar-Assisted Air-Conditioning in Buildings – A Handbook for Planners" (see bibliography).

Figure 18
Integration of solar collectors on the roof of the DIREN (Guadeloupe, (F)).

5.3 - Why carrying out a feasibility study ?

The choice for an appropriate air conditioning technology and system design requires more than considering nominal operation points only, since the fluctuation of solar energy gains causes that at most times the system components operate in part-load condition.
Furthermore, the operation conditions as well as the process properties of new applications like adsorption chillers or of complete desiccant cooling systems, are not familiar in a sufficient way to most planners and installers up to now. To date it is difficult to find an easy-to-use software on the market which allows an easy and fast selection of the most promising solar assisted air condition technology and of the system layout.
For this reason, a feasibility study, organized by an experienced engineering office, is highly recommended in the beginning of the planning phase. In a feasibility study the following steps may be analysed:

- determination of the cooling and heating loads and preparing time series of the loads (e.g. by means of building simulation);
- selection of the most promising solar assisted air conditioning technology and system layout;
- pre-sizing of the components, e.g. size of the solar collector field and of the heat / cold storages;
- analysis of control strategies and their effect to the system performance;
- calculation of efficiency and exploitation values like the Coefficient of Performance of the cooling system, the solar fraction of covering the loads by the solar thermal system, the net collector efficiency, etc.;
- calculation of consumption figures (electricity, water, gas);
- estimation of financial key figures and of the primary energy savings.

Which parts of the above listed items are useful to be investigated in a feasibility study depends on the individual project and on the depth of information required and available. In any case, the results of a feasibility study may contribute to an increased understanding of the potential of solar assisted air conditioning.

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- **http://www.ocp.tudelft.nl/ev/res/sace.htm** : EU project SACE – Solar Air Conditioning in Europe
- **http://www.raee.org/climasol** : EU project Climasol : Promoting Solar Air Conditioning
- **http://www.tecsol.fr/RafrSol/index.htm**

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