2
Technical overview of active techniques

This chapter describes the function of solar-assisted air-conditioning in buildings. It is important to understand technical terms, operation parameters, different concepts and their application scopes. This knowledge serves as basis for the right selection of technology and their suitable components regarding the case study, or rather, the pilot project in Guaratinguetá.

The definition choice “solar-assisted air conditioning” results from the fact that these systems are not running completely self-sufficient, they always need some sort of conventional energy source for their operation. e.g. for the fans or pumps. But they economize a tremendous amount of energy in comparison to the conventional electrical driven air conditioning system, because the main driving energy is generated regenerative by the solar thermal collector field.

Air conditioning is the cooling and dehumidification of indoor air for thermal comfort. In a broader sense, the term can refer to any form of cooling, heating, ventilation, or disinfection that modifies the condition of air [9].

2.1
Technologies applicable for solar-assisted air-conditioning

Because of the chosen Case study the cooling demand is around 15 -30 kW
(4,3 - 8,6 TR).
Therefore the focuses on the Technology overview are chillers in the small and medium size capacity range. The classification “small” and “medium” depends on the nominal chilling capacity, small application are below 20 kW (5,7 TR) and medium size system range up to approx. 100 kW (29 TR).

There are two general types of solar-assisted air-conditioning for this application and capacity range:

- closed cycles (chillers): chilled water
- open sorption cycles: direct treatment of fresh air (temperature, humidity)

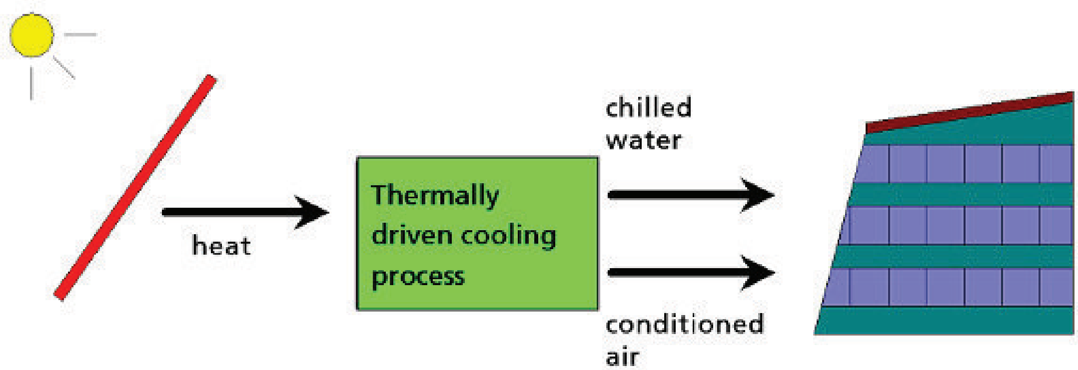

Figure 2.1 - General Scheme of the thermally driven cooling process [8].

A solar cooling installation consists of a typical solar thermal system made up of solar Collectors, storage tank, control unit, pipes and pumps. In closed cycles, it is added a thermally driven cooling machine (chiller) with heat rejection system necessary. The heat rejection is in the most cases done by a cooling tower. The cold water distribution occurs normally by insulated water pipes which are connected at fan coils (heat exchanger) or a chilling ceiling.

The dominated type of thermally driven cooling technology to produce chilled water is absorption cooling. Absorption chillers have been in commercial use for many years, mainly in combination with cogeneration plants, using waste heat or district heating. For air conditioning application, absorption systems commonly use the water/lithium bromide working pair. Another closed-cycle sorption technology to produce chilled water uses the physical process of adsorption but this kind of chiller has a much lower market share. Nevertheless, there are many installations that use solar-thermally driven adsorption chillers [10].

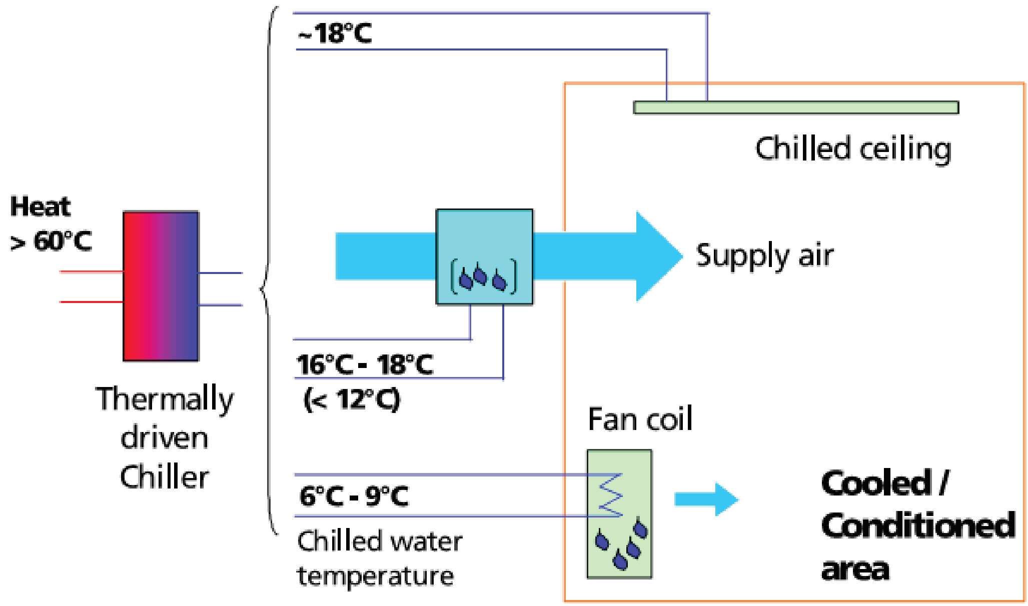

Figure 2.2 - Closed cycle system, chiller water is produced in a closed loop for different decentral application or for supply air cooling [9].

Another type of technology which has chained increasing attention over the last 15 years is desiccant cooling technology (DEC). Using this technology, air is conditioned directly. i.e. cooled and dehumidified. Desiccant cooling systems exploit the potential of sorption materials, such as silica gel, for air dehumidification. In an open cooling cycle, this dehumidification effect is generally used for two purposes: to control the humidity of the ventilation air in air-handling units and - if possible - to reduce the supply temperature of ventilation air by evaporating cooling [10].

In that case, the cold distributions medium is conditioned Air, thus huge air ducts and a double deck air handling unit inside the building are necessary. There is no need of a cooling machine and a cooling tower but also a typical solar thermal system to regenerate desiccant wheel of such an air handling unit.

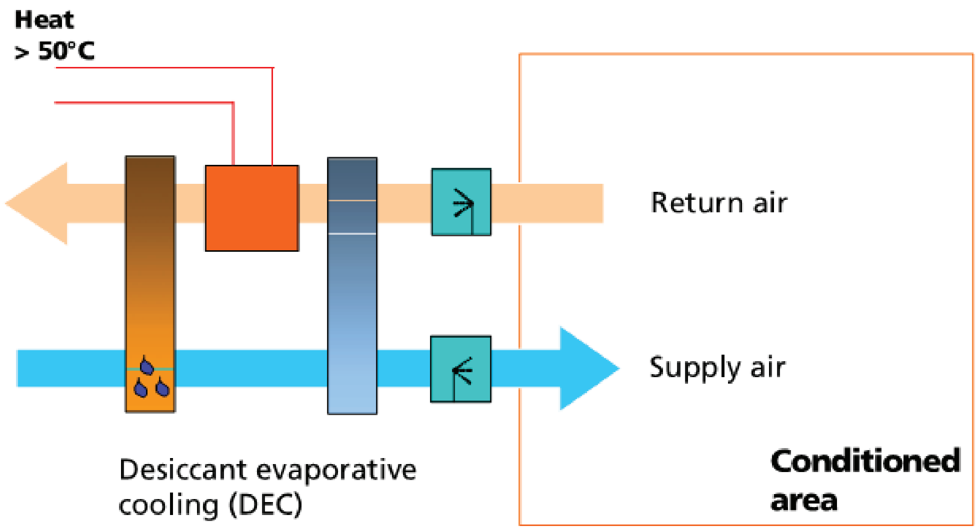

Figure 2.3 - Open sorption cycle: Supply air is directly cooled and dehumidified [8].

It must be mentioned that in both figures the required heat is supplied by a solar thermal collector field.

For a better understanding of the thermally driven process and their efficiency it's important to describe the thermodynamic principle.

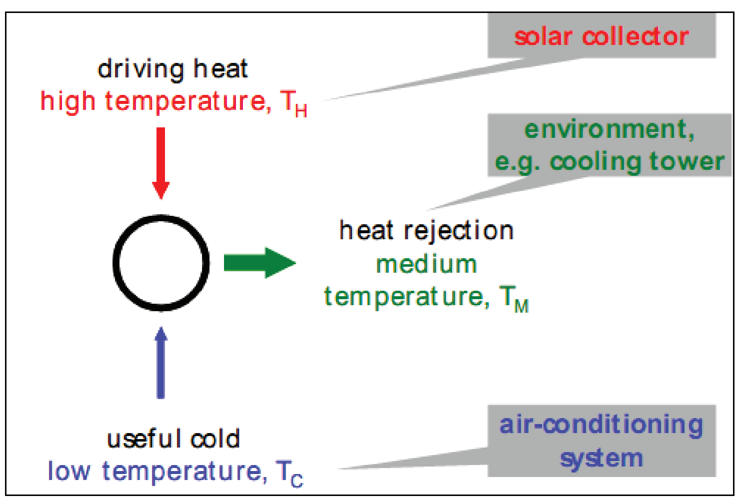

Figure 2.4 - Thermodynamic principle of thermally driven cooling [8].

Thermally driven chillers may be characterized by three temperature levels:

- The cycle is driven with heat from a high temperature heat source, e.g. solar collectors or waste heat.
- A low temperature level at which the chilling process is operated, hence useful cold. This extracts heat from a low temperature heat source.
- 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.

The two main equations to be taken into account for any thermally driven cooling cycle are:

First the conservation of energy governing the energy flows in the three temperature levels

$$Q_{medium} = Q_{high} + Q_{low} \qquad \text{(Eq. 2.1)}$$

and second the thermal Coefficient of Performance (COPth) giving the ratio of useful cold per unit of driving heat.

$$COP_{th} = \frac{useful\ cold}{driving\ heat} = \frac{Q_{Cold}}{Q_{drive}} \qquad \text{(Eq. 2.2)}$$

A key figure to characterise the energy performance of a refrigeration machine is the Coefficient of Performance, COPth.

The COPth is a characteristic of the particular thermodynamic cycle used, but in general is strongly dependent on the three temperature levels.
The theoretic limits of solar driven cooling can be calculated through the product of the COPth of the cooling process and the solar collector efficiency:

$$COP_{sol} = COP_{th} \cdot \eta_{coll} \qquad \text{(Eq. 2.3)}$$

Both systems in principle have a contrary characteristic: cooling processes perform better with higher temperatures while lower temperatures are better for the collectors. As a result, if both technologies are chosen, an optimum operation temperature results from both characteristics [9].

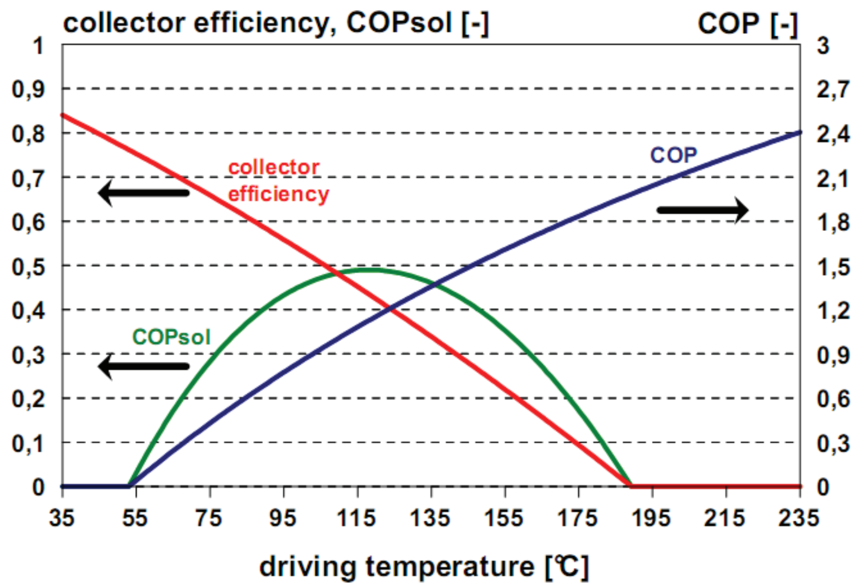

Figure 2.5 - Theoretic limit of solar thermal driven cooling processes [11].

Figure 2.5 shows, that the optimal driving temperature of a solar driven cooling system depends on the thermal performance of the cooling process and the collector efficiency curve.

Beside the influence of the driving temperature regarding cooling machine efficiency and the solar collector efficiency, the cooling tower performance has also an influence of the COP and cooling power which shows the following figure.

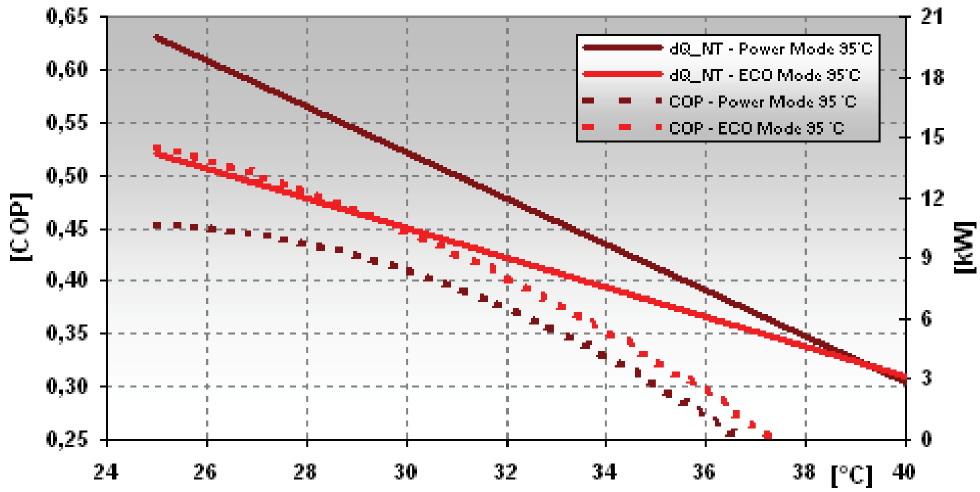

Figure 2.6 - Example manufacturer Data; COP and Cooling Power [KW] in relation to the heat rejection water temperature are shown as a function of the constant fan-coil cooling water temperature for driving a fan-coil. Source: Solvis Energy Systems GmbH&Co.KG

In the next shown figure 2.7 is discussed in more detail performance curve of the on the market available thermally driven chillers. The COP is between 0.5 to 0.8 in single-effect chillers, and till 1.4 in double-effect chiller. The different chiller types will be discussed in the next chapter.

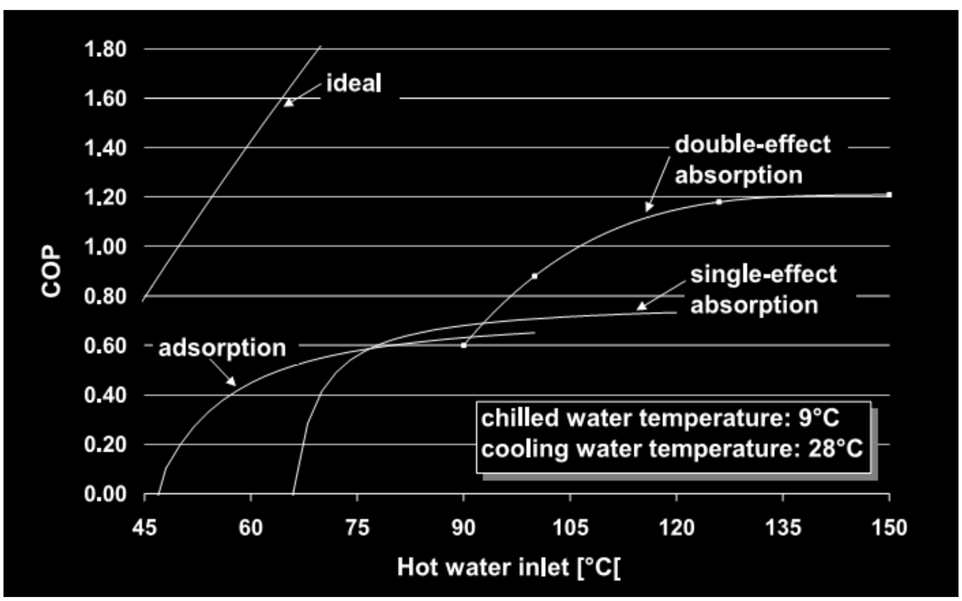

Figure 2.7 - Exemplary curves of the coefficient of performance COP for different sorption chiller technologies and the limit curve for an ideal process. The curves are shown as a function of the driving temperature and for a constant chilled and cooling water temperature [10].

The COPthermal of a desiccant cooling system is defined as the ratio between the enthalpy change (internal energy change of the air depending temperature and humidity) from ambient air to supply air, multiplied by the mass air-flow, and the external heat delivered to the regeneration heater, $\dot{Q}_{reg}$:

$$COPthermal = \frac{\dot{m}_{supply}(h_{amb} - h_{supply})}{\dot{Q}_{reg}} \quad \text{(Eq. 2.4)}$$

The value of COPthermal of a desiccant cooling system depends strongly on the conditions of ambient air and supply air. Under normal design conditions, a COPthermal of about 0.7 is achieved and the cooling power lies in the range of about 5-6 kW per 1000 m³/h of supply air [10].

2.1.1
Chilled water systems

In this chapter the technical function of the different chiller technologies is described.

The focus hereby is the mostly applied and on the market available Absorption chiller. This chapter is from importance, because most of the buyers or planners of solar-assisted air-conditioning systems are interested to know how they function and with which working principle.

2.1.1.1
Absorption Chillers

Absorption chillers use heat instead of mechanical energy to provide cooling.
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, a liquid H2O/LiBr solution is typically applied with water as a refrigerant. Most systems use an internal solution pump, but consume only little electric power.

The main components of absorption chillers are shown in the figure below:

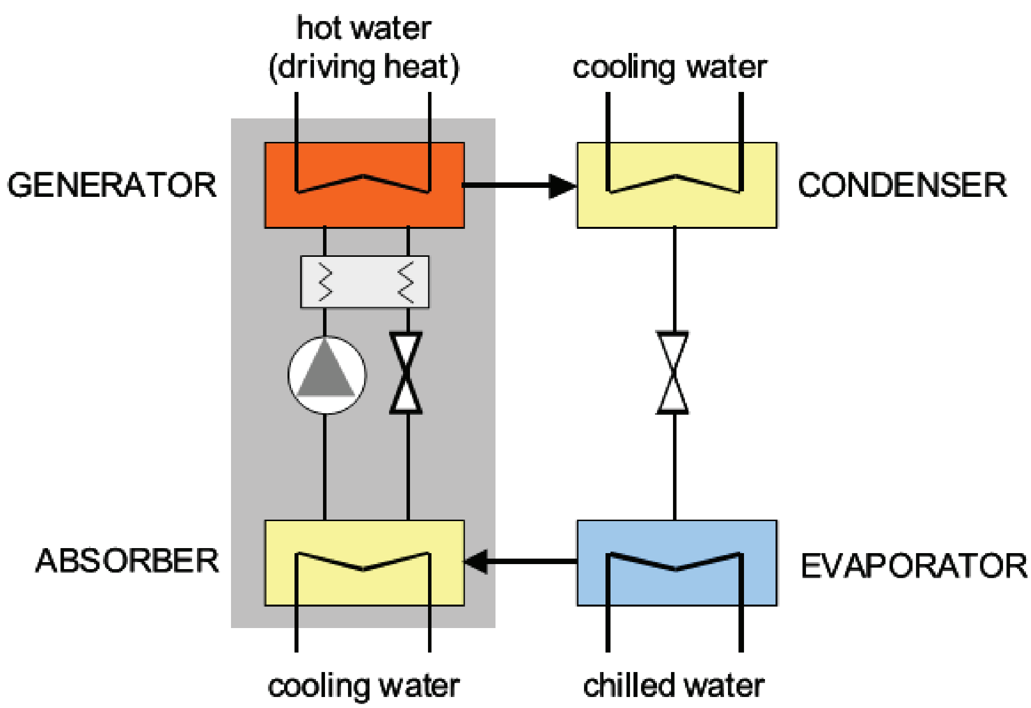

Figure 2.8 - Schematic drawing of an absorption chiller producing chilled water [8].

In the next two figures the thermal absorption cycle process is shown:

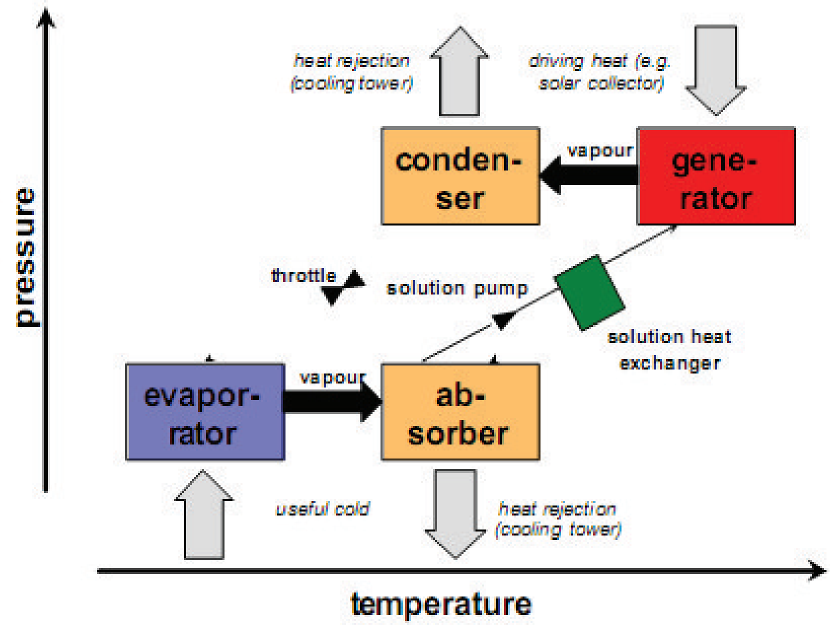

Figure 2.9 - Vapour pressure as a function of vapour temperature in an absorption Cooling cycle process [8].

Absorption cycles are based on the fact that the boiling point of a mixture is higher than the corresponding boiling point of a pure liquid. A more detailed description of the absorption cycle includes the following steps [10].

1. The refrigerant evaporates in the evaporator, thereby extracting heat from a low-temperature heat source. This results in the useful cooling effect.

2. The refrigerant vapour flows from the evaporator to the absorber, where it is absorbed in a concentrated solution. Latent heat of condensation and mixing heat must be extracted by a cooling medium, so the absorber is usually water-cooled using a cooling tower to keep the process going.

3. The diluted solution is pumped to the components connected to the driving heat source (i.e. generator or desorber), where it is heated above its boiling temperature, so that refrigerant vapour is released at high pressure. The concentrated solution flows back to the absorber.

4. The desorbed refrigerant condenses in the condenser, whereby heat is rejected at an intermediate temperature level. The condenser is usually water-cooled using a cooling tower top reject the “waste heat”.

5. The pressure of the refrigerant condensate is reduced and the refrigerant flows to the evaporator through a expansion valve.

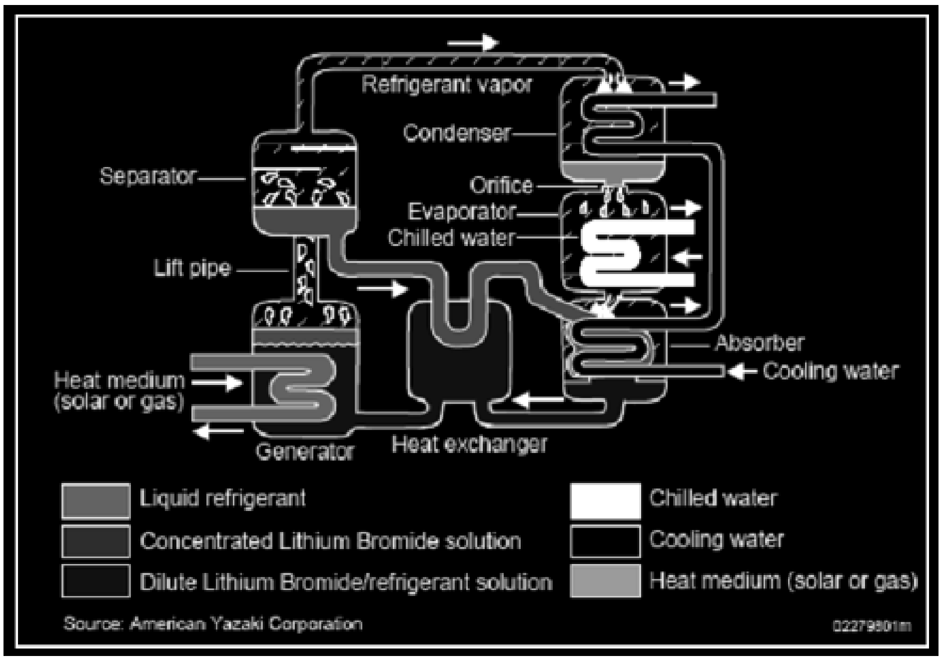

Figure 2.10 - Detail function scheme of a single-effect Absorption chiller. Source: Yazaki Energy Systems Inc.

The required heat source temperature is usually above 85°C and typical COP values are between 0.6 and 0.8. Until a few years ago, the smallest machine available was a Japanese product with a chilling capacity of 35 kW (10 TR). Recently the situation has improved due to a number of chiller products in the small and medium capacity range, which have entered the market. In general, they are designed to be operated with low driving temperatures and thus applicable for stationary solar collectors [7].

Thermax, a Indian company offers, also an 35 kW (10 TR) absorption chiller and is in Brazil represented by the company Trane. But, Trane offers only single-effect absorption chiller from a capacity of 70 kW (20 TR).

The Germany Company EAW does until now not offer their chillers for the Brazilian market, because of some operation problems.

In Brazil double-effect absorption chillers up to 700 kW (200TR) have already been installed in big buildings like hotels or shopping centre. In this case they are often driven with the waste heat of a cogeneration plant. Gas driven cogeneration under using the waste heat for air conditioning is an effective way of energy use. The generated electricity is self consumed. By the way, if the electric energy can not completely self consumed, by > 200 kW excess energy, there is no problem to find a purchaser. This issue is well treated in [12]. The Brazilian company TUMA installs refrigeration system and solar water heating systems and deals with big Absorption chillers from the Chinese company Broad.

Figure 2.11 shows some examples of market available Absorption chillers given, sorted by the chiller capacity.

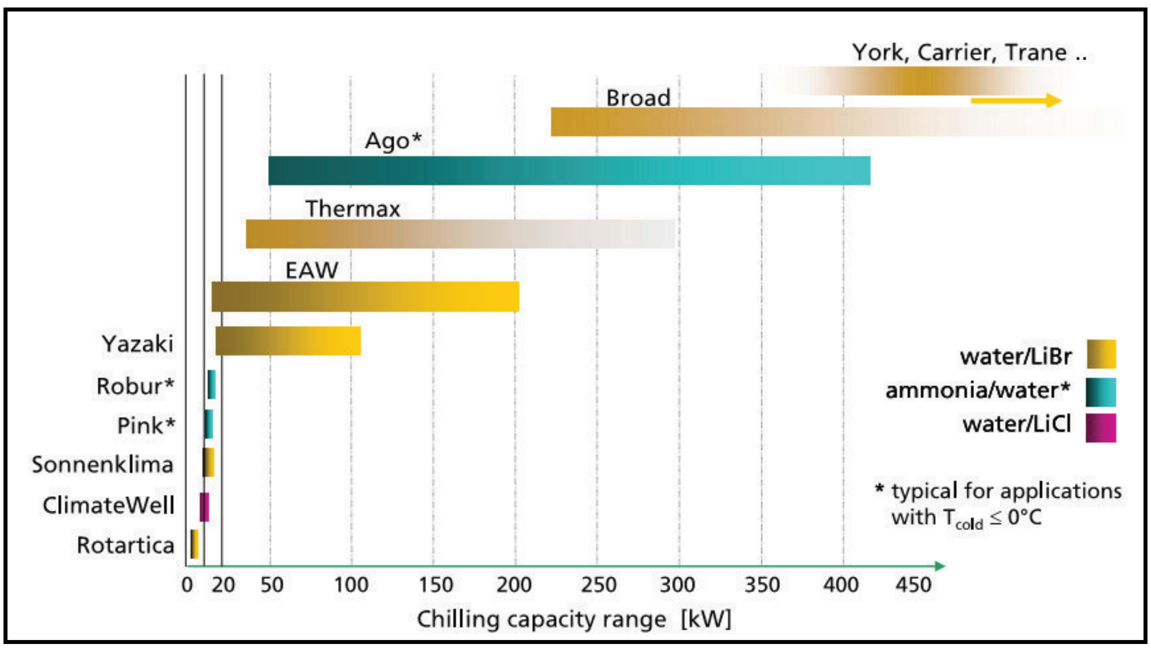

Figure 2.11 - Typical capacity range of hot water driven absorption chillers [7].
No claim to be complete.

Double-effect machines with two generators require for higher temperatures >140°C, but show higher COP values of > 1.0. The smallest available chiller of this type shows a capacity of approx. 170 kW (49 TR). With respect to the high driving temperature, this technology demands in combination with solar thermal heat for concentration collector systems. This is an option for climates with high fraction of direct irradiation [7].

Optimum conditions are given specially in the semiarid region in Brazil, like in the states of Ceará, Piauí, Maranhão, Tocantins, Bahia and Goiás where a high direct radiation exists, see figure 2.12.

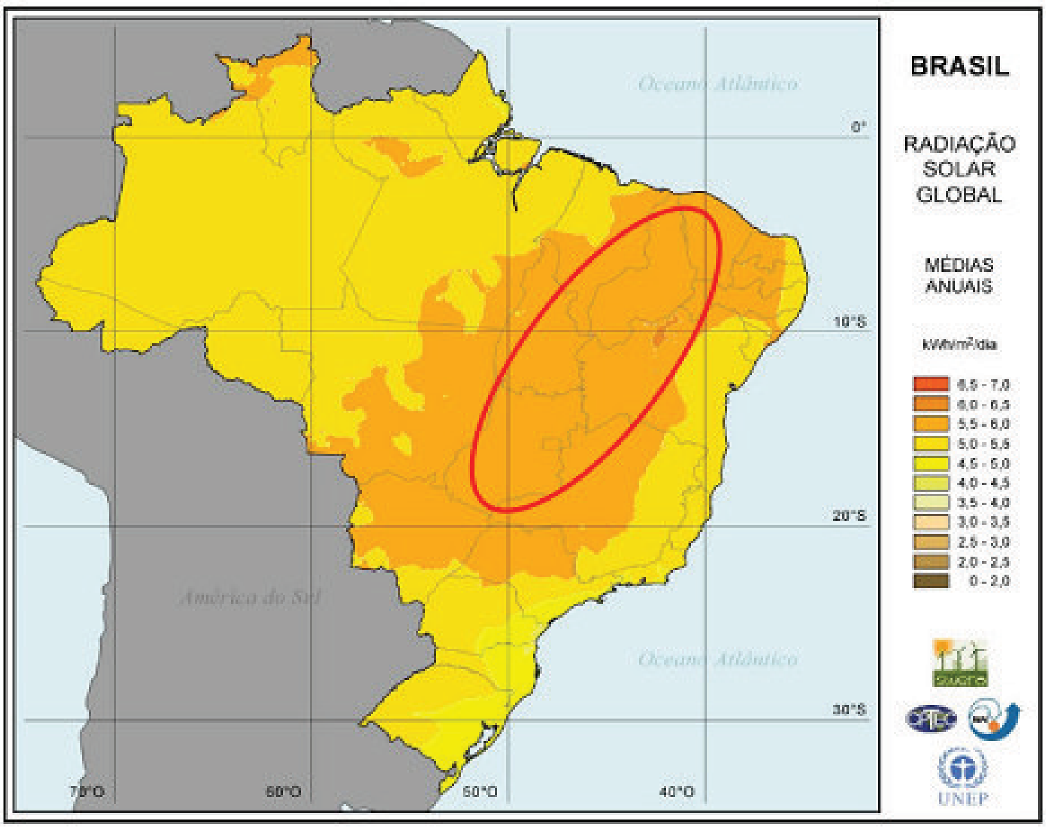

Figure 2.12 - Global solar radiation map of Brazil. In the highlighted area it makes sense to apply tracked concentration collector. Source: Atlas Brasileiro de Energia Solar

Brazil has an average solar radiation of 5 kWh/m²/day and a cooling demand up to 200 W/m². In Europe, where the most solar cooling systems are in operation, the average solar radiation is around 3 kWh/m²/day and the cooling demand is only 40..70 W/m².These facts show the good conditions for solar cooling applications in Brazil.

Tracked concentration collectors are suitable in this area for solar-assisted air-conditioning, but it must be considered, that the installation, operation and maintenance costs are higher. In Brazil high temperature collectors are not available and there is no technical knowledge about installation and operation.

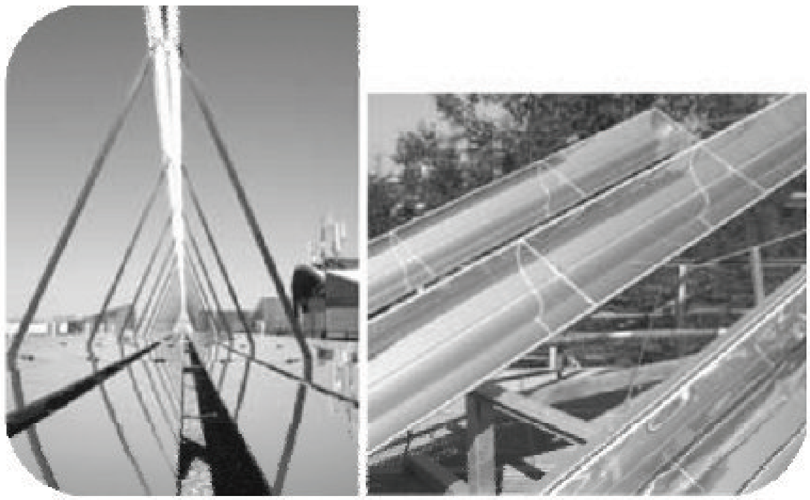

Figure 2.13 - Examples of 1-axis tracked concentration solar thermal collectors.

Left: Fresnel collector for hot water preparation up to 200°C. The mirrors are tracked to focus the direct radiation towards the absorber, located above the mirror area. Advantage: low sensitivity to high wing speeds and low space demand. Source PSE, Germany. Right: Parabolic trough collector, developed by Button Energy, Austria.

Generally, Solar-assisted air-conditioning systems in small and medium capacity range use common stationary solar collectors. Guaratinguetá is not located in the adequate area for using tracked concentration collectors and it will be a chiller with approx. 20 till 35 kW (5,7 - 10 TR) cooling power applied. In this capacity range there are no double-effect chillers available. For that reason double-effect chiller driven by tracked concentration collectors will be not more discussed in this work.

Figure 2.14 - Two examples of absorption chiller. Left: A 35 kW (10 TR) Chiller from Yakazi, Japan and Right: A 10 kW (2.8 TR) developed by ClimateWell, Sweden.

2.1.1.2 Adsorption Chillers

Beside processes using a liquid sorbent, also machines using solid sorption materials are also available. This material adsorbs the refrigerant, while it releases the refrigerant under a heat input. A quasi continuous operation requires at least two compartments with sorption material [7].

All on the market available Adsorption chillers use water as refrigerant and silica gel as sorbent. The Figure 2.15 below shows the function scheme of such a chiller.

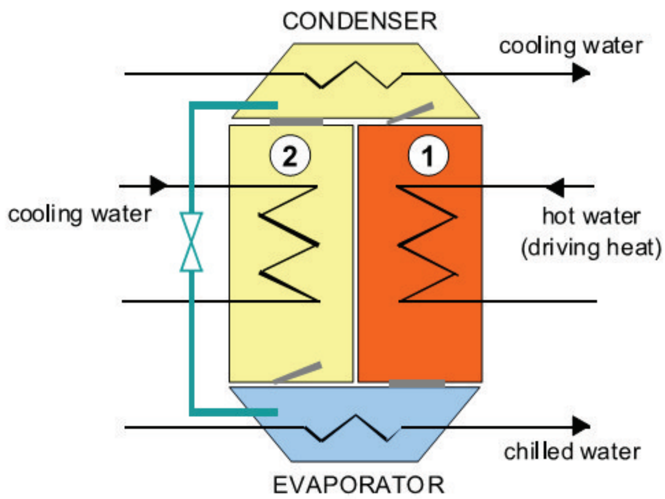

Figure 2.15 - Scheme of an adsorption chiller. They consist of two sorbent compartment 1 and 2, and the evaporator and condenser [8].

The cycle can be described as follows [10]:

1. The refrigerant previously adsorbed in the one adsorber is driven off by the use of hot water (compartment 1);
2. The refrigerant condenses in the condenser and the heat of condensation is removed by cooling water;
3. The condensate is sprayed in the evaporator, and evaporates under low pressure. This step produces the useful cooling effect.
4. The refrigerant vapour is adsorped onto the other adsorber (compartment 2). Heat is removed by the cooling water.

Figure 2.16 - Two Examples of adsorption chillers. 8 kW and 15 kW capacity chillers from Sortech AG, Germany.

Advantageous are the absence of a solution pump and a noiseless operation.
The COP values of Adsorption chiller are around 0.6. The chiller start to run at 60°C hot water but with low performance, but at already at 75°C and a cooling water (cooling tower) of 26°C the full power capacity is achieved.
Table 2.1, compares the performance of the Yakazi WFC-SC 10 (35kW/10TR) Absorption chiller and the Sortech ACS-15 Adsorption Chiller (15kW/4.3TR) as function of the driving and cooling water temperature.

Absorption Chiller (Yazaki WFC-SC10) 35 kW (10 TR)		Adsorption Chiller (Sortech ACS-15) 15 kW (4.3 TR)	
Cooling Capacity Factor	Driving / Cooling Water Temperature	Cooling Capacity Factor	Driving / Cooling Water Temperature
0.5	75°C/26°C	1	75°C/26°C
1	80°C/26°C	-	-
1.2	85°C/26°C	1.1	85°C/26°C
1.42	95°C/26°C	1.27	95°C/26°C
1	88°C/31°C	0.8	88°C/31°C
0,65	80°C/31°C	0.7	80°C/31°C

Table 2.1 - Cooling Capacity of an Absorption- and an Adsorption chiller in relation to driving- and cooling water Temperature. Source: Technical Data sheets

The Yakazi WFC-SC 10 (35kW/10TR) Absorption chiller starts to work at approx. 75°C, but only with the half capacity. With an hot water temperature of 80°C and an cooling water temperature of 26°C the chiller run with full performance, also at 88°C and a cooling water temperature of 31°C.

The cooling water of 26°C was chosen because a wet cooling tower can cool down the water till 26°C by an ambient dry bulb temperature of 27°C and a relative humidity of 60%, which meets the climate conditions from São Paulo during the summer.
The lower limit temperature of the cooling water is usually 3°C to 5°C above the wet-bulb temperature of air.

A relative humidity of 80% and a dry-bulb temperature of 30°C can also be reached; this corresponds to the summer temperature in Rio de Janeiro and a cooling water temperature of 31°C (wet-bulb air temperature +5°C). In this case the performance of the Absorption chiller is higher.

This specific performance data was chosen for a 15 kW Adsorption chiller, because in the range of around 35 kW no Adsorption chiller is available. Medium capacity adsorption chillers are available in the range of 50 kW till 350 kW, see figure 2.17.

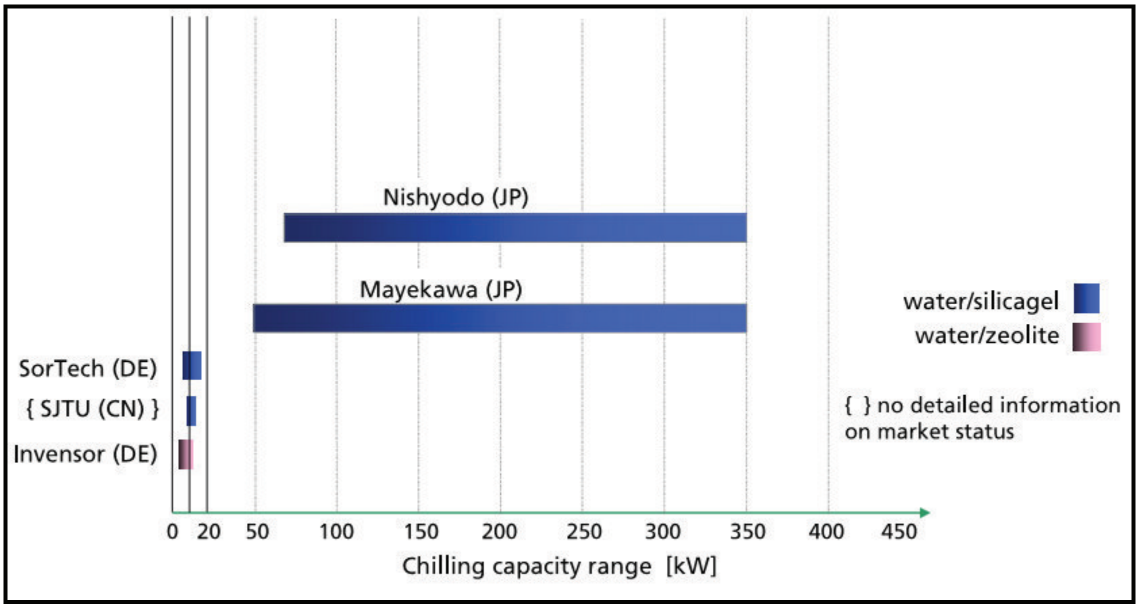

Figure 2.17 - Available adsorption chillers [7]. No claim to be complete.

In Guaratinguetá a Chiller with a capacity of approx. 20-35 kW will be needed, thus there is no suitable adsorption chiller for this application.

The University of João Pessoa in Paraíba (Brasil), is developing a 20 kW (5,7 TR) Adsorption Chiller. This is done by the Laboratory of Solar Energy (LES) and by the Laboratory of adsorption refrigeration systems (LABRADS). But the chiller is as yet not in operation.

2.1.1.3
Heat Rejection

An important component of solar-assisted air-conditioning is the cooling tower for the heat rejection. The cooling tower including cooling water circulation pump consumes the most electrical energy and influences the chiller performance. Figure 2.18 illustrates as an example the difference in the demand of heat rejection between a conventional compression chiller and an ab-or adsorption chiller system.

The higher demand of heat rejection in thermal chiller systems occurs through the fact that the building extracted heat ("useful cold") and the driving heat is charged to the environment at ambient (medium) temperature level.

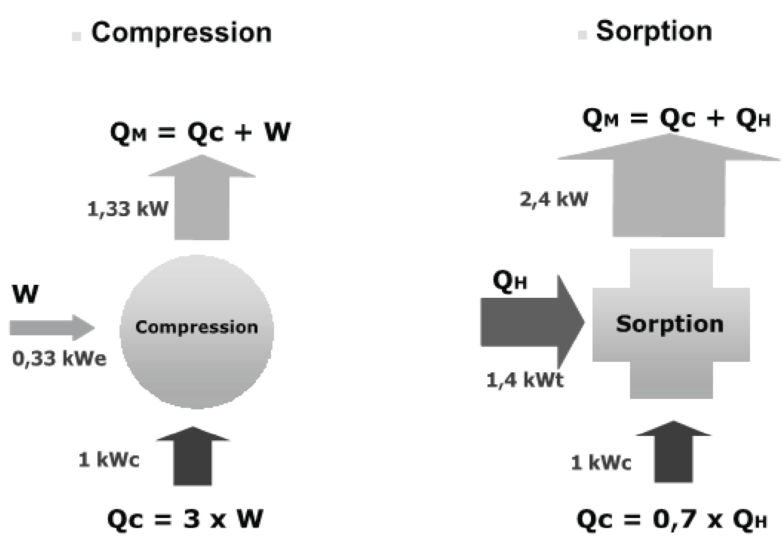

Figure 2.18 - Example on the demand for heat rejection in a conventional electrically driven compression chiller system (left) and in a (single-effect) thermally driven chiller system (right). In the comparison, the chilling capacity is 1 kW in both systems. Typical efficiency numbers have been used. Source: Tecsol

There are different possibilities and heat rejection technologies. Heat rejection by use of ground water, sea water, river or spring water causes the lowest electricity consumption, but is depends on the environment conditions. Basis for engineering of such system was found by [13].

The focus on this chapter is the most applied heat rejection technology - wet cooling by means of open cooling towers. The Figure 2.19 below illustrates the principle of such a heat rejection chiller:

The cooling water is sprayed on top of the cooling tower towards the filling material, which increases the effective exchange area between air and cooling water. The main cooling effect is obtained through evaporation of a small percentage of the cooling water (typically < 5%); this loss has to be compensated by fresh water supply. Then, the cooled water returns to the cooling circuit of the chiller.

A fan removes the saturated air in order to keep the process running. The process is very efficient in appropriate climates and in principle, the limitation temperature of the returned cooling water is not far from the wet-bulb temperature of the air (3° to 5°C above the wet-bulb temperature) [7].

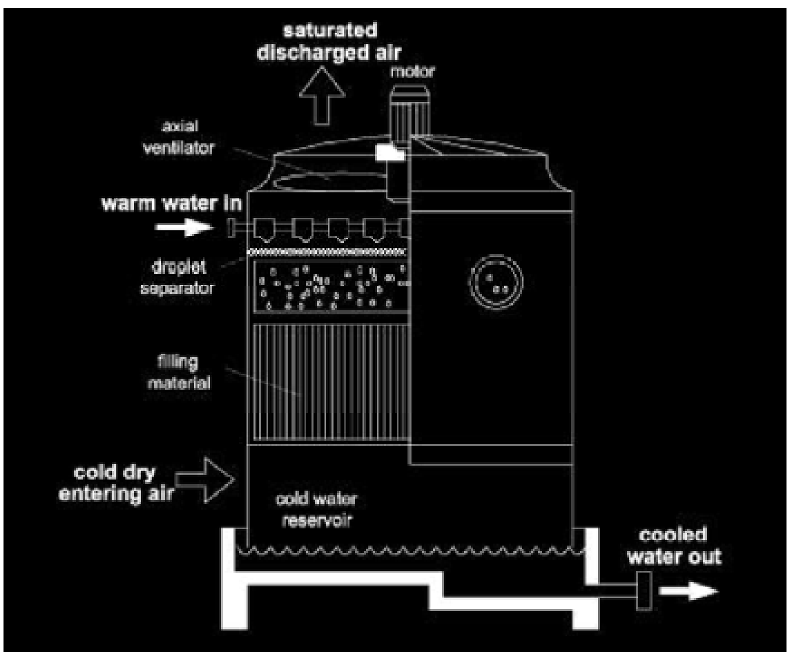

Figure 2.19 - Typical scheme of an open wet cooling tower [10].

In Brazil wet cooling towers are available. The company International Refrigeração from São Paulo is dealing with small capacity wet cooling towers which could be applied. In the main region of Brazil wet cooling towers must be applied because of tropic climate. Because of the high ambient humidity dry cooling towers with evaporation effect are not suitable.

2.1.2
Open cycle processes

Instead of chilled water, open cycles produce directly conditioned air. The cooling effect bases on a combination of evaporation cooling with air dehumidification by a desiccant (hydroscopic substance).

The components for such a cooling process, such as desiccant wheels, heat recovery units, humidifiers, fans and water air heat exchangers are standard components for air conditioning applications in buildings and factories since many years.

Figure 2.20 shows the standard in a desiccant evaporative cooling system (DEC):

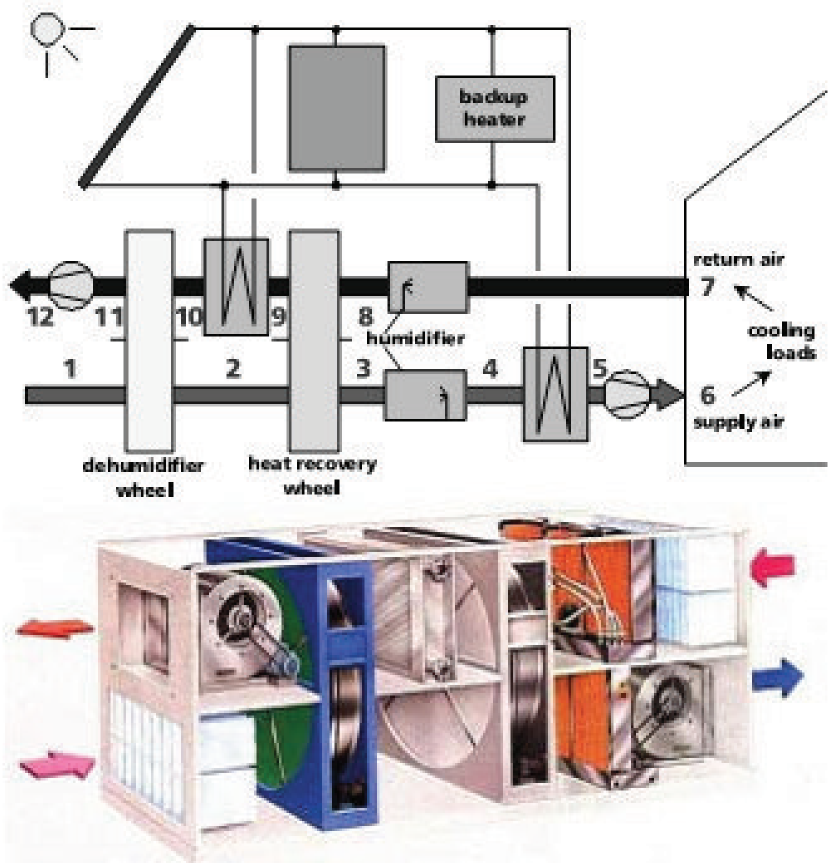

Figure 2.20 - Scheme of a solar thermally driven solid Desiccant Evaporative Cooling system (DEC), using rotating sorption and heat recovery wheels [8].

The successive processes in the air stream are as follows:

1 → 2 sorptive dehumidification of supply air; the process is almost adiabatic and the air is heated by the adsorption heat released in the matrix of the sorption wheel
2 → 3 pre-cooling of the supply air in counter-flow to the return air from the building
3 → 4 evaporative cooling of the supply air to the desired supply air humidity by means of a humidifier
4 → 5 the heating coil is used only in the heating season for pre-heating of air
5 → 6 small temperature increase, caused by the fan
6 → 7 supply air temperature and humidity are increased by means of internal loads
7 → 8 return air from the building is cooled using evaporative cooling close to the saturation line
8 → 9 the return air is pre-heated in counter-flow to the supply air by means of a high efficient air-to-air heat exchanger, e.g. a heat recovery wheel
9→10 regeneration heat is provided for instance by means of a solar thermal collector system
10→11 the water bound in the pores of the desiccant material of the dehumidifier wheel is desorbed by means of the hot air
11→12 exhaust air is removed to the environment by means of the return air fan.

The application of this cycle is limited to temperature climates, since the possible dehumidification is not high enough to enable evaporative cooling of the supply air at condition with far higher values of the humidity of ambient air [7].

Generally, desiccant evaporative cooling system makes sense in regions with moderately hot and moderately humid climate and in buildings with a centralized ventilation system. For the hot and humid climate in Brazil other configurations, like pre-dehumidification of the supply air by electric compression chilling must be applied. These configurations consuming on the other hand more electrical energy, thus no alternative to closed chilled water systems.

A study of the LEPTIAB (2008), University in La Rochelle, France shows clearly the limitations of the desiccant cooling technique regarding outside conditions. It demonstrates that high outside temperature reduces significantly the performance of the desiccant wheel.

Regarding the outside humidity ratio even if the dehumidification increase with increasing outside humidity ratio, we noticed that for outside temperature beyond 30°C the maximum dehumidification rate is 6 g/kg. Taking into account the maximum humidity inside the building (e.g. 11.8 g/kg) and the humidification across the supply humidifier we conclude that the maximum outside humidity under which a desiccant system will operate efficiently is 14.5 g/kg [14].

11.8 g/kg indoor humidity corresponds to a relative humidity of 60% at 24°C and 14.5 g/kg to 55% at 30°C. In Guaratinguetá and in and the main regions of Brazil the temperatures in summer are during the day often beyond 30°C and over 55% relative humidity, normally around 70-80%. The next figures show the maximum Temperature and relative humidity at the first day of the summer season 2009 from January till March.

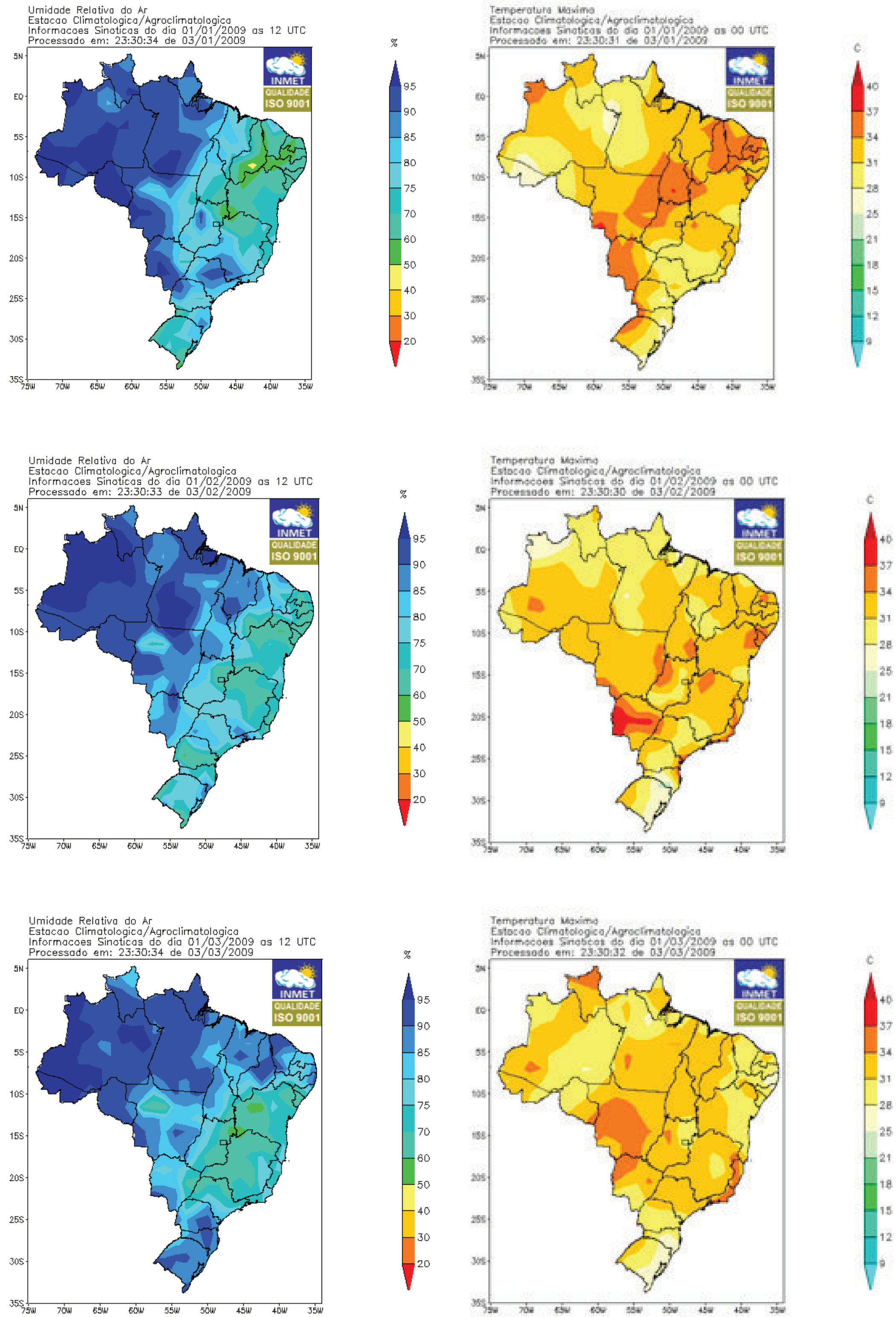

Figure 2.21 - Relative humidity of the air in relation to the maximum Temperature during the summer season 2009 from January till March chosen always the first day of the month at noon.
Source: Brazilian national institute of meteorology (www.inmet.gov.br/html/clima.php).

2.1.3
Solar thermal collector

A broad variety of solar thermal collectors is available and many of them are applicable in solar cooling and air-conditioning systems. However, the appropriate type of the collector depends on the selected cooling technology and on the site conditions, i.e., on the radiation availability. General types of stationary collectors are shown in Figure 2.22, construction principles of improved flat-plate collectors and evacuated tube collectors are given in Figure 2.23. The use of cost-effective solar air collectors in flat plate construction is limited to desiccant cooling systems, since this technology requires the lowest driving temperatures (starting from approx. 50°C) and allows under special conditions the operation without thermal storage. To operate thermally driven chillers with solar heat, at least flat plate collectors of high quality (selective coating, improved insulation, high stagnation safety) are to be applied [7].

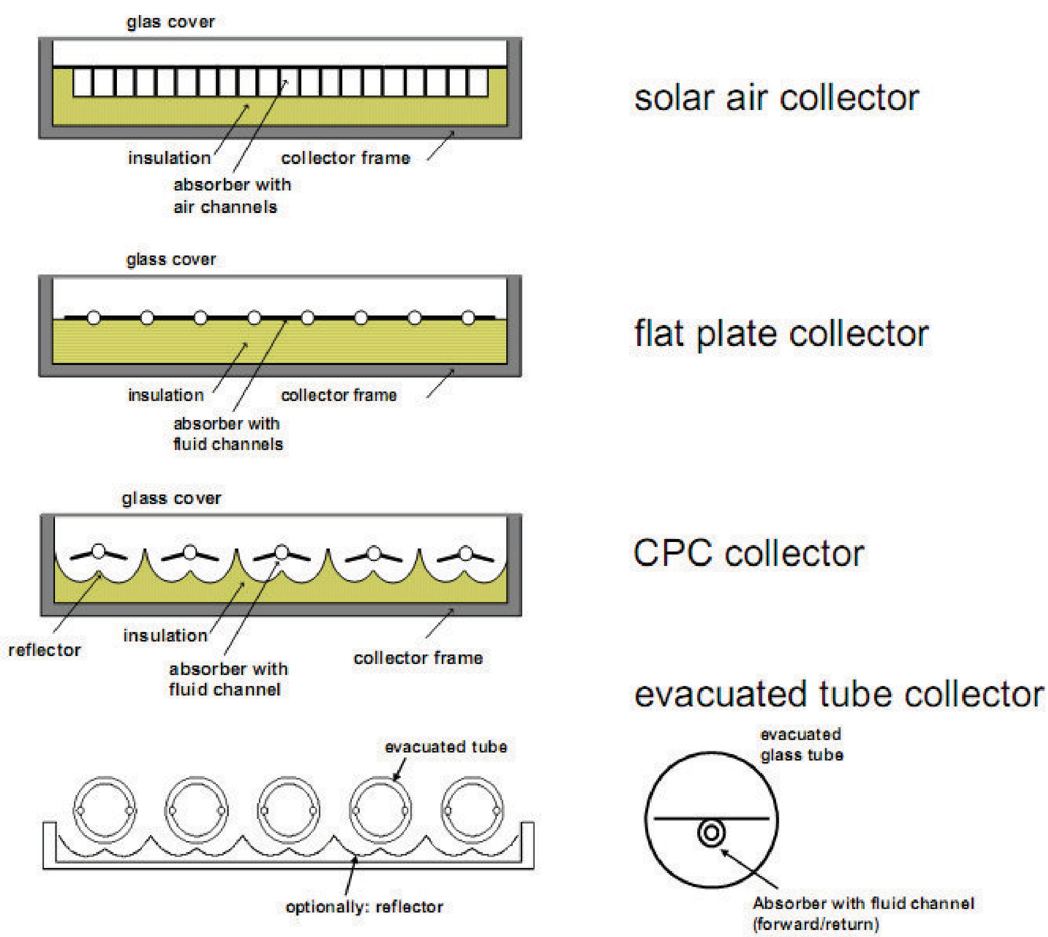

Figure 2.22 - General types of stationary solar collectors [7].

A wide range of concepts for evacuated tube collectors exist, e.g., collectors with direct flow of the collector fluid through the absorber pipe, or with a heat pipes in the tube. Also, the glass tube may either follow the traditional principle of a tube, sealed on both ends, or may follow the thermos flask principle [7].

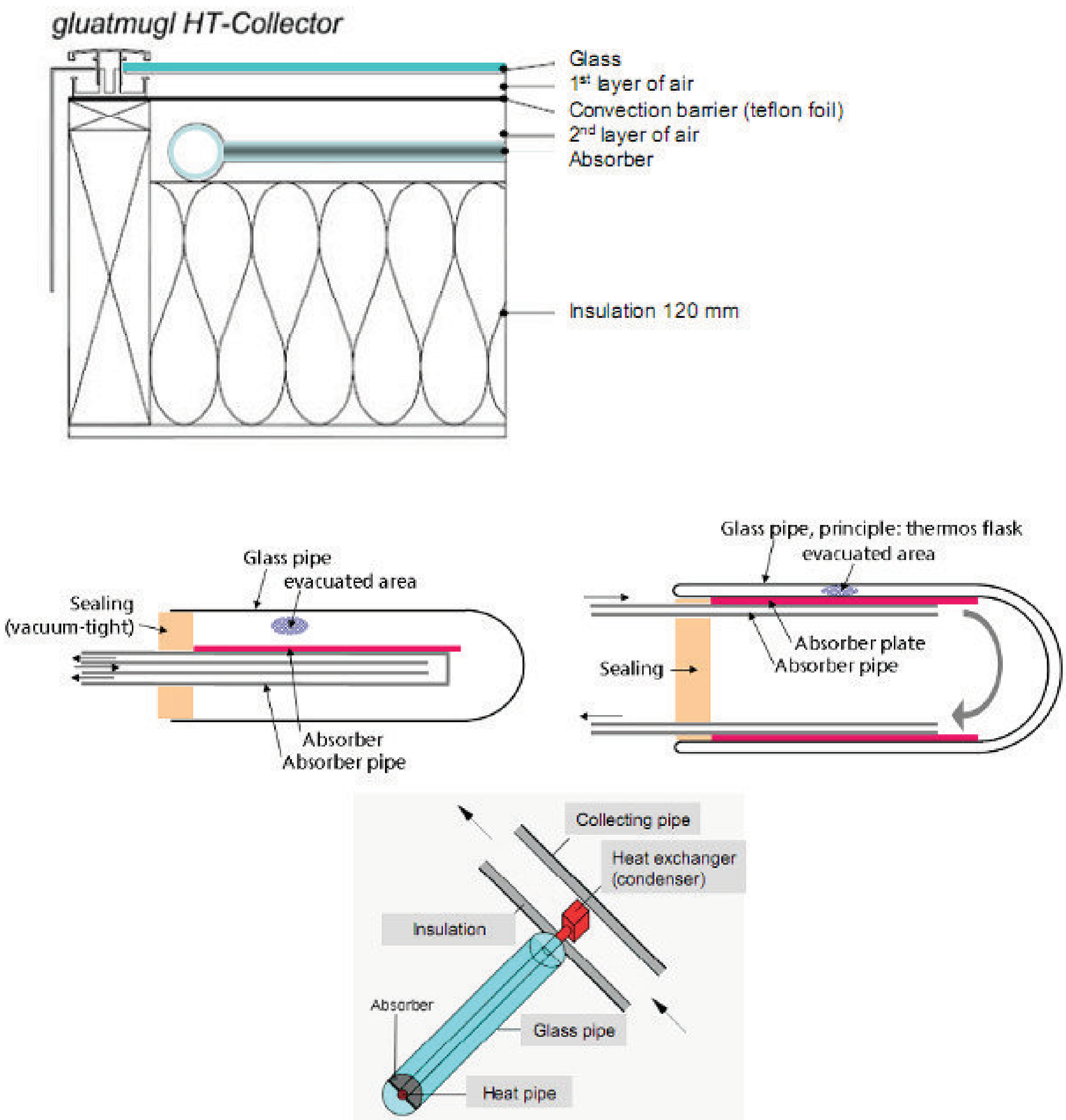

Figure 2.23 - Examples for different construction principles of stationary collectors [7].

Top: flat-plate collector, applicable with good results in the temperature range up to 90°C. The heat losses are minimised through improved insulation and an additional convection barrier (teflon foil) between glass cover and absorber. Source: S.O.L.I.D. Other manufacturers use a second glass cover and/or anti-reflective coatings. Middle: two principles of evacuated tube collectors. On the left, the 'classical' principle is shown, demanding for a vacuum tight sealing. On the right, the thermos flask principle is shown. Source: ISE. Bottom: application of the heat-pipe principle. The pipe is freeze protected and stagnation safe (but not the collecting pipe).This collector type usually has the highest cost of evacuated tube collectors [7].

The solar thermal market in Brazil is currently growing with an annual rate of approx 20%, the cumulated installed area is given with 4,4 million m² by 2008 [8].

In the year 2008 there were 20 companies offering by the INMETRO (Brazilian National Institute of Metrology, Industrial Standardization and Quality) certificated solar thermal collectors. The most of this companies dealing with flat plate collectors in the low temperate range for domestically water heating up to 60°C.

These types of collector have a low efficiency at high temperature, like 80-90°C which is needed for driving a thermal chiller.

There are two companies in Brazil which are offering high quality Flat-Plate collectors with a selected coating and an improved insulation and one company who offers an evacuated tube collector.

These more efficiently collectors will be tested of their applicability due to simulation with hourly climatic data to know their efficiency in dependency of the ambient temperature, Solar irradiation and hot water temperature. Besides this, a CPC collector without vacuum will be simulated. With these data the size of the collector field can be dimensioned and the relation collectors cost and performance can be de demonstrated.

The results will be discussed in sub-section 3.2.2.3.1. Thermal solar collector comparison.

At this point, it should be described how the colleted efficiency curve will be calculated.

The collector efficiency curve (Eq. 2.1) obtained to EN 12975-2:2006 (European standard):

$$\eta = \eta_0 - a_1 \frac{t_m - t_a}{G} - a_2 \frac{(t_m - t_a)^2}{G} \qquad \text{(Eq. 2.5)}$$

with

η_0 = optical efficiency

a_1, a_2 = collector heat-loss coefficients [W/(m²K)], [W/(m²K²)]

t_m = collector temperature (average between input and output temperature) [°C]

t_a = ambient temperature [°C]

G = solar irradiance at collector surface [W/m²]

The efficiency equation used by INMETRO Brazil is as follows:

$$\eta = \eta_0 - a_1 \frac{t_m - t_a}{G} \qquad \text{(Eq. 2.6)}$$

The second part of equation is not considered; this means that the second heat loss coefficient which is a function of the temperature difference does not enter in the efficiency calculation. The result is a linear efficiency curve. Practical measurements on solar panels show that this linear description in some cases does not adequately match the reality, thus large temperature differences between the absorber and ambient, the heat losses does not increase linearly with the temperature difference, due to higher amount of heat dissipation. This means, that the a_2-value is not constant, it’s a function of temperature difference.

To capture this more realistic situation, the second approximation equation, including an added a quadratic term should be used (see equation 2.5).

To compare Brazilian collectors with European collectors and to have a more realistic approach of the efficiency behaviour the second a_2-value is needed. Through contacts to the GREENSolar (National Test laboratory at the PUC University in Minas Gerais) the a_2-values of the Brazilian collectors were generated and for the Master Theses provided.

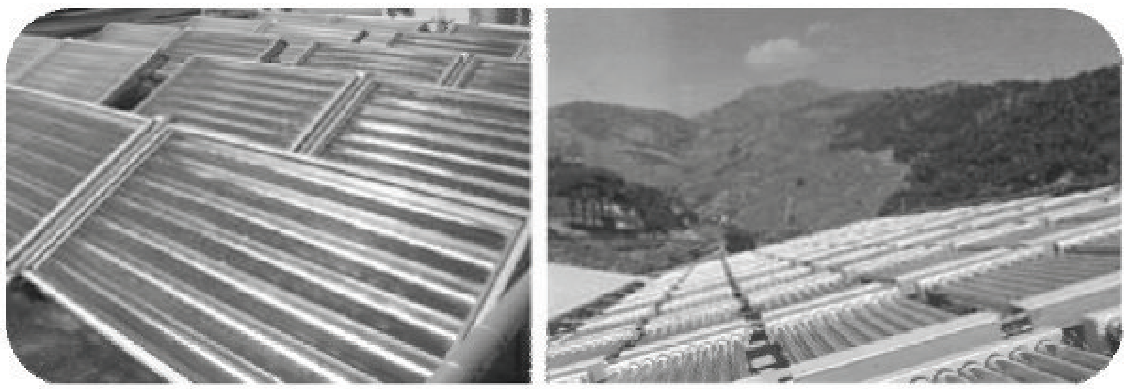

Figure 2.24 - Examples on solar collector, installed for solar cooling applications [7].

Note: Left: Flat-Plate CPC collector, installed at the National Energy Research Centre in Lisbon Source: INETI and Right: Evacuated tube collector at the wine storage building in Banyuls, France. Source: Tecsol

2.2
Non- thermally driven application

2.2.1
Conventional electricity driven vapour compression chiller

The most common refrigeration process applied in air-conditioning is the vapour compression cycle. Most of the cold production for air-conditioning of buildings is generated with this type of machine. The process employs a chemical refrigerant, e.g., R134a. A schematic drawing of the system is shown in Figure 2.25. In the evaporator, the refrigerant evaporates at a low temperature. The heat extracted from the external water supply is used to evaporate the refrigerant from the liquid to the gas phase. The external water is cooled down or – in other words – cooling power becomes available. The key component is the compressor, which compresses the refrigerant from a low pressure to a higher pressure (high temperature) in the condenser [10].

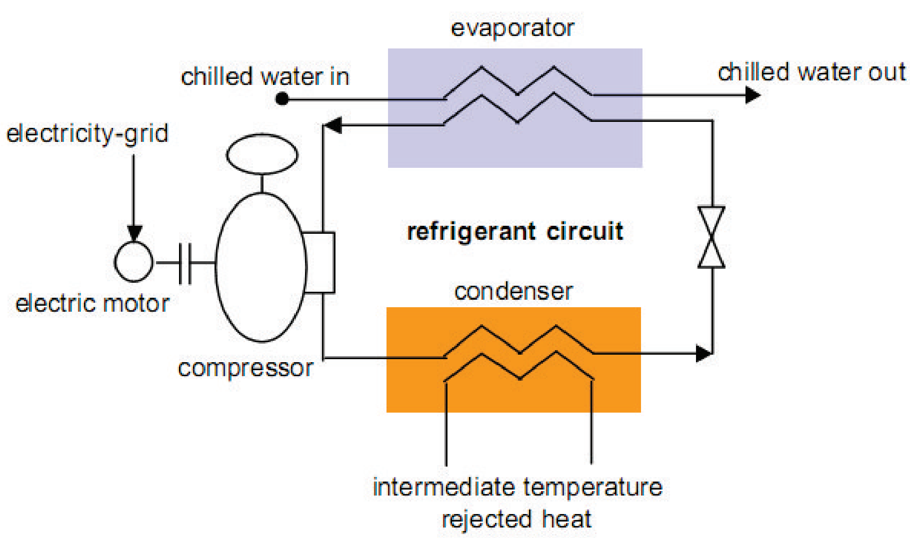

Figure 2.25 Schematic drawing of a vapour compression chiller [10].

For a conventional, electrically driven vapour compression chiller, the COP is defined as follows

$$COP = \frac{Q_c}{P_{el}}$$

Qc = cooling capacity [kW]

Pel = electric power input [kW]

The COP of vapour compression chillers depends on the pressure difference between evaporator and condenser and thus on the temperature difference between the evaporator and the condenser. Higher temperature differences lead to a reduced COP. Concepts that make lower temperature differences possible are therefore beneficial since they reduce the energy consumption of the process [10].

In small buildings in Brazil are often used ductless Split Air Conditioning Systems which have an COP of around 2 and available with the capacities from 1,4 kW to 14 kW. In bigger rooms with a high thermal load are often applied several Split's to achieve a capacity e.g. of 35 kW. The split unit is comprised of two parts: the outdoor unit and the indoor unit. The outdoor unit, fitted outside the room, and includes components like the compressor, condenser and expansion valve. The indoor unit comprises the evaporator or cooling coil and the cooling fan. 90% of their energy consumption occurs by the outdoor unit. These Split air conditioning systems are very cheap because they are a bulk product, in comparison to Ab,- or Adsorption chillers which are produced until now in small series. Figure 2.26 shows the typical function scheme of a split air-conditioner.

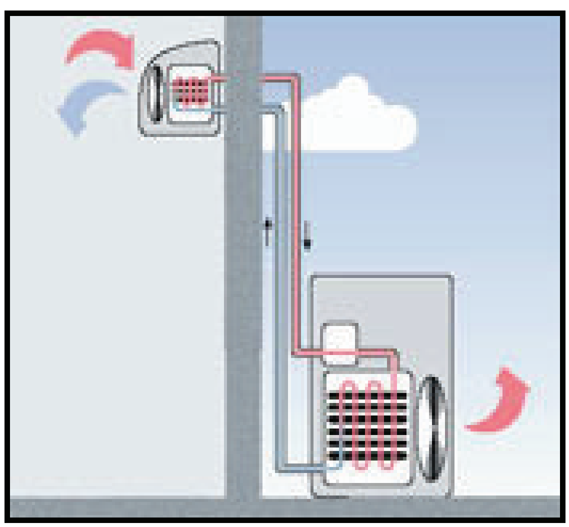

Figure 2.26 - Function scheme of a conventional electrically driven compression split air-conditioning system.

Central air conditioning system is used for cooling big buildings, offices, entire hotels, gyms, movie theaters, factories etc.

If the whole building is to be air conditioned an air-duct system must be installed. The central air conditioning system is comprised of a huge compressor that has the capacity to produce hundreds of tons of air conditioning. Cooling big halls, malls, huge spaces, is usually only feasible with central conditioning units.

There are three types of vapour compression chillers:

Reciprocating compressors:
COP 2.0 – 4.7;
Chilling capacity 10 – 500 kW

Screw compressors:
COP 2.0 – 7.0;
Chilling capacity 300 – 2000 kW

Centrifugal compressors:
COP 4.0 – 8.0;
Chilling capacity 300 – 30000 kW.

2.2.2 Photovoltaic driven compression cycle

There is also the possibility to run a conventional air-conditioning system by a photovoltaic system (PV).
Two technical solutions can be realized:

- A grid connected PV system generates independently on an annual average a certain amount of the energy, consumed by the compression chiller. At the moment the specific investment cost for 1 kW is around 3000 €. This match the specific investment of 1 kW solar thermally generated cooling power. This is only the investment for the considered material; the installation cost of a PV system is lower, because there is no need of piping. But, there is no electricity feed in regulation for PV generated energy in Brazil.

- The PV system is direct connected to the compression chiller, thus it can run without any grid connection. As yet there are only applications in small capacity ranges. e.g. food or medicine storages, since special components are necessary for this direct coupling. There exits no data base of the investment costs, but there are probably equal or higher then for small solar thermal driven cooling application.

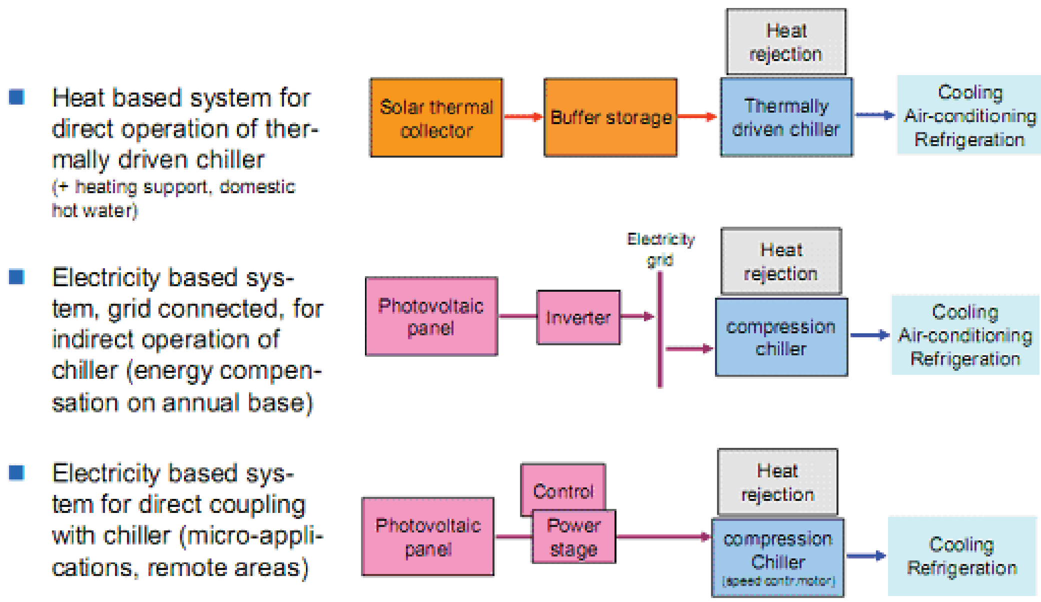

Figure 2.27 - Solar cooling possibilities [8].

It’s important to note that the solar collector field has at all options more or less the same size. The next figure shows a comparison between a PV direct coupling system and Solar thermal driven system, indicating the COP and efficiency of each system. Finally, solar thermally driven COP´s in the order of 0,28, compared to 0,3 photovoltaic panel system / vapour compression. Here must be mentioned that the COP of Solar/Sorption System can be increased by using a collector with an higher efficiency, for example some special types of Evacuated Tube collectors have an efficiency of max. 60% at 90°C water temperature. Normal Flat-Plate collectors with selective coating have efficiency at this temperature level of only 40%.

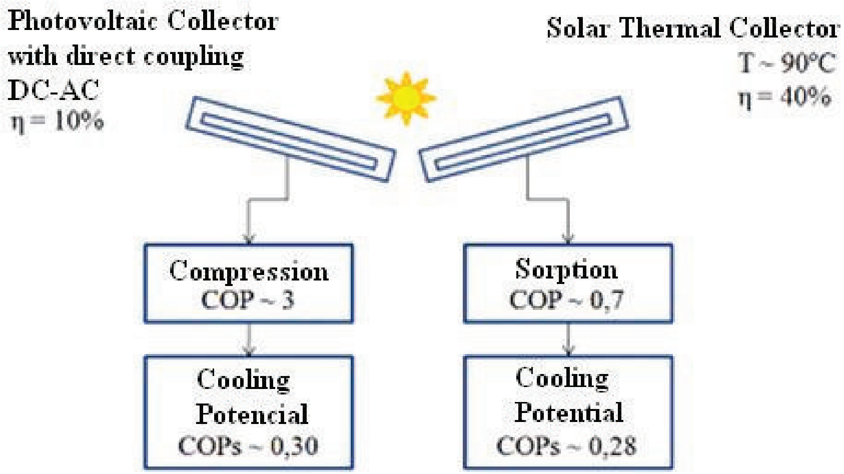

Figure 2.28 - Comparison of COP´s and efficiency between a PV direct coupling system and Solar thermal driven system [15].

Meunier (2007) has analysed the two possibilities in relation to the mitigation of the urban heat island effect. As urban areas develop, changes occur in their landscape. Buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist become impermeable and dry. These changes cause urban regions to become warmer, around 1-3 °C, than their rural surroundings, forming an "island" of higher temperatures in the landscape

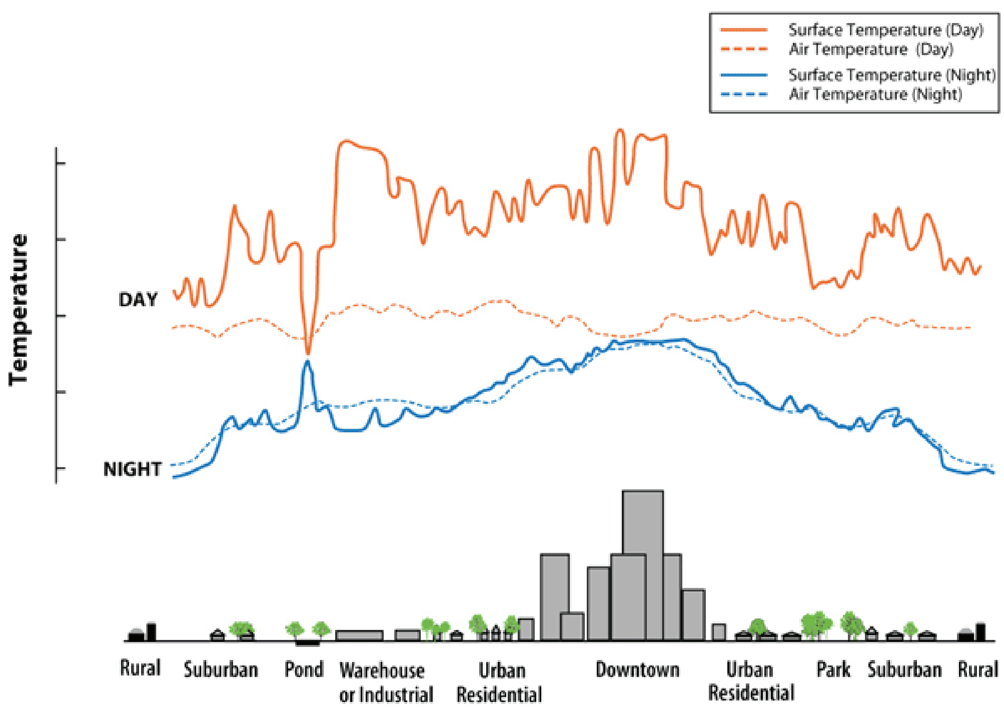

Figure 2.29 - Surface and atmospheric temperatures vary over different land use areas [16].

The temperatures displayed above do not represent absolute temperature values or any one particular measured heat island. Temperatures will fluctuate based on factors such as seasons, weather conditions, sun intensity, and ground cover [16].

Higher temperatures in summer increase energy demand for cooling and add pressure to the electricity grid during peak periods of demand. One study estimates that the heat island effect is responsible for 5–10% of peak electricity demand for cooling buildings in cities [17].

Meunier (2007) calculated the albedo and found out that thermal solar collectors transfer to the ambient air 30% of incident radiation, while the photovoltaic collector's transfers 60%.
A portion of the incoming solar radiation is absorbed by the surface and a portion is also reflected away. The proportion of light reflected from a surface is the albedo. Albedo values range from 0 for no reflection to 1 for complete reflection of light striking the surface. It can be expressed as a percentage (albedo multiplied by 100). For instance, grass has an albedo of about 0.25. This means that of the incoming solar radiation that strikes the grass, 25% of it is reflected away. On the other hand, highly reflective surfaces like snow have an albedo upwards of 0.87, or 87% of sunlight is reflected away. New concrete has an albedo of 55%, this means that 55% of the solar radiation is reradiated and 45% is absorbed by the concrete. This percentage of solar energy absorbed by the concrete is emitted during absence of the sun and thus influences the urban microclimate in a negative way through causing a higher temperature as normal.

According Meunier (2007) a thermal solar collector absorbs 70% of the incoming solar energy [18]; this energy is used to generate cold water for air conditioning and is not more emitted to the environment. PV collectors absorb only 40% of the solar energy and reradiate the rest to the ambient air. Hence these facts solar thermal systems are more potential to mitigate the urban heat island effect.

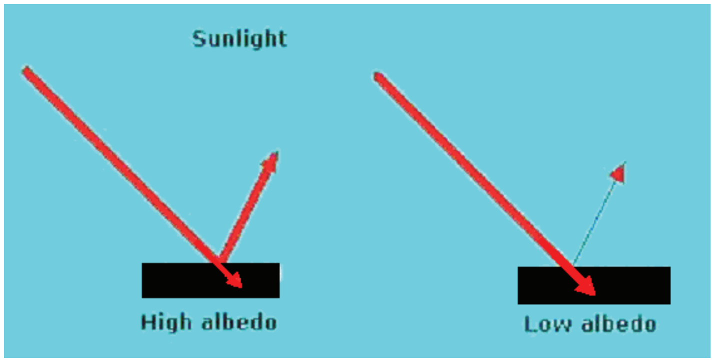

Figure 2.30 - Right: Low albedo of a solar thermal collector, only 30% is reflected; the rest is absorbed by the collector heating up the fluid. Left: PV collector transfer 60% of incident radiation to ambient air.

PV systems will not further considered, because the focus is on thermal systems and until now there are only existing PV direct coupling systems in very small range e.g. stand alone solar cooling containers. Air conditioning of buildings is still not realized with PV. Grid connected PV is also not to be promoted in Brazil.